(14.1) "FTP cycle". For passenger vehicles, light-duty trucks, and medium-duty vehicles certified on a chassis dynamometer, FTP cycle refers to the driving schedule in Code of Federal Regulations (CFR) 40, Appendix 1, Part 86, section (a) entitled, "EPA Urban Dynamometer Driving Schedule for Light-Duty Vehicles and Light-Duty Trucks." For medium-duty engines certified on an engine dynamometer, FTP cycle refers to the engine dynamometer schedule in CFR 40, Appendix 1, Part 86, section (f)(1), entitled, "EPA Engine Dynamometer Schedule for Heavy-Duty Otto-Cycle Engines," or section (f)(2), entitled, "EPA Engine Dynamometer Schedule for Heavy-Duty Diesel Engines."

(14.2) "FTP standard" refers to the certification tailpipe exhaust emission standards (both 50,000 mile and FTP full useful life standards) and test procedures applicable to the class to which the vehicle is certified.

(14.3) "FTP full useful life standard" refers to the FTP standard applicable when the vehicle reaches the end of its full useful life as defined in the certification requirements and test procedures incorporated by reference in title *13, CCR section 1961(d).*

(15) "Fuel trim" refers to feedback adjustments to the base fuel schedule. Short-term fuel trim refers to dynamic or instantaneous adjustments. Long-term fuel trim refers to much more gradual adjustments to the fuel calibration schedule than short-term trim adjustments.

(16) "Functional check" for an output component or system means verification of proper response of the component and system to a computer command.

(17) "Key on, engine off position" refers to a vehicle with the ignition key in the engine run position (not engine crank or accessory position) but with the engine not running.

(18) "Light-duty truck" is defined in title *13, CCR section 1900 (b).*

(19) "Low Emission Vehicle I application" refers to a vehicle or engine certified in California to the exhaust emission standards defined in title *13, CCR sections 1956.8(g),* 1960.1(g)(1), and 1960.1(h)(1) for any of the following vehicle emission categories: Transitional Low Emission Vehicle (TLEV), Low Emission Vehicle (LEV), Ultra Low Emission Vehicle (ULEV), or Super Ultra Low Emission Vehicle (SULEV). Additionally, vehicles certified to Federal emission standards (bins) in California but categorized in a Low Emission Vehicle I vehicle emission category for purposes of calculating NMOG fleet average in accordance with the certification requirements and test procedures incorporated by reference in title *13, CCR section 1961 (d)* are subject to all monitoring requirements applicable to Low Emission Vehicle I applications but shall use the Federal tailpipe emission standard (i.e., the Federal bin) for purposes of determining the malfunction thresholds in section (e).

(19.1) "MDV SULEV vehicles" refer only to medium-duty Low Emission Vehicle I applications certified to the SULEV vehicle emission category.

(19.2) "TLEV vehicles" refer only to Low Emission Vehicle I applications certified to the TLEV vehicle emission category.

(19.3) "LEV vehicles" refer only to Low Emission Vehicle I applications certified to the LEV vehicle emission category.

(19.4) "ULEV vehicles" refer only to Low Emission Vehicle I applications certified to the ULEV vehicle emission category.

(20) "Low Emission Vehicle II application" refers to a vehicle or engine certified in California to the exhaust emission standards defined in title *13, CCR section 1961* for any of the following vehicle emission categories: LEV, ULEV, or SULEV. Additionally, except as provided for in section (e)(18.1.3), vehicles certified to Federal emission standards (bins) in California but categorized in a Low Emission Vehicle II vehicle emission category for purposes of calculating NMOG fleet average in accordance with the certification requirements and test procedures incorporated by reference in title *13, CCR section 1961 (d)* are subject to all monitoring requirements applicable to Low Emission Vehicle II applications

but shall use the Federal tailpipe emission standard (i.e., the Federal bin) for purposes of determining the malfunction thresholds in section (e).

(20.1) "PC/LDT SULEV II vehicles" refer only to passenger car and light-duty truck Low Emission Vehicle II applications certified to the SULEV vehicle emission category.

(20.2) "MDV SULEV II vehicles" refer only to medium-duty Low Emission Vehicle II applications certified to the SULEV vehicle emission category.

(20.3) "LEV II vehicles" refer only to Low Emission Vehicle II applications certified to the LEV vehicle emission category.

(20.4) "ULEV II vehicles" refer only to Low Emission Vehicle II applications certified to the ULEV vehicle emission category.

(21) "Malfunction" means any deterioration or failure of a component that causes the performance to be outside of the applicable limits in section (e).

(22) "Medium-duty vehicle" is defined in title *13, CCR section 1900 (b).*

(22.1) "Medium-duty passenger vehicle" is defined in *Title 40, Section 86.1803-01, Code of Federal Regulations.*

(23) "Normal production" is the time after the start of production when the manufacturer has produced 2% of the projected volume for the test group or calibration, whichever is being evaluated in accordance with section (j).

(24) "Passenger car" is defined in title *13, CCR section 1900 (b).*

(25) "Pending fault code" is defined as the diagnostic trouble code stored upon the initial detection of a malfunction (e.g., typically on a single driving cycle) prior to illumination of the MIL in accordance with the requirements of section (e) and (f)(4.4).

(26) "Percentage of misfire" as used in (e)(3.2) means the percentage of misfires out of the total number of firing events for the specified interval.

(27) "Power Take-Off (PTO) unit" refers to an engine driven output provision for the purposes of powering auxiliary equipment (e.g., a dump-truck bed, aerial bucket, or tow-truck winch).

(28) "Rationality fault diagnostic" for an input component means verification of the accuracy of the input signal while in the range of normal operation and when compared to all other available information.

(29) "Redline engine speed" shall be defined by the manufacturer as either the recommended maximum engine speed as normally displayed on instrument panel tachometers or the engine speed at which fuel shutoff occurs.

(30) "Response rate" for oxygen sensors refers to the delay between a switch of the sensor from lean to rich or vice versa in response to a commanded change in air/fuel ratio. Specifically, the response rate is the delay from the time when the oxygen sensor is exposed to a change in exhaust gas from richer/leaner than stoichiometric to leaner/richer than stoichiometric to the time when the oxygen sensor indicates the lean/rich condition.

(31) "SC03 emission standards" refers to the certification tailpipe exhaust emission standards for the air conditioning (A/C) test of the Supplemental Federal Test Procedure Off-Cycle Emission Standards specified in title *13, CCR section 1961(a)* applicable to the class to which the vehicle is certified.

(32) "Secondary air" refers to air introduced into the exhaust system by means of a pump or aspirator valve or other means that is intended to aid in the oxidation of HC and CO contained in the exhaust gas stream.

(33) "Similar conditions" as used in sections (e)(3) and (e)(6) means engine conditions having an engine speed within 375 rpm, load conditions within 20 percent, and the same warm-up status (i.e.,

cold or hot) as the engine conditions stored pursuant to (e)(3.4.4) and (e)(6.4.5). The Executive Officer may approve other definitions of similar conditions based on comparable timeliness and reliability in detecting similar engine operation.

(34) "Small volume manufacturer" is defined in title *13, CCR section 1900(b)*. However, for a manufacturer that transitions from a small volume manufacturer to a non-small volume manufacturer, the manufacturer is still considered a small volume manufacturer for the first three model years that it no longer meets the definition in title *13, CCR section 1900(b)*.

(35) "Unified cycle" is defined in "Speed Versus Time Data for California's Unified Driving Cycle", dated December 12, 1996, incorporated by reference.

(36) "US06 cycle" refers to the driving schedule in CFR 40, Appendix 1, Part 86, section (g) entitled, "EPA US06 Driving Schedule for Light-Duty Vehicles and Light-Duty Trucks."

(37) "Warm-up cycle" means sufficient vehicle operation such that the coolant temperature has risen by at least 40 degrees Fahrenheit from engine starting and reaches a minimum temperature of at least 160 degrees Fahrenheit (140 degrees Fahrenheit for applications with diesel engines).

(d) General Requirements

Section (d) sets forth the general requirements of the OBD II system. Specific performance requirements for components and systems that shall be monitored are, set forth in section (e) below.

(1) The OBD II System.

(1.1) If a malfunction is present as specified in section (e), the OBD II system shall detect the malfunction, store a pending or confirmed fault code in the onboard computer's memory, and illuminate the MIL as required.

(1.2) The OBD II system shall be equipped with a standardized data link connector to provide access to the stored fault codes as specified in section (f).

(1.3) The OBD II system shall be designed to operate, without any required scheduled maintenance, for the actual life of the vehicle in which it is installed and may not be programmed or otherwise designed to deactivate based on age and/or mileage of the vehicle during the actual life of the vehicle. This section is not intended to alter existing law and enforcement practice regarding a manufacturer's liability for a vehicle beyond its useful life, except where a vehicle has been programmed or otherwise designed so that an OBD II system deactivates based on age and/or mileage of the vehicle.

(1.4) Computer-coded engine operating parameters may not be changeable without the use of specialized tools and procedures (e.g. soldered or potted computer components or sealed (or soldered) computer enclosures). Subject to Executive Officer approval, manufacturers may exempt from this requirement those product lines that are unlikely to require protection. Criteria to be evaluated in making an exemption include current availability of performance chips, high performance capability of the vehicle, and sales volume.

(2) MIL and Fault Code Requirements.

(2.1)MIL Specifications.

(2.1.1) The MIL shall be located on the driver's side instrument panel and be of sufficient illumination and location to be readily visible under all lighting conditions and shall be amber in color when illuminated. The MIL, when illuminated, shall display the phrase "Check Engine" or "Service Engine Soon". The word "Powertrain" may be substituted for "Engine" in the previous phrases. Alternatively, the International Standards Organization (ISO) engine symbol may be substituted for the word "Engine" or for the entire phrase.

(2.1.2) The MIL shall illuminate in the key on, engine off position before engine cranking to indicate that the MIL is functional. For all 2005 and subsequent model year vehicles, the MIL shall continuously illuminate during this functional check for a minimum of 15-20 seconds. During this

functional check of the MIL, the data stream value for MIL status shall indicate commanded off (see section (f)(4.2)) unless the MIL has also been commanded on for a detected malfunction. This functional check of the MIL is not required during vehicle operation in the key on, engine off position subsequent to the initial engine cranking of each driving cycle (e.g., due to an engine stall or other non-commanded engine shutoff).

(2.1.3) The MIL shall also illuminate within 10 seconds to inform the vehicle operator whenever the powertrain enters a default or "limp home" mode of operation that can affect emissions or the performance of the OBD II system or in the event of a malfunction of an on-board computer(s) itself that can affect the performance of the OBD II system. If the default or "limp home" mode of operation is recoverable (i.e., operation automatically returns to normal at the beginning of the following driving cycle), the OBD II system may wait and illuminate the MIL only if the default or "limp home" mode of operation is again entered before the end of the next driving cycle in lieu of illuminating the MIL within 10 seconds on the first driving cycle where the default or "limp home" mode of operation is entered.

(2.1.4) At the manufacturer's option, the MIL may be used to indicate readiness status in a standardized format (see section (f)(4.1.3)) in the key on, engine off position.

(2.1.5) A manufacturer may request Executive Officer approval to also use the MIL to indicate which, if any, fault codes are currently stored (e.g., to "blink" the stored codes). The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated that the method used to indicate the fault codes will not be activated during a California Inspection and Maintenance test or during routine driver operation.

(2.1.6) The MIL may not be used for any purpose other than specified in this regulation.

(2.2)MIL Illumination and Fault Code Storage Protocol.

(2.2.1) Upon detection of a malfunction, the OBD system shall store a pending fault code within ten seconds indicating the likely area of the malfunction.

(2.2.2) After storage of a pending fault code, if the identified malfunction is again detected before the end of the next driving cycle in which monitoring occurs, the MIL shall illuminate continuously and a confirmed fault code shall be stored within 10 seconds. If a malfunction is not detected before the end of the next driving cycle in which monitoring occurs (i.e., there is no indication of the malfunction at any time during the driving cycle), the corresponding pending fault code set according to section (d)(2.2.1) shall be erased at the end of the driving cycle.

(2.2.3) A manufacturer may request Executive Officer approval to employ alternate statistical MIL illumination and fault code storage protocols to those specified in these requirements. The Executive Officer shall grant approval upon determining that the manufacturer has provided data and/or engineering evaluation that demonstrate that the alternative protocols can evaluate system performance and detect malfunctions in a manner that is equally effective and timely. Except as otherwise provided in section (e) for evaporative system malfunctions, strategies requiring on average more than six driving cycles for MIL illumination may not be accepted.

(2.2.4) A manufacturer shall store and erase "freeze frame" conditions (as defined in section (f)(4.3)) present at the time a malfunction is detected. A manufacturer shall store and erase freeze frame conditions in conjunction with storage and erasure of either pending or confirmed fault codes as required elsewhere in section (d)(2.2).

(2.3) Extinguishing the MIL. Except as otherwise provided in sections (e)(3.4.5), (e)(4.4.2), and (e)(6.4.6) for misfire, evaporative system, and fuel system malfunctions, once the MIL has been illuminated it may be extinguished after three subsequent sequential driving cycles during which the monitoring system responsible for illuminating the MIL functions and the previously detected malfunction is no longer present provided no other malfunction has been detected that would independently illuminate the MIL according to the requirements outlined above.

(2.4) Erasing a confirmed fault code. The OBD II system may erase a confirmed fault code if the identified malfunction has not been again detected in at least 40 engine warm-up cycles, and the MIL is presently not illuminated for that malfunction.

(2.5) Exceptions to MIL and Fault Code Requirements. For 2004 model year vehicles only, wherever the requirements of section (d)(2) reflect a substantive change from the MIL and fault code requirements of title *13, CCR section 1968.1* for 2003 model year vehicles, the manufacturer may request Executive Officer approval to continue to use the requirements of section 1968.1 in lieu of the requirements of section (d)(2). The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or engineering evaluation which demonstrate that software or hardware changes would be required to comply with the requirements of section (d)(2) and that the system complies with the MIL and fault code requirements of title *13, CCR section 1968.1*.

(3) Monitoring Conditions. Section (d)(3) sets forth the general monitoring requirements while section (e) sets forth the specific monitoring requirements as well as identifies which of the following general monitoring requirements in section (d)(3) are applicable for each monitored component or system identified in section (e).

(3.1) For all 2004 and subsequent model year vehicles:

(3.1.1) As specifically provided for in section (e), manufacturers shall define monitoring conditions, subject to Executive Officer approval, for detecting malfunctions identified in section (e). The Executive Officer shall approve manufacturer defined monitoring conditions that are determined (based on manufacturer submitted data and/or other engineering documentation) to be: technically necessary to ensure robust detection of malfunctions (e.g., avoid false passes and false indications of malfunctions), designed to ensure monitoring will occur under conditions which may reasonably be expected to be encountered in normal urban vehicle operation and use, and designed to ensure monitoring will occur during the FTP cycle or Unified cycle.

(3.1.2) Monitoring shall occur at least once per driving cycle in which the monitoring conditions are met.

(3.1.3) Manufacturers may request Executive Officer approval to define monitoring conditions that are not encountered during the FTP cycle or Unified cycle as required in section (d)(3.1.1). In evaluating the manufacturer's request, the Executive Officer shall consider the degree to which the requirement to run during the FTP or Unified cycle restricts in-use monitoring, the technical necessity for defining monitoring conditions that are not encountered during the FTP or Unified cycle, data and/or an engineering evaluation submitted by the manufacturer which demonstrate that the component/system does not normally function, or monitoring is otherwise not feasible, during the FTP or Unified cycle, and, where applicable in section (d)(3.2), the ability of the manufacturer to demonstrate the monitoring conditions will satisfy the minimum acceptable in-use monitor performance ratio requirement as defined in section (d)(3.2).

(3.2) As specifically provided for in section (e), manufacturers shall define monitoring conditions in accordance with the criteria in sections (d)(3.2.1) through (3.2.3). The requirements of section (d)(3.2) shall be phased in as follows: 30 percent of all 2005 model year vehicles, 60 percent of all 2006 model year vehicles, and 100 percent of all 2007 and subsequent model year vehicles. Manufacturers may use an alternate phase-in schedule in lieu of the required phase-in schedule if the alternate phase-in schedule provides for equivalent compliance volume as defined in section (c) with the exception that 100 percent of 2007 and subsequent model year vehicles shall comply with the requirements. Small volume manufacturers shall meet the requirements on 100 percent of 2007 and subsequent model year vehicles but shall not be required to meet the specific phase-in requirements for the 2005 and 2006 model years.

(3.2.1) Manufacturers shall define monitoring conditions that, in addition to meeting the criteria in section (d)(3.1), ensure that the monitor yields an in-use performance ratio (as defined in section (d)(4)) that meets or exceeds the minimum acceptable in-use monitor performance ratio on in-use

vehicles. For purposes of this regulation, except as provided below in section (d)(3.2.1)(D), the minimum acceptable in-use monitor performance ratio is:

(A) 0.260 for secondary air system monitors and other cold start related monitors utilizing a denominator incremented in accordance with section (d)(4.3.2)(E);

(B) For evaporative system monitors:

(i) 0.260 for monitors designed to detect malfunctions identified in section (e)(4.2.2)(C) (i.e., 0.020 inch leak detection); and

(ii) 0.520 for monitors designed to detect malfunctions identified in section (e)(4.2.2)(A) and (B) (i.e., purge flow and 0.040 inch leak detection);

(C) 0.336 for catalyst, oxygen sensor, EGR, VVT system, and all other monitors specifically required in section (e) to meet the monitoring condition requirements of section (d)(3.2); and

(D) through the 2007 model year, for the first two years a vehicle is certified to the in-use performance ratio monitoring requirements of section (d)(3.2), 0.100 for all monitors specified in section (d)(3.2.1)(A) through (C) above. For example, the 0.100 ratio shall apply to the 2004 and 2005 model years for vehicles first certified in the 2004 model year and to the 2007 and 2008 model years for vehicles first certified in the 2007 model year.

(3.2.2) In addition to meeting the requirements of section (d)(3.2.1), manufacturers shall implement software algorithms in the OBD II system to individually track and report in-use performance of the following monitors in the standardized format specified in section (d)(5):

a. Catalyst (section (e)(1.3) or, where applicable, (e)(1.5.3));

b. Oxygen sensor (section (e)(7.3.1)(A));

c. Evaporative system (section (e)(4.3.2));

d. EGR system (section (e)(8.3.1)) and VVT system (section (e)(13.3)); and

e. Secondary air system (section (e)(5.3.2)(B)).

The OBD II system is not required to track and report in-use performance for monitors other than those specifically identified above.

(3.2.3) Manufacturers may not use the calculated ratio (or any element thereof) or any other indication of monitor frequency as a monitoring condition for any monitor (e.g., using a low ratio to enable more frequent monitoring through diagnostic executive priority or modification of other monitoring conditions, or using a high ratio to enable less frequent monitoring).

(4) In-Use Monitor Performance Ratio Definition.

(4.1) For monitors required to meet the minimum in-use monitor performance ratio in section (d)(3.2.1), the ratio shall be calculated in accordance with the following specifications for the numerator, denominator, and ratio.

(4.2) Numerator Specifications

(4.2.1) Definition: The numerator is defined as a measure of the number of times a vehicle has been operated such that all monitoring conditions necessary for a specific monitor to detect a malfunction have been encountered.

(4.2.2) Specifications for incrementing:

(A) Except as provided for in section (d)(4.2.2)(E), the numerator, when incremented, shall be incremented by an integer of one. The numerator may not be incremented more than once per driving cycle.

(B) The numerator for a specific monitor shall be incremented within ten seconds if and only if the following criteria are satisfied on a single driving cycle:

(i) Every monitoring condition necessary for the monitor of the specific component to detect a malfunction and store a pending fault code has been satisfied, including enable criteria, presence or absence of related fault codes, sufficient length of monitoring time, and diagnostic executive priority assignments (e.g., diagnostic "A" must execute prior to diagnostic "B", etc.). For the purpose of incrementing the numerator, satisfying all the monitoring conditions necessary for a monitor to determine the component is passing may not, by itself, be sufficient to meet this criteria;

(ii) For monitors that require multiple stages or events in a single driving cycle to detect a malfunction, every monitoring condition necessary for all events to have completed must be satisfied;

(iii) For monitors that require intrusive operation of components to detect a malfunction, a manufacturer shall request Executive Officer approval of the strategy used to determine that, had a malfunction been present, the monitor would have detected the malfunction. Executive Officer approval of the request shall be based on the equivalence of the strategy to actual intrusive operation and the ability of the strategy to accurately determine if every monitoring condition necessary for the intrusive event to occur was satisfied.

(iv) In addition to the requirements of section (d)(4.2.2)(B)(i) through (iii) above, the secondary air system monitor numerator(s) shall be incremented if and only if the criteria in section (B) above have been satisfied during normal operation of the secondary air system for vehicles that require monitoring during normal operation (sections (e)(5.2.2) through (5.2.4)). Monitoring during intrusive operation of the secondary air system later in the same driving cycle solely for the purpose of monitoring may not, by itself, be sufficient to meet this criteria.

(C) For monitors that can generate results in a "gray zone" or "non-detection zone" (i.e., results that indicate neither a passing system nor a malfunctioning system) or in a "non-decision zone" (e.g., monitors that increment and decrement counters until a pass or fail threshold is reached), the manufacturer shall submit a plan for appropriate incrementing of the numerator to the Executive Officer for review and approval. In general, the Executive Officer shall not approve plans that allow the numerator to be incremented when the monitor indicates a result in the "non-detection zone" or prior to the monitor reaching a decision. In reviewing the plan for approval, the Executive Officer shall consider data and/or engineering evaluation submitted by the manufacturer demonstrating the expected frequency of results in the "non-detection zone" and the ability of the monitor to accurately determine if a monitor would have detected a malfunction instead of a result in the "non-detection zone" had an actual malfunction been present.

(D) For monitors that run or complete during engine off operation, the numerator shall be incremented within 10 seconds after the monitor has completed during engine off operation or during the first 10 seconds of engine start on the subsequent driving cycle.

(E) Manufacturers utilizing alternate statistical MIL illumination protocols as allowed in section (d)(2.2.3) for any of the monitors requiring a numerator shall submit a plan for appropriate incrementing of the numerator to the Executive Officer for review and approval. Executive Officer approval of the plan shall be conditioned upon the manufacturer providing supporting data and/or engineering evaluation for the proposed plan, the equivalence of the incrementing in the manufacturer's plan to the incrementing specified in section (d)(4.2.2) for monitors using the standard MIL illumination protocol, and the overall equivalence of the manufacturer's plan in determining that the minimum acceptable in-use performance ratio in section (d)(3.2.1) is satisfied.

(4.3) Denominator Specifications

(4.3.1) Definition: The denominator is defined as a measure of the number of times a vehicle has been operated as defined in (d)(4.3.2).

(4.3.2) Specifications for incrementing:

(A) The denominator, when incremented, shall be incremented by an integer of one. The denominator may not be incremented more than once per driving cycle.

(B) The denominator for each monitor shall be incremented within ten seconds if and only if the following criteria are satisfied on a single driving cycle:

(i) Cumulative time since engine start is greater than or equal to 600 seconds while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit;

(ii) Cumulative vehicle operation at or above 25 miles per hour occurs for greater than or equal to 300 seconds while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit;

(iii) Continuous vehicle operation at idle (i.e., accelerator pedal released by driver and vehicle speed less than or equal to one mile per hour) for greater than or equal to 30 seconds while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit;

(C) In addition to the requirements of section (d)(4.3.2)(B) above, the secondary air system monitor denominator(s) shall be incremented if and only if commanded "on" operation of the secondary air system occurs for a time greater than or equal to ten seconds. For purposes of determining this commanded "on" time, the OBD II system may not include time during intrusive operation of the secondary air system solely for the purposes of monitoring;

(D) In addition to the requirements of section (d)(4.3.2)(B) above, the evaporative system monitor denominator(s) shall be incremented if and only if:

(i) Cumulative time since engine start is greater than or equal to 600 seconds while at an ambient temperature of greater than or equal to 40 degrees Fahrenheit but less than or equal to 95 degrees Fahrenheit;

(ii) Engine cold start occurs with engine coolant temperature at engine start greater than or equal to 40 degrees Fahrenheit but less than or equal to 95 degrees Fahrenheit and less than or equal to 12 degrees Fahrenheit higher than ambient temperature at engine start.

(E) In addition to the requirements of section (d)(4.3.2)(B) above, the denominator(s) for the following monitors shall be incremented if and only if the component or strategy is commanded "on" for a time greater than or equal to ten seconds:

(i) Heated catalyst (section (e)(2))

(ii) Cold Start Emission Reduction Strategy (section (e)(11))

(iii) Components or systems that operate only at engine start-up (e.g., glow plugs, intake air heaters, etc.) and are subject to monitoring under "other emission control or source devices" (section (e)(17)) or comprehensive component output components (section (e)(16))

For purposes of determining this commanded "on" time, the OBD II system may not include time during intrusive operation of any of the components or strategies later in the same driving cycle solely for the purposes of monitoring.

(F) In addition to the requirements of section (d)(4.3.2)(B) above, the denominator(s) for the following monitors of output components (except those operated only at engine start-up and

subject to the requirements of the previous section (d)(4.3.2)(E)) shall be incremented if and only if the component is commanded to function (e.g., commanded "on", "open", "closed", "locked", etc.) on two or more occasions during the driving cycle or for a time greater than or equal to ten seconds, whichever occurs first:

(i) Air conditioning system (section (e)(12))

(ii) Variable valve timing and/or control system (section (e)(13))

(iii) "Other emission control or source device" (section (e)(17))

(iv) Comprehensive component output component (section (e)(16)) (e.g., turbocharger waste-gates, variable length manifold runners, torque converter clutch lock-up solenoids, etc.)

(G) For monitors of the following components, the manufacturer may request Executive Officer approval to use alternate or additional criteria to that set forth in section (d)(4.3.2)(B) above for incrementing the denominator. Executive Officer approval of the proposed criteria shall be based on the equivalence of the proposed criteria in measuring the frequency of monitor operation relative to the amount of vehicle operation in accordance with the criteria in section (d)(4.3.2)(B) above:

(i) Engine cooling system input components (section (e)(10))

(ii) Air conditioning system input components (section (e)(12))

(iii) Direct ozone reduction systems (section (e)(14))

(iv) Particulate matter traps (section (e)(15))

(v) "Other emission control or source devices" (section (e)(17))

(vi) Comprehensive component input components that require extended monitoring evaluation (section (e)(16)) (e.g., stuck fuel level sensor rationality)

(H) For hybrid vehicles, vehicles that employ alternate engine start hardware or strategies (e.g., integrated starter and generators), or alternate fuel vehicles (e.g., dedicated, bi-fuel, or dual-fuel applications), the manufacturer may request Executive Officer approval to use alternate criteria to that set forth in section (d)(4.3.2)(B) above for incrementing the denominator. In general, the Executive Officer shall not approve alternate criteria for vehicles that only employ engine shut off at or near idle/vehicle stop conditions. Executive Officer approval of the alternate criteria shall be based on the equivalence of the alternate criteria to determine the amount of vehicle operation relative to the measure of conventional vehicle operation in accordance with the criteria in section (d)(4.3.2)(B) above.

(4.4) Ratio Specifications

(4.4.1) Definition: The ratio is defined as the numerator divided by the denominator.

(4.5) Disablement of Numerators and Denominators

(4.5.1) Within ten seconds of a malfunction that disables a monitor required to meet the monitoring conditions in section (d)(3.2.1) being detected (i.e., a pending or confirmed code is stored), the OBD II system shall disable further incrementing of the corresponding numerator and denominator for each monitor that is disabled. When the malfunction is no longer detected (i.e., the pending code is erased through self-clearing or through a scan tool command), incrementing of all corresponding numerators and denominators shall resume within ten seconds.

(4.5.2) Within ten seconds of the start of a PTO (see section (c)) operation that disables a monitor required to meet the monitoring conditions in section (d)(3.2.1), the OBD II system shall disable further incrementing of the corresponding numerator and denominator for each monitor that is

disabled. When the PTO operation ends, incrementing of all corresponding numerators and denominators shall resume within ten seconds.

(4.5.3) The OBD II system shall disable further incrementing of all numerators and denominators within ten seconds if a malfunction of any component used to determine if the criteria in sections (d)(4.3.2)(B) through (D) are satisfied (i.e., vehicle speed, ambient temperature, elevation, idle operation, engine cold start, or time of operation) has been detected and the corresponding pending fault code has been stored. Incrementing of all numerators and denominators shall resume within ten seconds when the malfunction is no longer present (e.g., pending code erased through self-clearing or by a scan tool command).

(5) Standardized tracking and reporting of monitor performance.

(5.1) For monitors required to track and report in-use monitor performance in section (d)(3.2.2), the performance data shall be tracked and reported in accordance with the specifications in sections (d)(4), (d)(5), and (f)(5). The OBD II system shall separately report an in-use monitor performance numerator and denominator for each of the following components: catalyst bank 1, catalyst bank 2, primary oxygen sensor bank 1, primary oxygen sensor bank 2, evaporative 0.020 inch leak detection system, EGR/VVT system, and secondary air system. The OBD II system shall also report a general denominator and an ignition cycle counter in the standardized format specified in sections (d)(5.5), (d)(5.6) and (f)(5).

(5.2) Numerator

(5.2.1) The OBD II system shall report a separate numerator for each of the components listed in section (d)(5.1).

(5.2.2) For specific components or systems that have multiple monitors that are required to be reported under section (e) (e.g., oxygen sensor bank 1 may have multiple monitors for sensor response or other sensor characteristics), the OBD II system shall separately track numerators and denominators for each of the specific monitors and report only the corresponding numerator and denominator for the specific monitor that has the lowest numerical ratio. If two or more specific monitors have identical ratios, the corresponding numerator and denominator for the specific monitor that has the highest denominator shall be reported for the specific component.

(5.2.3) The numerator(s) shall be reported in accordance with the specifications in section (f)(5.2.1).

(5.3) Denominator

(5.3.1) The OBD II system shall report a separate denominator for each of the components listed in section (d)(5.1).

(5.3.2) The denominator(s) shall be reported in accordance with the specifications in section (f)(5.2.1).

(5.4) Ratio

(5.4.1) For purposes of determining which corresponding numerator and denominator to report as required in section (d)(5.2.2), the ratio shall be calculated in accordance with the specifications in section (f)(5.2.2).

(5.5) Ignition cycle counter

(5.5.1) Definition:

(A) The ignition cycle counter is defined as a counter that indicates the number of ignition cycles a vehicle has experienced as defined in section (d)(5.5.2)(B).

(B) The ignition cycle counter shall be reported in accordance with the specifications in section (f)(5.2.1).

(5.5.2) Specifications for incrementing:

(A) The ignition cycle counter, when incremented, shall be incremented by an integer of one. The ignition cycle counter may not be incremented more than once per driving cycle.

(B) The ignition cycle counter shall be incremented within ten seconds if and only if the vehicle meets the engine start definition (see section (c)) for at least two seconds plus or minus one second.

(C) The OBD II system shall disable further incrementing of the ignition cycle counter within ten seconds if a malfunction of any component used to determine if the criteria in section (d)(5.5.2)(B) are satisfied (i.e., engine speed or time of operation) has been detected and the corresponding pending fault code has been stored. The ignition cycle counter may not be disabled from incrementing for any other condition. Incrementing of the ignition cycle counter shall resume within ten seconds when the malfunction is no longer present (e.g., pending code erased through self-clearing or by a scan tool command).

(5.6) General Denominator

(5.6.1) Definition:

(A) The general denominator is defined as a measure of the number of times a vehicle has been operated as defined in section (d)(5.6.2)(B).

(B) The general denominator shall be reported in accordance with the specifications in section (f)(5.2.1).

(5.6.2) Specifications for incrementing:

(A) The general denominator, when incremented, shall be incremented by an integer of one. The general denominator may not be incremented more than once per driving cycle.

(B) The general denominator shall be incremented within ten seconds if and only if the criteria identified in section (d)(4.3.2)(B) are satisfied on a single driving cycle.

(C) The OBD II system shall disable further incrementing of the general denominator within ten seconds if a malfunction of any component used to determine if the criteria in section (d)(4.3.2)(B) are satisfied (i.e., vehicle speed, ambient temperature, elevation, idle operation, or time of operation) has been detected and the corresponding pending fault code has been stored. The general denominator may not be disabled from incrementing for any other condition (e.g., the disablement criteria in sections (d)(4.5.1) and (d)(4.5.2) may not disable the general denominator). Incrementing of the general denominator shall resume within ten seconds when the malfunction is no longer present (e.g., pending code erased through self-clearing or by a scan tool command).

(6) Enforcement Testing.

(6.1) The procedures used to assure compliance with the requirements of title *13, CCR section 1968.2* are set forth in title *13, CCR section 1968.5*.

(6.2) Consistent with the requirements of title *13, CCR section 1968.5(b)(4)(A)* for enforcement OBD II emission testing, the manufacturer shall make available upon request by the Executive Officer all test equipment (e.g., malfunction simulators, deteriorated "threshold" components, etc.) necessary to determine the malfunction criteria in section (e) for major monitors subject to OBD II emission testing as defined in title *13, CCR section 1968.5*. To meet the requirements of this section, the manufacturers shall only be required to make available test equipment necessary to duplicate "threshold" testing performed by the manufacturer. This test equipment shall include, but is not limited to, aged "threshold" catalyst systems and computer equipment used to simulate misfire, oxygen sensor, fuel system, VVT system, and cold start reduction strategy system faults. The manufacturer is not required to make

available test equipment for vehicles that exceed the applicable full useful life age (e.g., 10 years for vehicles certified to a full useful life of 10 years and 100,000 miles).

(e) Monitoring Requirements

(1) Catalyst Monitoring

(1.1) Requirement: The OBD II system shall monitor the catalyst system for proper conversion capability.

(1.2) Malfunction Criteria:

(1.2.1) Low Emission Vehicle I applications: The OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that either of the following occurs:

(A) Non-Methane Organic Gas (NMOG) emissions exceed 1.75 times the FTP full useful life standards to which the vehicle has been certified with NMOG emissions multiplied by the certification reactivity adjustment factor for the vehicle;

(B) The average FTP test Non-Methane Hydrocarbon (NMHC) conversion efficiency of the monitored portion of the catalyst system falls below 50 percent (i.e., the cumulative NMHC emissions measured at the outlet of the monitored catalyst(s) are more than 50 percent of the cumulative engine-out emissions measured at the inlet of the catalyst(s)). With Executive Officer approval, manufacturers may use a conversion efficiency malfunction criteria of less than 50 percent if the catalyst system is designed such that the monitored portion of the catalyst system must be replaced along with an adjacent portion of the catalyst system sufficient to ensure that the total portion replaced will meet the 50 percent conversion efficiency criteria. Executive Officer approval shall be based on data and/or engineering evaluation demonstrating the conversion efficiency of the monitored portion and the total portion designed to be replaced, and the likelihood of the catalyst system design to ensure replacement of the monitored and adjacent portions of the catalyst system.

(1.2.2) Low Emission Vehicle II applications:

(A) 2004 model year vehicles.

(i) All LEV II, ULEV II, and MDV SULEV II vehicles shall use the malfunction criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1).

(ii) All PC/LDT SULEV II vehicles shall use the malfunction criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1) except the malfunction criterion in paragraph (e)(1.2.1)(A) shall be 2.5 times the applicable FTP full useful life NMOG standard.

(B) Except as provided below in section (e)(1.2.4), for 2005 and 2006 model years, the OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that any of the following occurs:

(i) For LEV II, ULEV II, and MDV SULEV II vehicles.

a. NMOG emissions exceed the criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1)(A).

b. The average FTP test NMHC conversion efficiency is below the criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1)(B).

c. Oxides of nitrogen (NOx) emissions exceed 3.5 times the FTP full useful life NOx standard to which the vehicle has been certified.

(ii) PC/LDT SULEV II vehicles shall use the same malfunction criteria as 2005 and 2006 model year LEV II, ULEV II, and MDV SULEV II vehicles (section (e)(1.2.2)(B)(i)) except

the malfunction criteria in paragraph a. shall be 2.5 times the applicable FTP full useful life NMOG standard.

(C) Except as provided below in section (e)(1.2.5), for 2007 and subsequent model years, the OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that any of the following occurs.

(i) For LEV II, ULEV II, and MDV SULEV II vehicles.

a. NMOG emissions exceed the criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1)(A).

b. The average FTP test NMHC conversion efficiency is below the criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1)(B).

c. NOx emissions exceed 1.75 times the FTP full useful life NOx standard to which the vehicle has been certified.

(ii) For PC/LDT SULEV II vehicles.

a. NMOG emissions exceed 2.5 times the applicable FTP full useful life NMOG standard to which the vehicle has been certified.

b. The average FTP test NMHC conversion efficiency is below the criteria specified for Low Emission Vehicle I applications in section (e)(1.2.1)(B).

c. NOx emissions exceed 2.5 times the applicable FTP full useful life NOx standard to which the vehicle has been certified.

(1.2.3) Non-Low Emission Vehicle I or II applications: The OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that NMHC emissions increase by more than 1.5 times the applicable FTP full useful life standards over an FTP test performed with a representative 4000 mile catalyst system.

(1.2.4) In lieu of using the malfunction criteria in section (e)(1.2.2)(B) for all 2005 and 2006 model year Low Emission Vehicle II applications, a manufacturer may phase-in the malfunction criteria on a portion of its Low Emission Vehicle II applications as long as that portion of Low Emission Vehicle II applications comprises at least 30% of all 2005 model year vehicles and 60% of all 2006 model year vehicles. For 2005 and 2006 model year Low Emission Vehicle II applications not included in the phase-in, the malfunction criteria in section (e)(1.2.2)(A) shall be used.

(1.2.5) In lieu of using the malfunction criteria in section (e)(1.2.2)(C) for all 2007 model year Low Emission Vehicle II applications, for the 2007 model year only, a manufacturer may continue to use the malfunction criteria in section (e)(1.2.2)(B) for any Low Emission Vehicle II applications previously certified in the 2005 or 2006 model year to the malfunction criteria in section (e)(1.2.2.)(B) and carried over to the 2007 model year.

(1.2.6) For purposes of determining the catalyst system malfunction criteria in sections (e)(1.2.1), (1.2.2)(A), and (1.2.3), the malfunction criteria shall be established by using a catalyst system with all monitored catalysts simultaneously deteriorated to the malfunction criteria while unmonitored catalysts shall be deteriorated to the end of the vehicle's full useful life.

(1.2.7) For purposes of determining the catalyst system malfunction criteria in sections (e)(1.2.2)(B) and (C):

(A) The manufacturer shall use a catalyst system deteriorated to the malfunction criteria using methods established by the manufacturer to represent real world catalyst deterioration under normal and malfunctioning operating conditions.

(B) Except as provided below in section (e)(1.2.7)(C), the malfunction criteria shall be established by using a catalyst system with all monitored and unmonitored (downstream of the

sensor utilized for catalyst monitoring) catalysts simultaneously deteriorated to the malfunction criteria.

(C) For vehicles using fuel shutoff to prevent over-fueling during misfire conditions (see section (e)(3.4.1)(D)), the malfunction criteria shall be established by using a catalyst system with all monitored catalysts simultaneously deteriorated to the malfunction criteria while unmonitored catalysts shall be deteriorated to the end of the vehicle's full useful life.

(1.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(1.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(1.2) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(1.4)MIL Illumination and Fault Code Storage:

(1.4.1) General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(1.4.2) The monitoring method for the catalyst(s) shall be capable of detecting when a catalyst fault code has been cleared (except OBD II system self-clearing), but the catalyst has not been replaced (e.g., catalyst overtemperature approaches may not be acceptable).

(1.5) Catalyst Monitoring for Diesels

(1.5.1) Requirement: On all 2004 and subsequent model year diesel passenger cars, light-duty trucks, and medium-duty passenger vehicles (see section (c)) and all 2005 and subsequent model year diesel medium-duty vehicles, the OBD II system shall monitor the catalyst system for proper conversion capability.

(1.5.2) Malfunction Criteria:

(A) For 2004 and subsequent model year diesel passenger cars, light-duty trucks, and medium-duty passenger vehicles certified to a chassis dynamometer tailpipe emission standard:

(i) The OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that emissions exceed 1.75 times the applicable FTP full useful life NMHC, NOx, or PM standard (or, if applicable, NMHC+NOx standard).

(ii) Except as provided below in section (e)(1.5.2)(A)(iv), if no failure or deterioration of the catalyst system NMHC conversion capability could result in a vehicle's emissions exceeding 1.75 times any of the applicable standards, the OBD II system shall detect a malfunction when the system has no detectable amount of NMHC conversion capability.

(iii) Except as provided below in section (e)(1.5.2)(A)(v), if no failure or deterioration of the catalyst system NOx conversion capability could result in a vehicle's emissions exceeding 1.75 times any of the applicable standards, the OBD II system shall detect a malfunction when the system has no detectable amount of NOx conversion capability.

(iv) For the 2004 through 2009 model year, a manufacturer may request to be exempted from the requirements for NMHC conversion catalyst system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated, through data and/or engineering evaluation, that the average FTP test NMHC conversion efficiency of the system is less than 30 percent (i.e., the cumulative NMHC emissions measured at the outlet of the catalyst are more than 70 percent of the cumulative engine-out NMHC emissions measured at the inlet of the catalyst(s)).

(v) For the 2004 through 2009 model year, a manufacturer may request to be exempted from the requirements for NOx conversion catalyst system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated, through data and/or engineering evaluation, that the average FTP test NOx conversion efficiency of the system is less than 30 percent (i.e., the cumulative NOx emissions measured at the outlet of the catalyst are more than 70 percent of the cumulative engine-out NOx emissions measured at the inlet of the catalyst(s)).

(B) For 2005 and 2006 model year diesel medium-duty vehicles (including medium-duty passenger vehicles certified to an engine dynamometer tailpipe standard):

(i) Except as provided below, the OBD II system shall detect a NOx conversion catalyst system malfunction when the catalyst system's conversion capability decreases to the point that emissions exceed 1.75 times the applicable FTP full useful life NOx or PM standard (or, if applicable, NMHC+NOx standard).

(ii) A manufacturer may request to be exempted from the requirements for NOx conversion catalyst system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated, through data and/or engineering evaluation, that no failure or deterioration of the system will cause emissions to exceed the emission threshold specified in section (e)(1.5.2)(B)(i).

(iii) Monitoring of the NMHC conversion catalyst system performance is not required.

(C) For 2007 and subsequent model year diesel medium-duty vehicles (including medium-duty passenger vehicles certified to an engine dynamometer tailpipe standard):

(i) The OBD II system shall detect a catalyst system malfunction when the catalyst system's conversion capability decreases to the point that emissions exceed 1.75 times the applicable FTP full useful life NMHC, NOx, or PM standard (or, if applicable, NMHC+NOx standard).

(ii) Except as provided below in section (e)(1.5.2)(C)(iv), if no failure or deterioration of the catalyst system NMHC conversion capability could result in a vehicle's emissions exceeding 1.75 times any of the applicable standards, the OBD II system shall detect a malfunction when the system has no detectable amount of NMHC conversion capability.

(iii) Except as provided below in section (e)(1.5.2)(C)(v), if no failure or deterioration of the catalyst system NOx conversion capability could result in a vehicle's emissions exceeding 1.75 times any of the applicable standards, the OBD II system shall detect a malfunction when the system has no detectable amount of NOx conversion capability.

(iv) For the 2007 through 2009 model year, a manufacturer may request to be exempted from the requirements for NMHC conversion catalyst system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated, through data and/or engineering evaluation, that the average FTP test NMHC conversion efficiency of the system is less than 30 percent (i.e., the cumulative NMHC emissions measured at the outlet of the catalyst are more than 70 percent of the cumulative engine-out NMHC emissions measured at the inlet of the catalyst(s)).

(v) For the 2007 through 2009 model year, a manufacturer may request to be exempted from the requirements for NOx conversion catalyst system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated, through data and/or engineering evaluation, that the average FTP test NOx conversion efficiency of the system is less than 30 percent (i.e., the cumulative NOx emissions measured at the outlet of the catalyst are more than 70 percent of the cumulative engine-out NOx emissions measured at the inlet of the catalyst(s)).

(1.5.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(1.5.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(1.5.2) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(1.5.4) MIL Illumination and Fault Code Storage:

(A) General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(B) The monitoring method for the catalyst(s) shall be capable of detecting all instances, except diagnostic self-clearing, when a catalyst fault code has been cleared but the catalyst has not been replaced (e.g., catalyst overtemperature approaches may not be acceptable).

(2) Heated Catalyst Monitoring

(2.1) Requirement:

(2.1.1) The OBD II system shall monitor all heated catalyst systems for proper heating.

(2.1.2) The efficiency of heated catalysts shall be monitored in conjunction with the requirements of section (e)(1).

(2.2) Malfunction Criteria:

(2.2.1) The OBD II system shall detect a catalyst heating system malfunction when the catalyst does not reach its designated heating temperature within a requisite time period after engine starting. The manufacturer shall determine the requisite time period, but the time period may not exceed the time that would cause emissions from a vehicle equipped with the heated catalyst system to exceed 1.75 times any of the applicable FTP full useful life standards.

(2.2.2) Manufacturers may use other monitoring strategies for the heated catalyst but must submit the alternate plan to the Executive Officer for approval. The Executive Officer shall approve alternate strategies for monitoring heated catalyst systems based on comparable reliability and timeliness to these requirements in detecting a catalyst heating malfunction.

(2.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(2.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(2.4)MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(3) Misfire Monitoring

(3.1) Requirement:

(3.1.1) The OBD II system shall monitor the engine for misfire causing catalyst damage and misfire causing excess emissions.

(3.1.2) The OBD II system shall identify the specific cylinder that is experiencing misfire. Manufacturers may request Executive Officer approval to store a general misfire fault code instead of a cylinder specific fault code under certain operating conditions. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that the misfiring cylinder cannot be reliably identified when the conditions occur.

(3.1.3) If more than one cylinder is misfiring, a separate fault code shall be stored indicating that multiple cylinders are misfiring except as allowed below. When identifying multiple cylinder misfire, the manufacturer is not required to also identify each of the misfiring cylinders individually through separate fault codes. For 2005 and subsequent model year vehicles, if more than 90 percent of the

detected misfires occur in a single cylinder, the manufacturer may elect to store the appropriate fault code indicating the specific misfiring cylinder in lieu of the multiple cylinder misfire fault code. If, however, two or more cylinders individually have more than 10 percent of the total number of detected misfires, a multiple cylinder fault code must be stored.

(3.2) Malfunction Criteria: The OBD II system shall detect a misfire malfunction pursuant to the following:

(3.2.1) Misfire causing catalyst damage:

(A) Manufacturers shall determine the percentage of misfire evaluated in 200 revolution increments for each engine speed and load condition that would result in a temperature that causes catalyst damage. The manufacturer shall submit documentation to support this percentage of misfire as required in section (h)(2.5). For every engine speed and load condition that this percentage of misfire is determined to be lower than five percent, the manufacturer may set the malfunction criteria at five percent.

(B) Subject to Executive Officer approval, a manufacturer may employ a longer interval than 200 revolutions but only for determining, on a given driving cycle, the first misfire exceedance as provided in section (e)(3.4.1)(A) below. Executive Officer approval shall be granted upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that catalyst damage would not occur due to unacceptably high catalyst temperatures before the interval has elapsed.

(C) A misfire malfunction shall be detected if the percentage of misfire established in section (e)(3.2.1)(A) is exceeded.

(D) For purposes of establishing the temperature at which catalyst damage occurs as required in section (e)(3.2.1)(A), on 2005 and subsequent model year vehicles, manufacturers may not define catalyst damage at a temperature more severe than what the catalyst system could be operated at for ten consecutive hours and still meet the applicable FTP full useful life standards.

(3.2.2) Misfire causing emissions to exceed 1.5 times the FTP standards:

(A) Manufacturers shall determine the percentage of misfire evaluated in 1000 revolution increments that would cause emissions from an emission durability demonstration vehicle to exceed 1.5 times any of the applicable FTP standards if the percentage of misfire were present from the beginning of the test. To establish this percentage of misfire, the manufacturer shall utilize misfire events occurring at equally spaced, complete engine cycle intervals, across randomly selected cylinders throughout each 1000-revolution increment. If this percentage of misfire is determined to be lower than one percent, the manufacturer may set the malfunction criteria at one percent.

(B) Subject to Executive Officer approval, a manufacturer may employ other revolution increments. The Executive Officer shall grant approval upon determining that the manufacturer has demonstrated that the strategy would be equally effective and timely in detecting misfire.

(C) A malfunction shall be detected if the percentage of misfire established in section (3.2.2)(A) is exceeded regardless of the pattern of misfire events (e.g., random, equally spaced, continuous, etc.).

(3.3) Monitoring Conditions:

(3.3.1) Manufacturers shall continuously monitor for misfire under the following conditions:

(A) From no later than the end of the second crankshaft revolution after engine start,

(B) During the rise time and settling time for engine speed to reach the desired idle engine speed at engine start-up (i.e., "flare-up" and "flare-down"), and

(C) Under all positive torque engine speeds and load conditions except within the following range: the engine operating region bound by the positive torque line (i.e., engine load with the transmission in neutral), and the two following engine operating points: an engine speed of 3000 rpm with the engine load at the positive torque line, and the redline engine speed (defined in section (c)) with the engine's manifold vacuum at four inches of mercury lower than that at the positive torque line.

(3.3.2) If a monitoring system cannot detect all misfire patterns under all required engine speed and load conditions as required in section (e)(3.3.1) above, the manufacturer may request Executive Officer approval to accept the monitoring system. In evaluating the manufacturer's request, the Executive Officer shall consider the following factors: the magnitude of the region(s) in which misfire detection is limited, the degree to which misfire detection is limited in the region(s) (i.e., the probability of detection of misfire events), the frequency with which said region(s) are expected to be encountered in-use, the type of misfire patterns for which misfire detection is troublesome, and demonstration that the monitoring technology employed is not inherently incapable of detecting misfire under required conditions (i.e., compliance can be achieved on other engines). The evaluation shall be based on the following misfire patterns: equally spaced misfire occurring on randomly selected cylinders, single cylinder continuous misfire, and paired cylinder (cylinders firing at the same crank angle) continuous misfire.

(3.3.3) A manufacturer may request Executive Officer approval of a monitoring system that has reduced misfire detection capability during the portion of the first 1000 revolutions after engine start that a cold start emission reduction strategy that reduces engine torque (e.g., spark retard strategies) is active. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated that the probability of detection is greater than or equal to 75 percent during the worst case condition (i.e., lowest generated torque) for a vehicle operated continuously at idle (park/neutral idle) on a cold start between 50-86 degrees Fahrenheit and that the technology cannot reliably detect a higher percentage of the misfire events during the conditions.

(3.3.4) A manufacturer may request Executive Officer approval to disable misfire monitoring or employ an alternate malfunction criterion when misfire cannot be distinguished from other effects.

(A) Upon determining that the manufacturer has presented documentation that demonstrates the disablement interval or period of use of an alternate malfunction criterion is limited only to that necessary for avoiding false detection, the Executive Officer shall approve the disablement or use of the alternate malfunction criterion for conditions involving:

(i) rough road,

(ii) fuel cut,

(iii) gear changes for manual transmission vehicles,

(iv) traction control or other vehicle stability control activation such as anti-lock braking or other engine torque modifications to enhance vehicle stability,

(v) off-board control or intrusive activation of vehicle components or diagnostics during service or assembly plant testing,

(vi) portions of intrusive evaporative system or EGR diagnostics that can significantly affect engine stability (i.e., while the purge valve is open during the vacuum pull-down of a evaporative system leak check but not while the purge valve is closed and the evaporative system is sealed or while an EGR diagnostic causes the EGR valve to be intrusively cycled on and off during positive torque conditions), or

(vii) engine speed, load, or torque transients due to throttle movements more rapid than occurs over the US06 cycle for the worst case vehicle within each test group.

(B) Additionally, the Executive Officer will approve a manufacturer's request in accordance with sections (e)(18.3) through (18.5) to disable misfire monitoring when fuel level is 15 percent or less of the nominal capacity of the fuel tank, when PTO units are active, or while engine coolant temperature is below 20 degrees Fahrenheit. The Executive Officer will approve a request to continue disablement on engine starts when engine coolant temperature is below 20 degrees Fahrenheit at engine start until engine coolant temperature exceeds 70 degrees Fahrenheit.

(C) In general, for 2005 and subsequent model year vehicles, the Executive Officer shall not approve disablement for conditions involving normal air conditioning compressor cycling from on-to-off or off-to-on, automatic transmission gear shifts (except for shifts occurring during wide open throttle operation), transitions from idle to off-idle, normal engine speed or load changes that occur during the engine speed rise time and settling time (i.e., "flare-up" and "flare-down") immediately after engine starting without any vehicle operator-induced actions (e.g., throttle stabs), or excess acceleration (except for acceleration rates that exceed the maximum acceleration rate obtainable at wide open throttle while the vehicle is in gear due to abnormal conditions such as slipping of a clutch).

(D) The Executive Officer may approve misfire monitoring disablement or use of an alternate malfunction criterion for any other condition on a case by case basis upon determining that the manufacturer has demonstrated that the request is based on an unusual or unforeseen circumstance and that it is applying the best available computer and monitoring technology.

(3.3.5) For engines with more than eight cylinders that cannot meet the requirements of section (e)(3.3.1), a manufacturer may request Executive Officer approval to use alternative misfire monitoring conditions. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation which demonstrate that misfire detection throughout the required operating region cannot be achieved when employing proven monitoring technology (i.e., a technology that provides for compliance with these requirements on other engines) and provided misfire is detected to the fullest extent permitted by the technology. However, the Executive Officer may not grant the request if the misfire detection system is unable to monitor during all positive torque operating conditions encountered during an FTP cycle.

(3.4)MIL Illumination and Fault Code Storage:

(3.4.1) Misfire causing catalyst damage. Upon detection of the level of misfire specified in section (e)(3.2.1) above, the following criteria shall apply for MIL illumination and fault code storage:

(A) Pending fault codes

(i) A pending fault code shall be stored immediately if, during a single driving cycle, the specified misfire level is exceeded three times when operating in the positive torque region encountered during an FTP cycle or is exceeded on a single occasion when operating at any other engine speed and load condition in the positive torque region defined in section (e)(3.3.1).

(ii) Immediately after a pending fault code is stored as specified in section (e)(3.4.1)(A)(i) above, the MIL shall blink once per second at all times while misfire is occurring during the driving cycle.

a. The MIL may be extinguished during those times when misfire is not occurring during the driving cycle.

b. If, at the time a misfire malfunction occurs, the MIL is already illuminated for a malfunction other than misfire, the MIL shall blink as previously specified in section (e)(3.4.1)(A)(ii) while misfire is occurring. If misfiring ceases, the MIL shall stop blinking but remain illuminated as required by the other malfunction.

(B) Confirmed fault codes

(i) If a pending fault code for exceeding the misfire level set forth in section (e)(3.2.1) is stored, the OBD II system shall immediately store a confirmed fault code if the percentage of misfire specified in section (e)(3.2.1) is again exceeded one or more times during either: (a) the driving cycle immediately following the storage of the pending fault code, regardless of the conditions encountered during the driving cycle; or (b) on the next driving cycle in which similar conditions (see section (c)) to the engine conditions that occurred when the pending fault code was stored are encountered.

(ii) If a pending fault code for exceeding the misfire level set forth in section (e)(3.2.2) is stored from a previous drive cycle, the OBD II system shall immediately store a confirmed fault code if the percentage of misfire specified in section (e)(3.2.1) is exceeded one or more times regardless of the conditions encountered.

(iii) Upon storage of a confirmed fault code, the MIL shall blink as specified in subparagraph (e)(3.4.1)(A)(ii) above as long as misfire is occurring and the MIL shall remain continuously illuminated if the misfiring ceases.

(C) Erasure of pending fault codes

Pending fault codes shall be erased at the end of the next driving cycle in which similar conditions to the engine conditions that occurred when the pending fault code was stored have been encountered without any exceedance of the specified misfire levels. The pending code may also be erased if similar driving conditions are not encountered during the next 80 driving cycles subsequent to the initial detection of a malfunction.

(D) Exemptions for vehicles with fuel shutoff and default fuel control. Notwithstanding sections (e)(3.4.1)(A) and (B) above, in vehicles that provide for fuel shutoff and default fuel control to prevent over fueling during catalyst damage misfire conditions, the MIL need not blink. Instead, the MIL may illuminate continuously in accordance with the requirements for continuous MIL illumination in sections (e)(3.4.1)(B)(iii) above upon detection of misfire, provided that the fuel shutoff and default control are activated as soon as misfire is detected. Fuel shutoff and default fuel control may be deactivated only to permit fueling outside of the misfire range. Manufacturers may also periodically, but not more than once every 30 seconds, deactivate fuel shutoff and default fuel control to determine if the specified catalyst damage misfire level is still being exceeded. Normal fueling and fuel control may be resumed if the specified catalyst damage misfire level is no longer being exceeded.

(E) Manufacturers may request Executive Officer approval of strategies that continuously illuminate the MIL in lieu of blinking the MIL during extreme catalyst damage misfire conditions (i.e., catalyst damage misfire occurring at all engine speeds and loads). Executive Officer approval shall be granted upon determining that the manufacturer employs the strategy only when catalyst damage misfire levels cannot be avoided during reasonable driving conditions and the manufacturer has demonstrated that the strategy will encourage operation of the vehicle in conditions that will minimize catalyst damage (e.g., at low engine speeds and loads).

(3.4.2) Misfire causing emissions to exceed 1.5 times the FTP standards. Upon detection of the misfire level specified in section (e)(3.2.2), the following criteria shall apply for MIL illumination and fault code storage:

(A) Misfire within the first 1000 revolutions after engine start.

(i) A pending fault code shall be stored no later than after the first exceedance of the specified misfire level during a single driving cycle if the exceedance occurs within the first 1000 revolutions after engine start (defined in section (c)) during which misfire detection is active.

(ii) If a pending fault code is stored, the OBD II system shall illuminate the MIL and store a confirmed fault code within ten seconds if an exceedance of the specified misfire level is

again detected in the first 1000 revolutions during any subsequent driving cycle, regardless of the conditions encountered during the driving cycle.

(iii) The pending fault code shall be erased at the end of the next driving cycle in which similar conditions to the engine conditions that occurred when the pending fault code was stored have been encountered without an exceedance of the specified percentage of misfire. The pending code may also be erased if similar conditions are not encountered during the next 80 driving cycles immediately following the initial detection of the malfunction.

(B) Exceedances after the first 1000 revolutions after engine start.

(i) A pending fault code shall be stored no later than after the fourth exceedance of the percentage of misfire specified in section (e)(3.2.2) during a single driving cycle.

(ii) If a pending fault code is stored, the OBD II system shall illuminate the MIL and store a confirmed fault code within ten seconds if the percentage of misfire specified in section (e)(3.2.2) is again exceeded four times during: (a) the driving cycle immediately following the storage of the pending fault code, regardless of the conditions encountered during the driving cycle; or (b) on the next driving cycle in which similar conditions (see section (c)) to the engine conditions that occurred when the pending fault code was stored are encountered.

(iii) The pending fault code may be erased at the end of the next driving cycle in which similar conditions to the engine conditions that occurred when the pending fault code was stored have been encountered without an exceedance of the specified percentage of misfire. The pending code may also be erased if similar conditions are not encountered during the next 80 driving cycles immediately following initial detection of the malfunction.

(3.4.3) Storage of freeze frame conditions.

(A) A manufacturer shall store and erase freeze frame conditions either in conjunction with storing and erasing a pending fault code or in conjunction with storing and erasing a confirmed fault code.

(B) If freeze frame conditions are stored for a malfunction other than misfire or fuel system malfunction (see section (e)(6)) when a fault code is stored as specified in section (e)(3.4) above, the stored freeze frame information shall be replaced with freeze frame information regarding the misfire malfunction.

(3.4.4) Storage of misfire conditions for similar conditions determination. Upon detection of misfire under sections (e)(3.4.1) or (3.4.2), manufacturers shall store the following engine conditions: engine speed, load, and warm-up status of the first misfire event that resulted in the storage of the pending fault code.

(3.4.5) Extinguishing the MIL. The MIL may be extinguished after three sequential driving cycles in which similar conditions have been encountered without an exceedance of the specified percentage of misfire.

(3.5) Misfire Monitoring for Diesels

(3.5.1) Requirement:

(A) The OBD II system on a diesel engine shall be capable of detecting misfire occurring continuously in one or more cylinders. To the extent possible without adding hardware for this specific purpose, the OBD II system shall also identify the specific continuously misfiring cylinder.

(B) If more than one cylinder is, continuously misfiring, a separate fault code shall be stored indicating that multiple cylinders are misfiring. When identifying multiple cylinder misfire, the

manufacturer is not required to also identify each of the continuously misfiring cylinders individually through separate fault codes.

(3.5.2) Malfunction Criteria: The OBD II system shall detect a misfire malfunction when one or more cylinders are continuously misfiring.

(3.5.3) Monitoring Conditions: The OBD II system shall monitor for misfire during engine idle conditions at least once per driving cycle in which the monitoring conditions for misfire are met. A manufacturer shall submit monitoring conditions to the Executive Officer for approval. The Executive Officer shall approve manufacturer defined monitoring conditions that are determined (based on manufacturer submitted data and/or other engineering documentation) to: (i) be technically necessary to ensure robust detection of malfunctions (e.g., avoid false passes and false detection of malfunctions), (ii) require no more than 1000 cumulative engine revolutions, and (iii) do not require any single continuous idle operation of more than 15 seconds to make a determination that a malfunction is present (e.g., a decision can be made with data gathered during several idle operations of 15 seconds or less). For 2004 model year vehicles only, a manufacturer may comply with the monitoring conditions for diesel misfire monitoring in title *13, CCR section 1968.1* in lieu of meeting the monitoring conditions in section (e)(3.5.3).

(3.5.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(4) Evaporative System Monitoring

(4.1) Requirement: The OBD II system shall verify purge flow from the evaporative system and shall monitor the complete evaporative system, excluding the tubing and connections between the purge valve and the intake manifold, for vapor leaks to the atmosphere. Individual components of the evaporative system (e.g. valves, sensors, etc.) shall be monitored in accordance with the comprehensive components requirements in section (e)(16) (e.g., for circuit continuity, out of range values, rationality, proper functional response, etc.).

(4.2) Malfunction Criteria:

(4.2.1) For purposes of section (e)(4), an orifice shall be defined as an O'Keefe Controls Co. precision metal "Type B" orifice with NPT connections with a diameter of the specified dimension (e.g., part number B-20-SS for a stainless steel 0.020 inch diameter orifice).

(4.2.2) The OBD II system shall detect an evaporative system malfunction when any of the following conditions exist:

(A) No purge flow from the evaporative system to the engine can be detected by the OBD II system;

(B) The complete evaporative system contains a leak or leaks that cumulatively are greater than or equal to a leak caused by a 0.040 inch diameter orifice; and

(C) The complete evaporative system contains a leak or leaks that cumulatively are greater than or equal to a leak caused by a 0.020 inch diameter orifice.

(4.2.3) On vehicles with fuel tank capacity greater than 25.0 gallons, a manufacturer may request the Executive Officer to revise the orifice size in sections (e)(4.2.2)(B) and/or (C) if the most reliable monitoring method available cannot reliably detect a system leak of the magnitudes specified. The Executive Officer shall approve the request upon determining that the manufacturer has provided data and/or engineering analysis that demonstrate the need for the request.

(4.2.4) Upon request by the manufacturer and upon determining that the manufacturer has submitted data and/or engineering evaluation which support the request, the Executive Officer shall revise the orifice size in sections (e)(4.2.2)(B) and/or (C) upward to exclude detection of leaks that cannot cause evaporative or running loss emissions to exceed 1.5 times the applicable standards.

(4.2.5) A manufacturer may request Executive Officer approval to revise the orifice size in section (e)(4.2.2)(B) to a 0.090 inch diameter orifice. The Executive Officer shall approve the request upon the manufacturer submitting data and/or engineering analysis and the Executive Officer finding that:

(A) the monitoring strategy for detecting orifices specified in section (e)(4.2.2)(C) meets the monitoring conditions requirements of section (e)(4.3.2); and

(B) the monitoring strategy for detecting 0.090 inch diameter orifices substantially exceeds the monitoring conditions requirements of section (e)(4.3.1) for monitoring strategies designed to detect orifices specified in section (e)(4.2.2)(B).

(4.2.6) For the 2004 and 2005 model years only, manufacturers that use separate monitors to identify leaks (as specified in (e)(4.2.2.)(B) or (C)) in different portions of the complete evaporative system (e.g., separate monitors for the fuel tank to canister portion and for the canister to purge valve portion of the system) may request Executive Officer approval to revise the malfunction criteria in sections (e)(4.2.2)(B) and (C) to identify a malfunction when the separately monitored portion of the evaporative system (e.g., the fuel tank to canister portion) has a leak (or leaks) that is greater than or equal to the specified size in lieu of when the complete evaporative system has a leak (or leaks) that is greater than or equal to the specified size. The Executive Officer shall approve the request upon determining that the manufacturer utilized the same monitoring strategy (e.g., monitoring portions of the complete system with separate monitors) on vehicles prior to the 2004 model year and that the monitoring strategy provides further isolation of the malfunction for repair technicians by utilizing separate fault codes for each monitored portion of the evaporative system.

(4.3) Monitoring Conditions:

(4.3.1) Manufacturers shall define the monitoring conditions for malfunctions identified in sections (e)(4.2.2)(A) and (B) (i.e., purge flow and 0.040 inch leak detection) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(4.3.2) Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(4.2.2)(C) (i.e., 0.020 inch leak detection) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(4.2.2)(C) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(4.3.3) Manufacturers may disable or abort an evaporative system monitor when the fuel tank level is over 85 percent of nominal tank capacity or during a refueling event.

(4.3.4) Manufacturers may request Executive Officer approval to execute the evaporative system monitor only on driving cycles determined by the manufacturer to be cold starts if the condition is needed to ensure reliable monitoring. The Executive Officer may not approve criteria that exclude engine starts from being considered as cold starts solely on the basis that ambient temperature exceeds (i.e., indicates a higher temperature than) engine coolant temperature at engine start. The Executive Officer shall approve the request upon determining that data and/or an engineering evaluation submitted by the manufacturer demonstrate that a reliable check can only be made on driving cycles when the cold start criteria are satisfied.

(4.3.5) Manufacturers may temporarily disable the evaporative purge system to perform an evaporative system leak check.

(4.4)MIL Illumination and Fault Code Storage:

(4.4.1) Except as provided below for fuel cap leaks and alternate statistical MIL illumination protocols, general requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(4.4.2) If the OBD II system is capable of discerning that a system leak is being caused by a missing or improperly secured fuel cap:

(A) The manufacturer is not required to illuminate the MIL or store a fault code if the vehicle is equipped with an alternative indicator for notifying the vehicle operator of the malfunction. The alternative indicator shall be of sufficient illumination and location to be readily visible under all lighting conditions.

(B) If the vehicle is not equipped with an alternative indicator and the MIL illuminates, the MIL may be extinguished and the corresponding fault codes erased once the OBD II system has verified that the fuel cap has been securely fastened and the MIL has not been illuminated for any other type of malfunction.

(C) The Executive Officer may approve other strategies that provide equivalent assurance that a vehicle operator will be promptly notified of a missing or improperly secured fuel cap and that corrective action will be undertaken.

(4.4.3) Notwithstanding section (d)(2.2.3), manufacturers may request Executive Officer approval to use alternative statistical MIL illumination and fault code storage protocols that require up to twelve driving cycles on average for monitoring strategies designed to detect malfunctions specified by section (e)(4.2.2)(C). Executive Officer approval shall be granted in accordance with the; bases identified in section (d)(2.2.3) and upon determination that the manufacturer has submitted data and/or an engineering analysis demonstrating that the most reliable monitoring method available cannot reliably detect a malfunction of the specified size without the additional driving cycles and that the monitoring system will still meet the monitoring conditions requirements specified in sections (d)(3.1) and (3.2).

(5) Secondary Air System Monitoring

(5.1) Requirement: The OBD II system on vehicles equipped with any form of secondary air delivery system shall monitor the proper functioning of the secondary air delivery system including all air switching valve(s). The individual electronic components (e.g., actuators, valves, sensors, etc.) in the secondary air system shall be monitored in accordance with the comprehensive component requirements in section (e)(16).

(5.2) Malfunction Criteria:

(5.2.1) For purposes of section (e)(5), "air flow" is defined as the air flow delivered by the secondary air system to the exhaust system. For vehicles using secondary air systems with multiple air flow paths/distribution points, the air flow to each bank (i.e., a group of cylinders that share a common exhaust manifold, catalyst, and control sensor) shall be monitored in accordance with the malfunction criteria in sections (e)(5.2.3) and (5.2.4).

(5.2.2) For all Low Emission Vehicle I applications:

(A) Except as provided in sections (e)(5.2.2)(B) and (e)(5.2.4), the OBD II system shall detect a secondary air system malfunction prior to a decrease from the manufacturer's specified air flow that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(B) Manufacturers may request Executive Officer approval to detect a malfunction when no detectable amount of air flow is delivered in lieu of the malfunction criteria in section (e)(5.2.2)(A). The Executive Office shall grant approval upon determining that deterioration of the secondary air system is unlikely based on data and/or engineering evaluation submitted by the manufacturer demonstrating that the materials used for the secondary air system (e.g., air hoses, tubing, valves, connectors, etc.) are inherently resistant to disconnection, corrosion, or other deterioration.

(5.2.3) For all Low Emission Vehicle II applications:

(A) For 2004 and 2005 model year vehicles, manufacturers shall use the malfunction criteria specified for Low Emission Vehicle I applications in section (e)(5.2.2).

(B) For 2006 and subsequent model year vehicles, except as provided in sections (e)(5.2.3)(C) and (e)(5.2.4), the OBD II system shall detect a secondary air system malfunction prior to a decrease from the manufacturer's specified air flow during normal operation that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards. For purposes of sections (e)(5.2) and (5.3), "normal operation" shall be defined as the condition when the; secondary air system is activated during catalyst and/or engine warm-up following engine start and may not include the condition when the secondary air system is intrusively turned on solely for the purpose of monitoring.

(C) For 2006 and 2007 model year vehicles only, a manufacturer may request Executive Officer approval to detect a malfunction when no detectable amount of air flow is delivered during normal operation in lieu of the malfunction criteria in section (e)(5.2.3)(B) (e.g., 1.5 times the standard) during normal operation. Executive Officer approval shall be granted upon determining that the manufacturer has submitted data and/or engineering analysis that demonstrate that the monitoring system is capable of detecting malfunctions prior to a decrease from the manufacturer's specified air flow that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards during an intrusive operation of the secondary air system later in the same driving cycle.

(5.2.4) For vehicles in which no deterioration or failure of the secondary air system would result in a vehicle's emissions exceeding 1.5 times any of the applicable standards, the OBD II system shall detect a malfunction when no detectable amount of air flow is delivered. For vehicles subject to the malfunction criteria in section (e)(5.2.3)(B), this monitoring for no detectable amount of air flow shall occur during normal operation of the secondary air system.

(5.3) Monitoring Conditions:

(5.3.1) For all Low Emission Vehicle I applications: Manufacturers shall define the monitoring conditions in accordance with section (d)(3.1).

(5.3.2) For all Low Emission Vehicle II applications:

(A) For 2004 and 2005 model year vehicles, manufacturers shall define the monitoring conditions in accordance with section (d)(3.1).

(B) For 2006 and subsequent model year vehicles, manufacturers shall define the monitoring conditions in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(5.2) during normal operation of the secondary air system shall be tracked separately but reported as a single set of values as specified in sections (d)(4.2.2)(C) and (d)(5.2.2).

(5.4)MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(6) Fuel System Monitoring

(6.1) Requirement:

(6.1.1) For all vehicles except vehicles with diesel engines, the OBD II system shall monitor the fuel delivery system to determine its ability to provide compliance with emission standards.

(6.1.2) For vehicles with diesel engines, the manufacturer shall monitor the performance of all electronic fuel system components to the extent feasible with respect to the malfunction criteria specified in section (e)(6.2) below.

(6.2) Malfunction Criteria:

(6.2.1) The OBD II system shall detect a malfunction of the fuel delivery system (including feedback control based on a secondary oxygen sensor) when the fuel delivery system is unable to maintain a vehicle's emissions at or below 1.5 times any of the applicable FTP standards.

(6.2.2) Except as provided for in section (e)(6.2.3) below, if the vehicle is equipped with adaptive feedback control, the OBD II system shall detect a malfunction when the adaptive feedback control has used up all of the adjustment allowed by the manufacturer.

(6.2.3) If the vehicle is equipped with feedback control that is based on a secondary oxygen (or equivalent) sensor, the OBD II system is not required to detect a malfunction of the fuel system solely when the feedback control based on a secondary oxygen sensor has used up all of the adjustment allowed by the manufacturer. However, if a failure or deterioration results in vehicle emissions that exceed the malfunction criteria in section (e)(6.2.1), the OBD II system is required to detect a malfunction.

(6.2.4) The OBD II system shall detect a malfunction whenever the fuel control system fails to enter closed-loop operation (if employed) within a manufacturer specified time interval.

(6.2.5) Manufacturers may adjust the criteria and/or limit(s) to compensate for changes in altitude, for temporary introduction of large amounts of purge vapor, or for other similar identifiable operating conditions when they occur.

(6.3) Monitoring Conditions: The fuel system shall be monitored continuously for the presence of a malfunction.

(6.4)MIL Illumination and Fault Code Storage:

(6.4.1) A pending fault code shall be stored immediately upon the fuel system exceeding the malfunction criteria established pursuant to section (e)(6.2).

(6.4.2) Except as provided below, if a pending fault code is stored, the OBD II system shall immediately illuminate the MIL and store a confirmed fault code if a malfunction is again detected during either of the following two events: (a) the driving cycle immediately following the storage of the pending fault code, regardless of the conditions encountered during the driving cycle; or (b) on the next driving cycle in which similar conditions (see section (c)) to those that occurred when the pending fault code was stored are encountered.

(6.4.3) The pending fault code may be erased at the end of the next driving cycle in which similar conditions have been encountered without an exceedance of the specified fuel system malfunction criteria. The pending code may also be erased if similar conditions are not encountered during the 80 driving cycles immediately after the initial detection of a malfunction for which the pending code was set.

(6.4.4) Storage of freeze frame conditions.

(A) A manufacturer shall store and erase freeze frame conditions either in conjunction with storing and erasing a pending fault code or in conjunction with storing and erasing a confirmed fault code.

(B) If freeze frame conditions are stored for a malfunction other than misfire (see section (e)(3)) or fuel system malfunction when a fault code is stored as specified in section (e)(6.4) above, the stored freeze frame information shall be replaced with freeze frame information regarding the fuel system malfunction.

(6.4.5) Storage of fuel system conditions for determining similar conditions of operation. Upon detection of a fuel system malfunction under section (e)(6.2), manufacturers shall store the engine speed, load, and warm-up status of the first fuel system malfunction that resulted in the storage of the pending fault code.

(6.4.6) Extinguishing the MIL. The MIL may be extinguished after three sequential driving cycles in which similar conditions have been encountered without a malfunction of the fuel system.

(7) Oxygen Sensor Monitoring

(7.1) Requirement:

(7.1.1) The OBD II system shall monitor the output voltage, response rate, and any other parameter which can affect emissions of all primary (fuel control) oxygen (lambda) sensors for malfunction. Both the lean-to-rich and rich-to-lean response rates shall be monitored.

(7.1.2) The OBD II system shall also monitor all secondary oxygen sensors (those used for fuel trim control or as a monitoring device) for proper output voltage, activity, and/or response rate.

(7.1.3) For vehicles equipped with heated oxygen sensors, the OBD II system shall monitor the heater for proper performance.

(7.1.4) For other types of sensors (e.g., wide range or universal lambda sensors, etc.), the manufacturer shall submit a monitoring plan to the Executive Officer for approval. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and an engineering evaluation that demonstrate that the monitoring plan is as reliable and effective as the monitoring plan required for conventional sensors under section (e)(7).

(7.2) Malfunction Criteria:

(7.2.1) Primary Sensors:

(A) The OBD II system shall detect a malfunction prior to any failure or deterioration of the oxygen sensor voltage, response rate, amplitude, or other characteristic(s) (including drift or bias corrected for by secondary sensors) that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(B) The OBD II system shall detect malfunctions of the oxygen sensor caused by either a lack of circuit continuity or out of range values.

(C) The OBD II system shall detect a malfunction of the oxygen sensor when a sensor failure or deterioration causes the fuel system to stop using that sensor as a feedback input (e.g., causes default or open loop operation).

(D) The OBD II system shall detect a malfunction of the oxygen sensor when the sensor output voltage, amplitude, activity, or other characteristics are no longer sufficient for use as an OBD II system monitoring device (e.g., for catalyst monitoring).

(7.2.2) Secondary Sensors:

(A) The OBD II system shall detect a malfunction prior to any failure or deterioration of the oxygen sensor voltage, response rate, amplitude, or other characteristic(s) that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(B) The OBD II system shall detect malfunctions of the oxygen sensor caused by a lack of circuit continuity.

(C) To the extent feasible, the OBD II system shall detect a malfunction of the oxygen sensor when the sensor output voltage, amplitude, activity, or other characteristics are no longer sufficient for use as an OBD II system monitoring device (e.g., for catalyst monitoring).

(D) The OBD II system shall detect malfunctions of the oxygen sensor caused by out of range values.

(7.2.3) Sensor Heaters:

(A) The OBD II system shall detect a malfunction of the heater performance when the current or voltage drop in the heater circuit is no longer within the manufacturer's specified limits for

normal operation (i.e., within the criteria required to be met by the component vendor for heater circuit performance at high mileage). Subject to Executive Officer approval, other malfunction criteria for heater performance malfunctions may be used upon the Executive Officer determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate the monitoring reliability and timeliness to be equivalent to the stated criteria in section (e)(7.2.3)(A).

(B) The OBD II system shall detect malfunctions of the heater circuit including open or short circuits that conflict with the commanded state of the heater (e.g., shorted to 12 Volts when commanded to 0 Volts (ground), etc.).

(7.3) Monitoring Conditions:

(7.3.1) Primary Sensors

(A) Manufacturers shall define the monitoring conditions for malfunctions identified in sections (e)(7.2.1)(A) and (D) (e.g., proper response rate) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in sections (e)(7.2.1)(A) and (D) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(B) Except as provided in section (e)(7.3.1)(C), monitoring for malfunctions identified in sections (e)(7.2.1)(B) and (C) (i.e., circuit continuity, out-of-range, and open-loop malfunctions) shall be:

(i) Conducted in accordance with title *13, CCR section 1968.1* for Low Emission Vehicle I applications and 2004 and 2005 model year Low Emission Vehicle II applications;

(ii) Conducted continuously for all 2006 and subsequent model year Low Emission Vehicle II applications.

(C) A manufacturer may request Executive Officer approval to disable continuous oxygen sensor monitoring when an oxygen sensor malfunction cannot be distinguished from other effects (e.g., disable out-of-range low monitoring during fuel cut conditions). The Executive Officer shall approve the disablement upon determining that the manufacturer has submitted test data and/or documentation that demonstrate a properly functioning sensor cannot be distinguished from a malfunctioning sensor and that the disablement interval is limited only to that necessary for avoiding false detection.

(7.3.2) Secondary Sensors

(A) Manufacturers shall define monitoring conditions for malfunctions identified in sections (e)(7.2.2)(A), (B), and (C) (e.g., proper sensor activity) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(B) Except as provided in section (e)(7.3.2)(C), monitoring for malfunctions identified in section (e)(7.2.2)(D) (i.e., out-of-range malfunctions) shall be:

(i) Conducted in accordance with title *13, CCR section 1968.1* for Low Emission Vehicle I applications and 2004 and 2005 model year Low Emission Vehicle II applications;

(ii) Conducted continuously for all 2006 and subsequent model year Low Emission Vehicle II applications.

(C) A manufacturer may request Executive Officer approval to disable continuous oxygen sensor monitoring when an oxygen sensor malfunction cannot be distinguished from other effects (e.g., disable out-of-range low monitoring during fuel cut conditions). The Executive Officer shall approve the disablement upon determining that the manufacturer has submitted test data and/or documentation that demonstrate a properly functioning sensor cannot be

distinguished from a malfunctioning sensor and that the disablement interval is limited only to that necessary for avoiding false detection.

(7.3.3) Sensor Heaters

(A) Manufacturers shall define monitoring conditions for malfunctions identified in section (e)(7.2.3)(A) (e.g., sensor heater performance) in accordance sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(B) Monitoring for malfunctions identified in section (e)(7.2.3)(B) (e.g., circuit malfunctions) shall be:

(i) Conducted in accordance with title *13, CCR section 1968.1* for 2004 and 2005 model year vehicles;

(ii) Conducted continuously for all 2006 and subsequent model year vehicles.

(7.4)MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(8) Exhaust Gas Recirculation (EGR) System Monitoring

(8.1) Requirement: The OBD II system shall monitor the EGR system on vehicles so-equipped for low and high flow rate malfunctions. The individual electronic components (e.g., actuators, valves, sensors, etc.) that are used in the EGR system shall be monitored in accordance with the comprehensive component requirements in section (e)(16).

(8.2) Malfunction Criteria:

(8.2.1) The OBD II system shall detect a malfunction of the EGR system prior to an increase or decrease from the manufacturer's specified EGR flow rate that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(8.2.2) For vehicles in which no failure or deterioration of the EGR system could result in a vehicle's emissions exceeding 1.5 times any of the applicable standards, the OBD II system shall detect a malfunction when the system has no detectable amount of EGR flow.

(8.3) Monitoring Conditions:

(8.3.1) Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(8.2) (e.g., flow rate) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(8.2) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(8.3.2) Manufacturers may request Executive Officer approval to temporarily disable the EGR system check under specific conditions (e.g., when freezing may affect performance of the system). The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation which demonstrate that a reliable check cannot be made when these conditions exist.

(8.4)MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(9) Positive Crankcase Ventilation (PCV) System Monitoring

(9.1) Requirement:

(9.1.1) On all 2004 and subsequent model year vehicles, manufacturers shall monitor the PCV system on vehicles so-equipped for system integrity. A manufacturer may use an alternate phase-in schedule in lieu of meeting the requirements of section (e)(9) on all 2004 model year vehicles if the alternate phase-in schedule provides for equivalent compliance volume (as defined in section

(c)) to the phase-in schedule specified in title 13, CCR section 1968.1(b)(10.1). Vehicles not required to be equipped with PCV systems shall be exempt from monitoring of the PCV system.

(9.1.2) For vehicles with diesel engines, the manufacturer shall submit a plan for Executive Officer approval of the monitoring strategy, malfunction criteria, and monitoring conditions prior to introduction on a production vehicle. Executive Officer approval shall be based on the effectiveness of the monitoring strategy to monitor the performance of the PCV system to the extent feasible with respect to the malfunction criteria in section (e)(9.2) below and the monitoring conditions required by the diagnostic.

(9.2) Malfunction Criteria:

(9.2.1) For the purposes of section (e)(9), "PCV system" is defined as any form of crankcase ventilation system, regardless of whether it utilizes positive pressure. "PCV valve" is defined as any form of valve or orifice used to restrict or control crankcase vapor flow. Further, any additional external PCV system tubing or hoses used to equalize crankcase pressure or to provide a ventilation path between various areas of the engine (e.g., crankcase and valve cover) are considered part of the PCV system "between the crankcase and the PCV valve" and subject to the malfunction criteria in section (e)(9.2.2) below.

(9.2.2) Except as provided below, the OBD II system shall detect a malfunction of the PCV system when a disconnection of the system occurs between either the crankcase and the PCV valve, or between the PCV valve and the intake manifold.

(9.2.3) If the PCV system is designed such that the PCV valve is fastened directly to the crankcase in a manner which makes it significantly more difficult to remove the valve from the crankcase rather than disconnect the line between the valve and the intake manifold (taking aging effects into consideration), the Executive Officer shall exempt the manufacturer from detection of disconnection between the crankcase and the PCV valve.

(9.2.4) Subject to Executive Officer approval, system designs that utilize tubing between the valve and the crankcase shall also be exempted from the portion of the monitoring requirement for detection of disconnection between the crankcase and the PCV valve. The manufacturer shall file a request and submit data and/or engineering evaluation in support of the request. The Executive Officer shall approve the request upon determining that the connections between the valve and the crankcase are: (i) resistant to deterioration or accidental disconnection, (ii) significantly more difficult to disconnect than the line between the valve and the intake manifold, and (iii) not subject to disconnection per manufacturer's repair procedures for non-PCV system repair work.

(9.2.5) Manufacturers are not required to detect disconnections between the PCV valve and the intake manifold if said disconnection (1) causes the vehicle to stall immediately during idle operation; or (2) is unlikely to occur due to a PCV system design that is integral to the induction system (e.g., machined passages rather than tubing or hoses).

(9.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(9.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(9.4)MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2). The stored fault code need not specifically identify the PCV system (e.g., a fault code for idle speed control or fuel system monitoring can be stored) if the manufacturer demonstrates that additional monitoring hardware would be necessary to make this identification, and provided the manufacturer's diagnostic and repair procedures for the detected malfunction include directions to check the integrity of the PCV system.

(10) Engine Cooling System Monitoring

(10.1) Requirement:

(10.1.1) The OBD II system shall monitor the thermostat on vehicles so-equipped for proper operation.

(10.1.2) The OBD II system shall monitor the engine coolant temperature (ECT) sensor for circuit continuity, out-of-range values, and rationality faults.

(10.2) Malfunction Criteria:

(10.2.1) Thermostat

(A) The OBD II system shall detect a thermostat malfunction if, within an Executive Officer approved time interval after starting the engine, either of the following two conditions occur:

(i) The coolant temperature does not reach the highest temperature required by the OBD II system to enable other diagnostics;

(ii) The coolant temperature does not reach a warmed-up temperature within 20 degrees Fahrenheit of the manufacturer's nominal thermostat regulating temperature. Subject to Executive Officer approval, a manufacturer may utilize lower temperatures for this criterion upon the Executive Officer determining that the manufacturer has demonstrated that the fuel, spark timing, and/or other coolant temperature-based modifications to the engine control strategies would not cause an emission increase of 50 or more percent of any of the applicable standards (e.g., 50 degree Fahrenheit emission test, etc.).

(B) Executive Officer approval of the time interval after engine start shall be granted upon determining that the data and/or engineering evaluation submitted by the manufacturer supports the specified times.

(C) With Executive Officer approval, a manufacturer may use alternate malfunction criteria and/or monitoring conditions (see section (e)(10.3)) that are a function of temperature at engine start on vehicles that do not reach the temperatures specified in the malfunction criteria when the thermostat is functioning properly. Executive Officer approval shall be granted upon determining that the manufacturer has submitted data that demonstrate that a properly operating system does not reach the specified temperatures, that the monitor is capable of meeting the specified malfunction criteria at engine start temperatures greater than 50oF, and that the overall effectiveness of the monitor is comparable to a monitor meeting these thermostat monitoring requirements at lower temperatures.

(D) With Executive Officer approval, manufacturers may omit this monitor. Executive Officer approval shall be granted upon determining that the manufacturer has demonstrated that a malfunctioning thermostat cannot cause a measurable increase in emissions during any reasonable driving condition nor cause any disablement of other monitors.

(10.2.2) ECT Sensor

(A) Circuit Continuity. The OBD II system shall detect a malfunction when a lack of circuit continuity or out-of-range values occur.

(B) Time to Reach Closed-Loop Enable Temperature.

(i) The OBD II system shall detect a malfunction if the ECT sensor does not achieve the stabilized minimum temperature which is needed for the fuel control system to begin closed-loop operation (closed-loop enable temperature) within an Executive Officer approved time interval after starting the engine. For diesel applications, the minimum temperature needed for warmed-up fuel control to begin shall be used instead of the closed-loop enable temperature.

(ii) The time interval shall be a function of starting ECT and/or a function of intake air temperature and, except as provided below in section (e)(10.2.2)(B)(iii), may not exceed:

a. two minutes for engine start temperatures at or above 50 degrees Fahrenheit and five minutes for engine start temperatures at or above 20 degrees Fahrenheit and below 50 degrees Fahrenheit for Low Emission Vehicle I applications and 2004 and 2005 model year Low Emission Vehicle II applications;

b. two minutes for engine start temperatures up to 15 degrees Fahrenheit below the closed-loop enable temperature and five minutes for engine start temperatures between 15 and 35 degrees Fahrenheit below the closed-loop enable temperature for all 2006 and subsequent model year Low Emission Vehicle II applications.

(iii) Executive Officer approval of the time interval shall be granted upon determining that the data and/or engineering evaluation submitted by the manufacturer supports the specified times. The Executive Officer shall allow longer time intervals upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that the vehicle requires a longer time to warm up under normal conditions.

(iv) The Executive Officer shall exempt manufacturers from the requirement of section (e)(10.2.2)(B) if the manufacturer does not utilize ECT to enable closed loop fuel control.

(C) Stuck in Range Below the Highest Minimum Enable Temperature. To the extent feasible when using all available information, the OBD II system shall detect a malfunction if the ECT sensor inappropriately indicates a temperature below the highest minimum enable temperature required by the OBD II system to enable other diagnostics (e.g., an OBD II system that requires ECT to be greater than 140 degrees Fahrenheit to enable a diagnostic must detect malfunctions that cause the ECT sensor to inappropriately indicate a temperature below 140 degrees Fahrenheit). Manufacturers are exempted from this requirement for temperature regions in which the monitors required under sections (e)(10.2.1) or (e)(10.2.2)(B) will detect ECT sensor malfunctions as defined in section (e)(10.2.2)(C).

(D) Stuck in Range Above the Lowest Maximum Enable Temperature.

(i) To the extent feasible when using all available information, the OBD II system shall detect a malfunction if the ECT sensor inappropriately indicates a temperature above the lowest maximum enable temperature required by the OBD II system to enable other diagnostics (e.g., an OBD II system that requires ECT to be less than 90 degrees Fahrenheit at engine start to enable a diagnostic must detect malfunctions that cause the ECT sensor to inappropriately indicate a temperature above 90 degrees Fahrenheit).

(ii) Manufacturers are exempted from this requirement for temperature regions in which the monitors required under sections (e)(10.2.1), (e)(10.2.2)(B), or (e)(10.2.2)(C) (i.e., ECT sensor or thermostat malfunctions) will detect ECT sensor malfunctions as defined in section (e)(10.2.2)(D) or in which the MIL will be illuminated under the requirements of section (d)(2.1.3) for default mode operation (e.g., overtemperature protection strategies).

(iii) For Low Emission Vehicle I applications and 2004 and 2005 model year Low Emission Vehicle II applications only, manufacturers are also exempted from the requirements of section (e)(10.2.2)(D) for vehicles that have a temperature gauge (not a warning light) on the instrument panel and utilize the same ECT sensor for input to the OBD II system and the temperature gauge.

(iv) For 2006 and subsequent model year Low Emission Vehicle II applications, manufacturers are also exempted from the requirements of section (e)(10.2.2)(D) for temperature regions where the temperature gauge indicates a temperature in the red zone (engine overheating zone) for vehicles that have a temperature gauge (not a warning light) on the instrument panel and utilize the same ECT sensor for input to the OBD II system and the temperature gauge.

(10.3) Monitoring Conditions:

(10.3.1) Thermostat

(A) Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(10.2.1)(A) in accordance with section (d)(3.1). Additionally, except as provided for in sections (e)(10.3.1)(B) and (C), monitoring for malfunctions identified in section (e)(10.2.1)(A) shall be conducted once per driving cycle on every driving cycle in which the ECT sensor indicates, at engine start, a temperature lower than the temperature established as the malfunction criteria in section (e)(10.2.1)(A).

(B) Manufacturers may disable thermostat monitoring at ambient starting temperatures below 20 degrees Fahrenheit.

(C) Manufacturers may request Executive Officer approval to suspend or disable thermostat monitoring if the vehicle is subjected to conditions which could lead to false diagnosis (e.g., vehicle operation at idle for more than 50 percent of the warm-up time, hot restart conditions, etc.). In general, the Executive Officer shall not approve disablement of the monitor on engine starts where the ECT at engine start is more than 35 degrees Fahrenheit lower than the thermostat malfunction threshold temperature determined under section (e)(10.2.1)(A). The Executive Officer shall approve the request upon determining that the manufacturer has provided data and/or engineering analysis that demonstrate the need for the request.

(10.3.2) ECT Sensor

(A) Except as provided below in section (e)(10.3.2)(E), monitoring for malfunctions identified in section (e)(10.2.2)(A) (i.e., circuit continuity and out of range) shall be conducted continuously.

(B) Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(10.2.2)(B) in accordance with section (d)(3.1). Additionally, except as provided for in section (e)(10.3.2)(D), monitoring for malfunctions identified in section (e)(10.2.2)(B) shall be conducted once per driving cycle on every driving cycle in which the ECT sensor indicates a temperature lower than the closed loop enable temperature at engine start (i.e., all engine start temperatures greater than the ECT sensor out of range low temperature and less than the closed loop enable temperature).

(C) Manufacturers shall define the monitoring conditions for malfunctions identified in sections (e)(10.2.2)(C) and (D) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(D) Manufacturers may suspend or delay the time to reach closed loop enable temperature diagnostic if the vehicle is subjected to conditions which could lead to false diagnosis (e.g., vehicle operation at idle for more than 50 to 75 percent of the warm-up time).

(E) A manufacturer may request Executive Officer approval to disable continuous ECT sensor monitoring when an ECT sensor malfunction cannot be distinguished from other effects. The Executive Officer shall approve the disablement upon determining that the manufacturer has submitted test data and/or engineering evaluation that demonstrate a properly functioning sensor cannot be distinguished from a malfunctioning sensor and that the disablement interval is limited only to that necessary for avoiding false detection.

(10.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(11) Cold Start Emission Reduction Strategy Monitoring

(11.1) Requirement:

(11.1.1) For all 2006 and subsequent model year Low Emission Vehicle II applications, if a vehicle incorporates a specific engine control strategy to reduce cold start emissions, the OBD II system shall monitor the key control or feedback parameters (e.g., engine speed, mass air flow, ignition timing, etc.), other than secondary air, while the control strategy is active to ensure proper

operation of the control strategy. Secondary air systems shall be monitored under the provisions of section (e)(5).

(11.1.2) In lieu of meeting the requirements of section (e)(11) on all 2006 and subsequent model year Low Emission Vehicle II applications, a manufacturer may phase in the requirements on a portion of its Low Emission Vehicle II applications as long as that portion of Low Emission Vehicle II applications comprises at least 30 percent of all 2006 model year vehicles, 60 percent of all 2007 model year vehicles, and 100 percent of all 2008 and subsequent model year vehicles.

(11.2) Malfunction Criteria:

(11.2.1) The OBD II system shall detect a malfunction prior to any failure or deterioration of the individual components associated with the cold start emission reduction control strategy that would cause a vehicle's emissions to exceed 1.5 times the applicable FTP standards. Manufacturers shall:

(A) Establish the malfunction criteria based on data from one or more representative vehicle(s).

(B) Provide an engineering evaluation for establishing the malfunction criteria for the remainder of the manufacturer's product line. The Executive Officer shall waive the evaluation requirement each year if, in the judgement of the Executive Officer, technological changes do not affect the previously determined malfunction criteria.

(11.2.2) For components where no failure or deterioration of the component used for the cold start emission reduction strategy could result in a vehicle's emissions exceeding 1.5 times the applicable standards, the individual component shall be monitored for proper functional response in accordance with the malfunction criteria in section (e)(16.2) while the control strategy is active.

(11.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(11.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(11.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(12) Air Conditioning (A/C) System Component Monitoring

(12.1) Requirement: If a vehicle incorporates an engine control strategy that; alters off-idle fuel and/or spark control when the A/C system is on,; the OBD II system shall monitor all electronic air conditioning system components for malfunctions that cause the system to fail to invoke the alternate control while the A/C system is on or cause the system to invoke the alternate control while the A/C system is off. Additionally, the OBD II system shall monitor for malfunction all electronic air conditioning system components that are used as part of the diagnostic strategy for any other monitored system or component. The requirements of section (e)(12) shall be phased in as follows: 30 percent of all 2006 model year vehicles, 60 percent of all 2007 model year vehicles, and 100 percent of all 2008 and subsequent model year vehicles.

(12.2) Malfunction Criteria:

(12.2.1) The OBD II system shall detect a malfunction prior to any failure or deterioration of an electronic component of the air conditioning system that would cause a vehicle's emissions to exceed 1.5 times any of the appropriate applicable emission standards or would, through software, effectively disable any other monitored system or component covered by this regulation. For malfunctions that result in the alternate control being erroneously invoked while the A/C system is off, the appropriate emission standards shall be the FTP standards. For malfunctions that result in the alternate control failing to be invoked while the A/C system is on, the appropriate emission standards shall be the SC03 emission standards.

(12.2.2) If no single electronic component failure or deterioration causes emissions to exceed 1.5 times any of the appropriate applicable emission standards as defined above in section (e)(12.2.1) nor is used as part of the diagnostic strategy for any other monitored system or component, manufacturers are not required to monitor any air conditioning system component for purposes of section (e)(12).

(12.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(12.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(12.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(13) Variable Valve Timing and/or Control (VVT) System Monitoring

(13.1) Requirement: On all 2006 and subsequent model year Low Emission Vehicle II applications, the OBD II system shall monitor the VVT system on vehicles so-equipped for target error and slow response malfunctions. The individual electronic components (e.g., actuators, valves, sensors, etc.) that are used in the VVT system shall be monitored in accordance with the comprehensive components requirements in section (e)(16). VVT systems on Low Emission Vehicle I applications and 2004 and 2005 model year Low Emission Vehicle II applications shall be monitored in accordance with the comprehensive components requirements in section (e)(16).

(13.2) Malfunction Criteria:

(13.2.1) Target Error. The OBD II system shall detect a malfunction prior to any failure or deterioration in the capability of the VVT system to achieve the commanded valve timing and/or control within a crank angle and/or lift tolerance that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(13.2.2) Slow Response. The OBD II system shall detect a malfunction prior to any failure or deterioration in the capability of the VVT system to achieve the commanded valve timing and/or control within a time that would cause a vehicle's emissions to exceed 1.5 times any of the applicable FTP standards.

(13.2.3) For vehicles in which no failure or deterioration of the VVT system could result in a vehicle's emissions exceeding 1.5 times any of the applicable standards, the VVT system shall be monitored for proper functional response in accordance with the malfunction criteria in section (e)(16.2).

(13.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for VVT system malfunctions identified in section (e)(13.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements), with the exception that monitoring shall occur every time the monitoring conditions are met during the driving cycle in lieu of once per driving cycle as required in section (d)(3.1.2). Additionally, manufacturers shall track and report VVT system monitor performance under section (d)(3.2.2). For purposes of tracking and reporting as required in section (d)(3.2.2), all monitors used to detect malfunctions identified in section (e)(13.2) shall be tracked separately but reported as a single set of values as specified in section (d)(5.2.2).

(13.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(14) Direct Ozone Reduction (DOR) System Monitoring

(14.1) Requirement:

(14.1.1) The OBD II system shall monitor the DOR system on vehicles so-equipped for malfunctions that reduce the ozone reduction performance of the system.

(14.1.2) For 2003, 2004, and 2005 model year vehicles subject to the malfunction criteria of section (e)(14.2.1) below, manufacturers may request to be exempted from DOR system monitoring. The Executive Officer shall approve the exemption upon the manufacturer:

(A) Agreeing that the DOR system receive only 50 percent of the NMOG credit assigned to the DOR system as calculated under Air Resources Board (ARB) Manufacturers Advisory Correspondence (MAC) No. 99-06, December 20, 1999, which is hereby incorporated by reference herein.

(B) Identifying the DOR system component(s) as an emission control device on both the underhood emission control label and a separate label as specified below. The DOR system shall be included in the list of emission control devices on the underhood emission control label and be identified as a "DOR system" or other equivalent term from SAE J1930 "Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms - Equivalent to ISO/TR 15031-2:April 30, 2002 (SAE 1930)", incorporated by reference. A separate label shall be located on or near the DOR system component(s) in a location that is visible to repair technicians prior to the removal of any parts necessary to replace the DOR system component(s) and shall identify the components as a "DOR system" or other equivalent SAE J1930 term.

(14.2) Malfunction Criteria:

(14.2.1) For vehicles in which the NMOG credit assigned to the DOR system, as calculated in accordance with ARB MAC No. 99-06, is less than or equal to 50 percent of the applicable FTP NMOG standard, the OBD II system shall detect a malfunction when the DOR system has no detectable amount of ozone reduction.

(14.2.2) For vehicles in which the NMOG credit assigned to the DOR system, as calculated in accordance with ARB MAC No. 99-06, is greater than 50 percent of the applicable FTP NMOG standard, the OBD II system shall detect a malfunction when the ozone reduction performance of the DOR system deteriorates to a point where the difference between the NMOG credit assigned to the properly operating DOR system and the NMOG credit calculated for a DOR system performing at the level of the malfunctioning system exceeds 50 percent of the applicable FTP NMOG standard.

(14.2.3) For vehicles equipped with a DOR system, the manufacturer may modify any of the applicable NMOG malfunction criteria in sections (e)(1)-(3), (e)(5)-(8), (e)(11)-(e)(13), and (e)(17) by adding the NMOG credit received by the DOR system to the required NMOG malfunction criteria (e.g., a malfunction criteria of 1.5 x NMOG standard would be modified to (1.5 x NMOG standard) + DOR system NMOG credit).

(14.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(14.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(14.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(15) Particulate Matter (PM) Trap Monitoring

(15.1) Requirement: On all 2004 and subsequent model year diesel passenger cars, light-duty trucks, and medium-duty passenger vehicles (see section (c)) and all 2005 and subsequent model year diesel medium-duty vehicles, manufacturers shall monitor the PM trap on vehicles so-equipped for proper performance.

(15.2) Malfunction Criteria:

(15.2.1) For 2004 and subsequent model year diesel passenger cars, light-duty trucks, and medium-duty passenger vehicles certified to a chassis dynamometer tailpipe standard, the OBD II

system shall detect a malfunction prior to a decrease in the capability of the PM trap that would cause a vehicle's emissions to exceed 1.5 times the applicable standards.

(15.2.2) For 2005 and 2006 model year diesel medium-duty vehicles (including medium-duty passenger vehicles certified to an engine dynamometer tailpipe standard), the OBD II system shall detect a malfunction of the PM trap when catastrophic failure occurs. The Executive Officer shall exempt vehicles from this PM trap monitoring requirement upon determining that the manufacturer has demonstrated with data and/or engineering evaluation that catastrophic failure of the PM trap will not cause emissions to exceed 1.5 times the applicable standards.

(15.2.3) For 2007 and subsequent model year diesel medium-duty vehicles, the OBD II system shall detect a malfunction prior to a decrease in the capability of the PM trap that would cause a vehicle's emissions to exceed 1.5 times the applicable standards.

(15.2.4) For vehicles subject to the malfunction criteria in sections (e)(15.2.1) or (15.2.3) above, if no failure or deterioration of the PM trap could result in a vehicle's emissions exceeding 1.5 times any of the applicable standards, the OBD II system shall detect a malfunction when catastrophic failure of the PM trap occurs.

(15.3) Monitoring Conditions: Manufacturers shall define the monitoring conditions for malfunctions identified in section (e)(15.2) in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements).

(15.4) MIL Illumination and Fault Code Storage: General requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(16) Comprehensive Component Monitoring

(16.1) Requirement:

(16.1.1) Except as provided in section (e)(16.1.3) and (e)(17), the OBD II system shall monitor for malfunction any electronic powertrain component/system not otherwise described in sections (e)(1) through (e)(15) that either provides input to (directly or indirectly) or receives commands from the on-board computer(s), and: (1) can affect emissions during any reasonable in-use driving condition, or (2) is used as part of the diagnostic strategy for any other monitored system or component.

(A) Input Components: Input components required to be monitored may include the vehicle speed sensor, crank angle sensor, knock sensor, throttle position sensor, cam position sensor, fuel composition sensor (e.g. flexible fuel vehicles), and transmission electronic components such as sensors, modules, and solenoids which provide signals to the powertrain control system.

(B) Output Components/Systems: Output components/systems required to be monitored may include the idle speed control system, automatic transmission solenoids or controls, variable length intake manifold runner systems, supercharger or turbocharger electronic components, heated fuel preparation systems, the wait-to-start lamp on diesel applications, and a warm-up catalyst bypass valve.

(16.1.2) For purposes of criteria (1) in section (e)(16.1.1) above, the manufacturer shall determine whether a powertrain input or output component/system can affect emissions. If the Executive Officer reasonably believes that a manufacturer has incorrectly determined that a component/system cannot affect emissions, the Executive Officer shall require the manufacturer to provide emission data showing that the component/system, when malfunctioning and installed in a suitable test vehicle, does not have an emission effect. Emission data may be requested for any reasonable driving condition.

(16.1.3) Manufacturers shall monitor for malfunction electronic powertrain input or output components/systems associated with an electronic transfer case only if the transfer case

component or system is used as part of the diagnostic strategy for any other monitored system or component.

(16.2) Malfunction Criteria:

(16.2.1) Input Components:

(A) The OBD II system shall detect malfunctions of input components caused by a lack of circuit continuity, out of range values, and, where feasible, rationality faults. To the extent feasible, the rationality fault diagnostics shall verify that a sensor output is neither inappropriately high nor inappropriately low (e.g., "two-sided" diagnostics).

(B) To the extent feasible on all 2005 and subsequent model year vehicles, rationality faults shall be separately detected and store different fault codes than the respective lack of circuit continuity and out of range diagnostics. Additionally, input component lack of circuit continuity and out of range faults shall be separately detected and store different fault codes for each distinct malfunction (e.g., out-of-range low, out-of-range high, open circuit, etc.). Manufacturers are not required to store separate fault codes for lack of circuit continuity faults that cannot be distinguished from other out-of-range circuit faults.

(C) For vehicles that require precise alignment between the camshaft and the crankshaft, the OBD II system shall monitor the crankshaft position sensor(s) and camshaft position sensor(s) to verify proper alignment between the camshaft and crankshaft in addition to monitoring the sensors for circuit continuity and rationality malfunctions. Proper alignment monitoring between a camshaft and a crankshaft shall only be required in cases where both are equipped with position sensors. For 2006 and subsequent model year Low Emission Vehicle II applications equipped with VVT systems and a timing belt or chain, the OBD II system shall detect a malfunction if the alignment between the camshaft and crankshaft is off by one or more cam/crank sprocket cogs (e.g., the timing belt/chain has slipped by one or more teeth/cogs). If a manufacturer demonstrates that a single tooth/cog misalignment cannot cause a measurable increase in emissions during any reasonable driving condition, the manufacturer shall detect a malfunction when the minimum number of teeth/cogs misalignment needed to cause a measurable emission increase has occurred. For the 2006 through 2008 model years only, a manufacturer may also request Executive Officer approval to use a larger threshold than one tooth/cog. The Executive Officer shall approve the request upon determining that the manufacturer has demonstrated that hardware modifications are necessary to meet the one tooth/cog threshold and that further software modifications are not able to reduce the larger threshold.

(16.2.2) Output Components/Systems:

(A) The OBD II system shall detect a malfunction of an output component/system when proper functional response of the component and system to computer commands does not occur. If a functional check is not feasible, the OBD II system shall detect malfunctions of output components/systems caused by a lack of circuit continuity or circuit fault (e.g., short to ground or high voltage). For output component lack of circuit continuity faults and circuit faults, manufacturers are not required to store different fault codes for each distinct malfunction (e.g., open circuit, shorted low, etc.). Manufacturers are not required to activate an output component/system when it would not normally be active exclusively for the purposes of performing functional monitoring of output components/systems as required in section (e)(16).

(B) The idle speed control system shall be monitored for proper functional response to computer commands. For strategies based on deviation from target idle speed, a malfunction shall be detected when either of the following conditions occur:

(i) The idle speed control system cannot achieve the target idle speed within 200 revolutions per minute (rpm) above the target speed or 100 rpm below the target speed. The Executive Officer shall allow larger engine speed tolerances upon determining that a

manufacturer has submitted data and/or an engineering evaluation which demonstrate that the tolerances can be exceeded without a malfunction being present.

(ii) The idle speed control system cannot achieve the target idle speed within the smallest engine speed tolerance range required by the OBD II system to enable any other monitors.

(C) Glow plugs shall be monitored for proper functional response to computer commands. The glow plug circuit(s) shall be monitored for proper current and voltage drop. The Executive Officer shall approve other monitoring strategies based on manufacturer's data and/or engineering analysis demonstrating equally reliable and timely detection of malfunctions. Manufacturers shall detect a malfunction when a single glow plug no longer operates within the manufacturer's specified limits for normal operation. If a manufacturer demonstrates that a single glow plug failure cannot cause a measurable increase in emissions during any reasonable driving condition, the manufacturer shall detect a malfunction for the minimum number of glow plugs needed to cause an emission increase. Further, to the extent feasible on existing engine designs (without adding additional hardware for this purpose) and on all new design engines, the stored fault code shall identify the specific malfunctioning glow plug(s).

(16.3) Monitoring Conditions:

(16.3.1) Input Components:

(A) Except as provided in section (e)(16.3.1)(C), input components shall be monitored continuously for proper range of values and circuit continuity.

(B) For rationality monitoring (where applicable):

(i) For 2004 model year vehicles, manufacturers shall define the monitoring conditions for detecting malfunctions in accordance with section (d)(3.1).

(ii) For 2005 and subsequent model year vehicles, manufacturers shall define the monitoring conditions for detecting malfunctions in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements), with the exception that rationality monitoring shall occur every time the monitoring conditions are met during the driving cycle in lieu of once per driving cycle as required in section (d)(3.1.2).

(C) A manufacturer may request Executive Officer approval to disable continuous input component proper range of values or circuit continuity monitoring when a malfunction cannot be distinguished from other effects. The Executive Officer shall approve the disablement upon determining that the manufacturer has submitted test data and/or documentation that demonstrate a properly functioning input component cannot be distinguished from a malfunctioning input component and that the disablement interval is limited only to that necessary for avoiding false detection.

(16.3.2) Output Components/Systems:

(A) Except as provided in section (e)(16.3.2)(D), monitoring for circuit continuity and circuit faults shall be conducted continuously.

(B) Except as provided in section (e)(16.3.2)(C), for functional monitoring, manufacturers shall define the monitoring conditions for detecting malfunctions in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum, ratio requirements).

(C) For the idle speed control system on all 2005 and subsequent model year vehicles, manufacturers shall define the monitoring conditions for functional monitoring in accordance with sections (d)(3.1) and (d)(3.2) (i.e., minimum ratio requirements), with the exception that functional monitoring shall occur every time the monitoring conditions are met during the driving cycle in lieu of once per driving cycle as required in section (d)(3.1.2).

(D) A manufacturer may request Executive Officer approval to disable continuous output component circuit continuity or circuit fault monitoring when a malfunction cannot be distinguished from other effects. The Executive Officer shall approve the disablement upon determining that the manufacturer has submitted test data and/or documentation that demonstrate a properly functioning output component cannot be distinguished from a malfunctioning output component and that the disablement interval is limited only to that necessary for avoiding false detection.

(16.4) MIL Illumination and Fault Code Storage:

(16.4.1) Except as provided in section (e)(16.4.2) below, general requirements for MIL illumination and fault code storage are set forth in section (d)(2).

(16.4.2) Exceptions to general requirements for MIL illumination. MIL illumination is not required in conjunction with storing a confirmed fault code for any comprehensive component if:

(A) the component or system, when malfunctioning, could not cause vehicle emissions to increase by:

(i) 25 percent or more of the FTP standard for PC/LDT SULEV II vehicles, or

(ii) 15 percent or more of the FTP standard for all other vehicles, and

(B) the component or system is not used as part of the diagnostic strategy for any other monitored system or component.

(17) Other Emission Control or Source System Monitoring

(17.1) Requirement: For other emission control or source systems that are: (1) not identified or addressed in sections (e)(1) through (e)(16) (e.g., hydrocarbon traps, NOx storage devices, fuel-fired passenger compartment heaters, etc.), or (2) identified or addressed in section (e)(16) but not corrected or compensated for by the adaptive fuel control system (e.g., swirl control valves), manufacturers shall submit a plan for Executive Officer approval of the monitoring strategy, malfunction criteria, and monitoring conditions prior to introduction on a production vehicle. Executive Officer approval shall be based on the effectiveness of the monitoring strategy, the malfunction criteria utilized, the monitoring conditions required by the diagnostic, and, if applicable, the determination that the requirements of section (e)(17.3) below are satisfied.

(17.2) For purposes of section (e)(17), emission source systems are components or devices that emit pollutants subject to vehicle evaporative and exhaust emission standards (e.g., NMOG, CO, NOx, PM, etc.) and include non-electronic components and non-powertrain components (e.g., fuel-fired passenger compartment heaters, on-board reformers, etc.).

(17.3) Except as provided below in this paragraph, for 2005 and subsequent model year vehicles that utilize emission control systems that alter intake air flow or cylinder charge characteristics by actuating valve(s), flap(s), etc. in the intake air delivery system (e.g., swirl control valve systems), the manufacturers, in addition to meeting the requirements of section (e)(17.1) above, may elect to have the OBD II system monitor the shaft to which all valves in one intake bank are physically attached in lieu of monitoring the intake air flow, cylinder charge, or individual valve(s)/flap(s) for proper functional response. For non-metal shafts or segmented shafts, the monitor shall verify all shaft segments for proper functional response (e.g., by verifying the segment or portion of the shaft furthest from the actuator properly functions). For systems that have more than one shaft to operate valves in multiple intake banks, manufacturers are not required to add more than one set of detection hardware (e.g., sensor, switch, etc.) per intake bank to meet this requirement. Vehicles utilizing these emission control systems designed and certified for 2004 or earlier model year vehicles and carried over to the 2005 through 2008 model year shall be not be required to meet the provisions of section (e)(17.3) until the engine or intake air delivery system is redesigned.

(18) Exceptions to Monitoring Requirements

(18.1) Except as provided in sections (e)(18.1.1) through (18.1.3) below, upon request of a manufacturer or upon the best engineering judgment of the ARB, the Executive Officer may revise the emission threshold for a malfunction on any check on a Low Emission Vehicle I application or Low Emission Vehicle II application if the most reliable monitoring method developed requires a higher threshold to prevent significant errors of commission in detecting a malfunction.

(18.1.1) For PC/LDT SULEV II vehicles, the Executive Officer shall approve a malfunction criteria of 2.5 times the applicable FTP standards in lieu of 1.5 wherever required in section (e).

(18.1.2) For 2004 model year PC/LDT SULEV II vehicles only, the Executive Officer shall approve monitors with thresholds that exceed 2.5 times the applicable FTP standard if the manufacturer demonstrates that a higher threshold is needed given the state of development of the vehicle and that the malfunction criteria and monitoring approach and technology (e.g., fuel system limits, percent misfire, monitored catalyst volume, etc.) are at least as stringent as comparable ULEV (not ULEV II) vehicles.

(18.1.3) For vehicles certified to Federal Bin 3 or Bin 4 emission standards, manufacturers shall utilize the ULEV II vehicle NMOG and CO malfunction criteria (e.g., 1.5 times the Bin 3 or Bin 4 NMOG and CO standards) and the PC/LDT SULEV II vehicle NOx malfunction criteria (e.g., 2.5 times the Bin 3 or Bin 4 NOx standards).

(18.2) Whenever the requirements in section (e) of this regulation require a manufacturer to meet a specific phase-in schedule (e.g., (e)(11) cold start emission reduction strategy monitoring requires 30 percent in 2006 model year, 60 percent in 2007 model year, and 100 percent in 2008 model year):

(18.2.1) The phase-in percentages shall be based on the manufacturer's projected sales volume for all vehicles subject to the requirements of title *13, CCR section 1968.2* unless specifically stated otherwise in section (e).

(18.2.2) Manufacturers may use an alternate phase-in schedule in lieu of the required phase-in schedule if the alternate phase-in schedule provides for equivalent compliance volume as defined in section (c) except as specifically noted for the phase in of in-use monitor performance ratio monitoring conditions in section (d)(3.2).

(18.2.3) Small volume manufacturers may use an alternate phase-in schedule in accordance with section (e)(18.2.2) in lieu of the required phase-in schedule or may meet the requirement on all vehicles by the final year of the phase-in in lieu of meeting the specific phase-in requirements for each model year (e.g., in the example in section (e)(18.2), small volume manufacturers are required to meet 100% in the 2008 model year for cold start emission reduction strategy monitoring, but not 30% in the 2006 model year or 60% in the 2007 model year).

(18.3) Manufacturers may request Executive Officer approval to disable an OBD II system monitor at ambient engine starting temperatures below twenty degrees Fahrenheit (20oF) (low ambient temperature conditions may be determined based on intake air or engine coolant temperature at engine starting) or at elevations above 8000 feet, above sea level. The Executive Officer shall approve the request upon determining that the manufacturer has provided data and/or an engineering evaluation that demonstrate that monitoring during the conditions would be unreliable. A manufacturer may further request, and the Executive Officer shall approve, that an OBD II system monitor be disabled at other ambient engine starting temperatures upon determining that the manufacturer has demonstrated with data and/or an engineering evaluation that misdiagnosis would occur at the ambient temperatures because of its effect on the component itself (e.g., component freezing).

(18.4) Manufacturers may request Executive Officer approval to disable monitoring systems that can be affected by low fuel level or running out of fuel (e.g., misfire detection) when the fuel level is 15 percent or less of the nominal capacity of the fuel tank. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that monitoring at the fuel levels would be unreliable.

(18.5) Manufacturers may disable monitoring systems that can be affected by vehicle battery or system voltage levels.

(18.5.1) For monitoring systems affected by low vehicle battery or system voltages, manufacturers may disable monitoring systems when the battery or system voltage is below 11.0 Volts. Manufacturers may request Executive Officer approval to utilize a voltage threshold higher than 11.0 Volts to disable system monitoring. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that monitoring at the voltages would be unreliable and that either operation of a vehicle below the disablement criteria for extended periods of time is unlikely or the OBD II system monitors the battery or system voltage and will detect a malfunction at the voltage used to disable other monitors.

(18.5.2) For monitoring systems affected by high vehicle battery or system voltages, manufacturers may request Executive Officer approval to disable monitoring systems when the battery or system voltage exceeds a manufacturer-defined voltage. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that monitoring above the manufacturer-defined voltage would be unreliable and that either the electrical charging system/alternator warning light is illuminated (or voltage gauge is in the "red zone") or that the OBD II system monitors the battery or system voltage and will detect a malfunction at the voltage used to disable other monitors.

(18.6) A manufacturer may disable affected monitoring systems in vehicles designed to accommodate the installation of Power Take-Off (PTO) units (as defined in section (c)), provided disablement occurs only while the PTO unit is active, and the OBD II readiness status is cleared by the on-board computer (i.e., all monitors set to indicate "not complete") while the PTO unit is activated (see section (f)(4.1) below). If the disablement occurs, the readiness status may be restored to its state prior to PTO activation when the disablement ends.

(18.7) A manufacturer may request Executive Officer approval to disable affected monitoring systems in vehicles equipped with tire pressure monitoring systems that cause a vehicle to enter a default mode of operation (e.g., reduced top speed) when a tire pressure problem is detected. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or an engineering evaluation that demonstrate that the default mode can affect monitoring system performance, that the tire pressure monitoring system will likely result in action by the consumer to correct the problem, and that the disablement will not prevent or hinder effective testing in an Inspection and Maintenance program.

(18.8) For 2004 model year vehicles certified to run on alternate fuels, manufacturers may request the Executive Officer to waive specific monitoring requirements in section (e) for which monitoring may not be reliable with respect to the use of alternate fuels. The Executive Officer shall grant the request upon determining that the manufacturer has demonstrated that the use of the alternate fuel could cause false illumination of the MIL even when using the best available monitoring technologies.

(18.9) For 2004 model year vehicles only, wherever the requirements of section (e) (except for diesel catalyst (section (e)(1.5)) and particulate matter trap (section (e)(15)) monitoring) reflect a substantive change from the requirements of title *13, CCR section 1968.1(b)* for 2003 model year vehicles, the manufacturer may request Executive Officer approval to continue to use the requirements of section 1968.1 in lieu of the requirements of section (e). The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or engineering evaluation that demonstrate that software or hardware changes would be required to comply with the requirements of section (e) and that the system complies with the requirements of section 1968.1(b).

(f) Standardization Requirements

(1) Reference Documents: The following Society of Automotive Engineers (SAE) and International Organization of Standards (ISO) documents are incorporated by reference into this regulation:

(1.1)SAE J1930 "Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms - Equivalent to ISO/TR 15031-2:April 30, 2002", April 2002 (SAE J1930).

(1.2)SAE J1962 "Diagnostic Connector - Equivalent to ISO/DIS 15031-3:December 14, 2001", April 2002 (SAE J1962).

(1.3)SAE J1978 "OBD II Scan Tool - Equivalent to ISO/DIS 15031-4:December 14, 2001", April 2002 (SAE J1978).

(1.4)SAE J1979 "E/E Diagnostic Test Modes - Equivalent to ISO/DIS 15031-5:April 30, 2002", April 2002 (SAE J1979).

(1.5)SAE J1850 "Class B Data Communications Network Interface", May 2001 (SAE 1850).

(1.6)SAE J2012 "Diagnostic Trouble Code Definitions - Equivalent to ISO/DIS 15031-6:April 30, 2002", April 2002 (SAE J2012).

(1.7)ISO 9141-2:1994 "Road Vehicles-Diagnostic Systems-CARB Requirements for Interchange of Digital Information", February 1994 (ISO 9141-2).

(1.8)ISO 14230-4:2000 "Road Vehicles-Diagnostic Systems-KWP 2000 Requirements for Emission-related Systems", June 2000 (ISO 14230-4).

(1.9)ISO 15765-4:2001 "Road Vehicles-Diagnostics on Controller Area Network (CAN) - Part 4: Requirements for emission-related systems", December 2001 (ISO 15765-4).

(1.10) SAE J1939 APR00-"Recommended Practice for a Serial Control and Communications Vehicle Network" and the associated subparts included in SAE HS-1939, "Truck and Bus Control and Communications Network Standards Manual", 2001 Edition (SAE J1939).

(2) Diagnostic Connector: A standard data link connector conforming to SAE J1962 specifications (except as specified in section (f)(2.3)) shall be incorporated in each vehicle.

(2.1) The connector shall be located in the driver's side foot-well region of the vehicle interior in the area bound by the driver's side of the vehicle and the driver's side edge of the center console (or the vehicle centerline if the vehicle does not have a center console) and at a location no higher than the bottom of the steering wheel when in the lowest adjustable position. The connector may not be located on or in the center console (i.e., neither on the horizontal faces near the floor-mounted gear selector, parking brake lever, or cup-holders nor on the vertical faces near the car stereo, climate system, or navigation system controls). The location of the connector shall be capable of being easily identified by a "crouched" technician entering the vehicle from the driver's side.

(2.2) If the connector is covered, the cover must be removable by hand without the use of any tools and be labeled to aid technicians in identifying the location of the connector. Access to the diagnostic connector may not require opening or the removal of any storage accessory (e.g., ashtray, coinbox, etc.). The label shall be submitted to the Executive Officer for review and approval, at or before the time the manufacturer submits its certification application. The Executive Officer shall approve the label upon determining that it clearly identifies that the connector is located behind the cover and is consistent with language and/or symbols commonly used in the automotive industry.

(2.3) Any pins in the connector that provide electrical power shall be properly fused to protect the integrity and usefulness of the connector for diagnostic purposes and may not exceed 20.0 Volts DC regardless of the nominal vehicle system or battery voltage (e.g., 12V, 24V, 42V, etc.).

(3) Communications to a Scan Tool: Manufacturers shall use one of the following standardized protocols for communication of all required emission related messages from on-board to off-board network communications to a scan tool meeting SAE J1978 specifications:

(3.1) SAE J1850. All required emission related messages using this protocol shall use the Cyclic Redundancy Check and the three byte header, may not use inter-byte separation or checksums,

and may not require a minimum delay of 100 ms between SAE J1978 scan tool requests. This protocol may not be used on any 2008 or subsequent model year vehicle.

(3.2) ISO 9141-2. This protocol may not be used on any 2008 or subsequent model year vehicle.

(3.3) ISO 14230-4. This protocol may not be used on any 2008 or subsequent model year vehicle.

(3.4) ISO 15765-4. This protocol shall be allowed on any 2003 and subsequent model year vehicle and required on all 2008 and subsequent model year vehicles. All required emission-related messages using this protocol shall use a 500 kbps baud rate.

(4) Required Emission Related Functions: The following standardized functions shall be implemented in accordance with the specifications in SAE J1979 to allow for access to the required information by a scan tool meeting SAE J1978 specifications:

(4.1) Readiness Status: In accordance with SAE J1979 specifications, the OBD II system shall indicate "complete" or "not complete" for each of the installed monitored components and systems identified in section (e)(1) through (e)(8) since the fault memory was last cleared. All components or systems that are monitored continuously shall always indicate "complete". Those components or systems that are not subject to continuous monitoring shall immediately indicate "complete" upon the respective diagnostic(s) being fully executed and determining that the component or system is not malfunctioning. A component or system shall also indicate "complete" if after the requisite number of decisions necessary for determining MIL status have been fully executed, the monitor indicates a malfunction for the component or system. The status for each of the monitored components or systems shall indicate "not complete" whenever fault memory has been cleared or erased by a means other than that allowed in section (d)(2). Normal vehicle shut down (i.e., key off, engine off) may not cause the status to indicate "not complete".

(4.1.1) Subject to Executive Officer approval, if monitoring is disabled for a multiple number of driving cycles due to the continued presence of extreme operating conditions (e.g., cold ambient temperatures, high altitudes, etc), readiness status for the subject monitoring system may be set to indicate "complete" without monitoring having been completed. Executive Officer approval shall be based on the conditions for monitoring system disablement and the number of driving cycles specified without completion of monitoring before readiness is indicated as "complete".

(4.1.2) For the evaporative system monitor:

(A) Except as provided below in section (f)(4.1.2)(B), the readiness status shall be set in accordance with section (f)(4.1) when both the functional check of the purge valve and the leak detection monitor of the orifice size specified in either section (e)(4.2.2)(B) or (C) (e.g., 0.040 inch or 0.020 inch) indicate that they are complete.

(B) For vehicles that utilize a 0.090 inch (in lieu of 0.040 inch) leak detection monitor in accordance with section (e)(4.2.5), the readiness status shall be set in accordance with section (f)(4.1) when both the functional check of the purge valve and the leak detection monitor of the orifice size specified in section (e)(4.2.2)(C) (e.g., 0.020 inch) indicate that they are complete.

(4.1.3) If the manufacturer elects to additionally indicate readiness status through the MIL in the key on, engine off position as provided for in section (d)(2.1.4), the readiness status shall be indicated in the following manner: If the readiness status for all monitored components or systems is "complete", the MIL shall remain continuously illuminated in the key on, engine off position for at least 15-20 seconds. If the readiness status for one or more of the monitored components or systems is "not complete", after 15-20 seconds of operation in the key on, engine off position with the MIL illuminated continuously, the MIL shall blink once per second for 5-10 seconds. The data stream value for MIL status (section (f)(4.2)) shall indicate

"commanded off" during this sequence unless the MIL has also been "commanded on" for a detected fault.

(4.2) Data Stream: The following signals shall be made available on demand through the standardized data link connector in accordance with SAE J1979 specifications. The actual signal value shall always be used instead of a default or limp home value.

(4.2.1) For all vehicles: calculated load value, number of stored confirmed fault codes, engine coolant temperature, engine speed, absolute throttle position (if equipped with a throttle), vehicle speed, and MIL status (i.e., commanded-on or commanded-off).

(4.2.2) For all vehicles so equipped: fuel control system status (e.g., open loop, closed loop, etc.), fuel trim, fuel pressure, ignition timing advance, intake air temperature, manifold absolute pressure, air flow rate from mass air flow sensor, secondary air status (upstream, downstream, or atmosphere), oxygen sensor output, air/fuel ratio sensor output.

(4.2.3) For all 2005 and subsequent model year vehicles using the ISO 15765-4 protocol for the standardized functions required in section (f), the following signals shall also be made available: absolute load, fuel level (if used to enable or disable any other diagnostics), relative throttle position (if equipped with a throttle), barometric pressure (directly measured or estimated), engine control module system voltage, commanded equivalence ratio, catalyst temperature (if directly measured or estimated for purposes of enabling the catalyst monitor(s)), monitor status (i.e., disabled for the rest of this driving cycle, complete this driving cycle, or not complete this driving cycle) since last engine shut-off for each monitor used for readiness status, time elapsed since engine start, distance traveled while MIL activated, distance traveled since fault memory last cleared, and number of warm-up cycles since fault memory last cleared.

(4.2.4) For all 2005 and subsequent model year vehicles so equipped and using the ISO 15765-4 protocol for the standardized functions required in section (f): ambient air temperature, evaporative system vapor pressure, commanded purge valve duty cycle/position, commanded EGR valve duty cycle/position, EGR error between actual and commanded, PTO status (active or not active), redundant absolute throttle position (for electronic throttle or other systems that utilize two or more sensors), absolute pedal position, redundant absolute pedal position, and commanded throttle motor position.

(4.3) Freeze Frame.

(4.3.1) "Freeze frame" information required to be stored pursuant to sections (d)(2.2.4), (e)(3.4.3), and (e)(6.4.4) shall be made available on demand through the standardized data link connector in accordance with SAE J1979 specifications.

(4.3.2) "Freeze frame" conditions must include the fault code which caused the data to be stored and all of the signals required in section (f)(4.2.1) except number of stored confirmed fault codes and MIL status. Freeze frame conditions shall also include all of the signals required on the vehicle in sections (f)(4.2.2) through (4.2.4) that are used for diagnostic or control purposes in the specific diagnostic or emission-critical powertrain control unit that stored the fault code except: oxygen sensor output, air/fuel ratio sensor output, catalyst temperature, evaporative system vapor pressure, monitor status since last engine shut off, distance traveled while MIL activated, distance traveled since fault memory last cleared, and number of warm-up cycles since fault memory last cleared.

(4.3.3) Only one frame of data is required to be recorded. Manufacturers may choose to store additional frames provided that at least the required frame can be read by a scan tool meeting SAE J1978 specifications.

(4.4) Fault Codes

(4.4.1) For all monitored components and systems, stored pending and confirmed fault codes shall be made available through the diagnostic connector in accordance with SAE J1979 specifications. Standardized fault codes conforming to SAE J2012 shall be employed.

(4.4.2) The stored fault code shall, to the fullest extent possible, pinpoint the likely cause of the malfunction. To the extent feasible on all 2005 and subsequent model year vehicles, manufacturers shall use separate fault codes for every diagnostic where the diagnostic and repair procedure or likely cause of the failure is different. In general, rationality and functional diagnostics shall use different fault codes than the respective circuit continuity diagnostics. Additionally, input component circuit continuity diagnostics shall use different fault codes for distinct malfunctions (e.g., out-of-range low, out-of-range high, open circuit, etc.).

(4.4.3) Manufacturers shall use appropriate SAE-defined fault codes of SAE J2012 (e.g., P0xxx, P2xxx) whenever possible. With Executive Officer approval, manufacturers may use manufacturer-defined fault codes in accordance with SAE J2012 specifications (e.g., P1xxx). Factors to be considered by the Executive Officer for approval shall include the lack of available SAE-defined fault codes, uniqueness of the diagnostic or monitored component, expected future usage of the diagnostic or component, and estimated usefulness in providing additional diagnostic and repair information to service technicians. Manufacturer-defined fault codes shall be used consistently (i.e., the same fault code may not be used to represent two different failure modes) across a manufacturer's entire product line.

(4.4.4) A fault code (pending and/or confirmed, as required in sections (d) and (e)) shall be stored and available to an SAE J1978 scan tool within 10 seconds after a diagnostic has determined that a malfunction has occurred.

(4.4.5) Pending fault codes:

(A) On all 2005 and subsequent model year vehicles, pending fault codes for all components and systems (including continuously and non-continuously monitored components) shall be made available through the diagnostic connector in accordance with SAE J1979 specifications (e.g., Mode/Service $ 07).

(B) On all 2005 and subsequent model year vehicles, a pending fault code(s) shall be stored and available through the diagnostic connector for all currently malfunctioning monitored component(s) or system(s), regardless of the MIL illumination status or confirmed fault code status (e.g., even after a pending fault has matured to a confirmed fault code and the MIL is illuminated, a pending fault code shall be stored and available if the most recent monitoring event indicates the component is malfunctioning).

(C) Manufacturers using alternate statistical protocols for MIL illumination as allowed in section (d)(2.2.3) shall submit to the Executive Officer a protocol for setting pending fault codes. The Executive Officer shall approve the proposed protocol upon determining that, overall, it is equivalent to the requirements in sections (f)(4.4.5)(A) and (B) and that it effectively provides service technicians with a quick and accurate indication of a pending failure.

(4.5) Test Results

(4.5.1) For all monitored components and systems identified in section (e)(1) through (e)(8) except misfire detection and fuel system monitoring, results of the most recent monitoring of the components and systems and the test limits established for monitoring the respective components and systems shall be stored and available through the data link in accordance with SAE J1979 specifications.

(4.5.2) The test results shall be reported such that properly functioning components and systems (e.g., "passing" systems) do not store test values outside of the established test limits.

(4.5.3) The test results shall be stored until updated by a more recent valid test result or the fault memory of the OBD II system computer is cleared. Upon fault memory being cleared, test results reported for monitors that have not yet completed since the last time the fault memory was cleared shall report values that do not indicate a failure (i.e., a test value which is outside of the test limits).

(4.5.4) Additionally, for vehicles using ISO 15765-4 (see section (f)(3.4)) as the communication protocol:

(A) The test results and limits shall be made available in the standardized format specified in SAE J1979 for the ISO 15765-4 protocol.

(B) Test limits shall include both minimum and maximum acceptable values and shall be reported for all monitored components and systems identified in sections (e)(1) through (e)(8), except fuel system monitoring. The test limits shall be defined so that a test result equal to either test limit is a "passing" value, not a "failing" value.

(C) For 2005 and subsequent model year vehicles, misfire monitoring test results shall be calculated and reported in the standardized format specified in SAE J1979.

(D) Monitors that have not yet completed since the last time the fault memory was cleared shall report values of zero for the test result and test limits.

(E) All test results and test limits shall always be reported and the test results shall be stored until updated by a more recent valid test result or the fault memory of the OBD II system computer is cleared.

(F) The OBD II system shall store and report unique test results for each separate diagnostic (e.g., an OBD II system with individual evaporative system diagnostics for 0.040 inch and 0.020 inch leaks shall separately report 0.040 inch and 0.020 inch test results).

(4.6) Software Calibration Identification: On all vehicles, a software calibration identification number (CAL ID) for the diagnostic or emission critical powertrain control unit(s) shall be made available through the standardized data link connector in accordance with the SAE J1979 specifications. A unique CAL ID shall be used for every emission-related calibration and/or software set having at least one bit of different data from any other emission-related calibration and/or software set. Control units coded with multiple emission or diagnostic calibrations and/or software sets shall indicate a unique CAL ID for each variant in a manner that enables an off-board device to determine which variant is being used by the vehicle. Control units that utilize a strategy that will result in MIL illumination if the incorrect variant is used (e.g., control units that contain variants for manual and automatic transmissions but will illuminate the MIL if the variant selected does not match the type of transmission on the vehicle) are not required to use unique CAL IDs.

(4.7) Software Calibration Verification Number

(4.7.1) All 20052 and subsequent model year vehicles shall use an algorithm to calculate a calibration verification number (CVN) that verifies the on-board computer software integrity in diagnostic or emission critical electronically reprogrammable powertrain control units. The CVN shall be made available through the standardized data link connector in accordance with the SAE J1979 specifications. The CVN shall be capable of being used to determine if the emission-related software and/or calibration data are valid and applicable for that vehicle and CAL ID.

(4.7.2) Manufacturers shall request Executive Officer approval of the algorithm used to calculate the CVN. Executive Officer approval of the algorithm shall be based on the complexity of the algorithm and the difficulty in achieving the same CVN with modified calibration values.

(4.7.3) The CVN shall be calculated at least once per driving cycle and stored until the CVN is subsequently updated. Except for immediately after a reprogramming event or a non-volatile

memory clear or for the first 30 seconds of engine operation after a volatile memory clear or battery disconnect, the stored value shall be made available through the data link connector to a generic scan tool in accordance with SAE J1979 specifications. The stored CVN value may not be erased when fault memory is erased by a generic scan tool in accordance with SAE J1979 specifications or during normal vehicle shut down (i.e., key off, engine off).

(4.7.4) For purposes of Inspection and Maintenance (I/M) testing, manufacturers shall make the CVN and CAL ID combination information available for all 2005 and subsequent model year vehicles in a standardized electronic format that allows for off-board verification that the CVN is valid and appropriate for a specific vehicle and CAL ID.

(4.8) Vehicle Identification Number: All 2005 and subsequent model year vehicles shall have the vehicle identification number (VIN) available in a standardized format through the standardized data link connector in accordance with SAE J1979 specifications. Only one electronic control unit per vehicle shall report the VIN to an SAE J1978 scan tool.

(5) In-use Performance Ratio Tracking Requirements:

(5.1) For each monitor required in section (e) to separately report an in-use performance ratio, manufacturers shall implement software algorithms to report a numerator and denominator in the standardized format specified below and in accordance with the SAE J1979 specifications.

(5.2) Numerical Value Specifications:

(5.2.1) For the numerator, denominator, general denominator, and ignition cycle counter:

(A) Each number shall have a minimum value of zero and a maximum value of 65,535 with a resolution of one.

(B) Each number shall be reset to zero only when a non-volatile memory reset occurs (e.g., reprogramming event, etc.) or, if the numbers are stored in keep-alive memory (KAM), when KAM is lost due to an interruption in electrical power to the control module (e.g., battery disconnect, etc.). Numbers may not be reset to zero under any other circumstances including when a scan tool command to clear fault codes or reset KAM is received.

(C) If either the numerator or denominator for a specific component reaches the maximum value of 65,535 +2, both numbers shall be divided by two before either is incremented again to avoid overflow problems.

(D) If the ignition cycle counter reaches the maximum value of 65,535 +2, the ignition cycle counter shall rollover and increment to zero on the next ignition cycle to avoid overflow problems.

(E) If the general denominator reaches the maximum value of 65,535 +2, the general denominator shall rollover and increment to zero on the next driving cycle that meets the general denominator definition to avoid overflow problems.

(F) If a vehicle is not equipped with a component (e.g., oxygen sensor bank 2, secondary air system), the corresponding numerator and denominator for that specific component shall always be reported as zero.

(5.2.2) For the ratio:

(A) The ratio shall have a minimum value of zero and a maximum value of 7.99527 with a resolution of 0.000122.

(B) A ratio for a specific component shall be considered to be zero whenever the corresponding numerator is equal to zero and the corresponding denominator is not zero.

(C) A ratio for a specific component shall be considered to be the maximum value of 7.99527 if the corresponding denominator is zero or if the actual value of the numerator divided by the denominator exceeds the maximum value of 7.99527.

(6) Service Information:

(6.1) Motor vehicle manufacturers shall provide the aftermarket service and repair industry emission-related service information for all 1994 and subsequent model year vehicles equipped with OBD II systems as set forth in sections (f)(6.3) through (6.5). The requirements of section (f)(6) shall supersede the service information requirements set forth in title *13, CCR section 1968.1*.

(6.2) The Executive Officer shall waive the requirements of sections (f)(6.3) through (6.5) upon determining that the ARB or U.S. EPA has adopted a service information regulation or rule that is in effect and operative and requires motor vehicle manufacturers to provide emission-related service information:

(A) of comparable or greater scope than required under these provisions;

(B) in an easily accessible format and in a timeframe that is equivalent to or exceeds the timeframes set forth below; and

(C) at fair and reasonable cost.

(6.3) For all 1994 and subsequent model year vehicles equipped with an OBD II system, manufacturers shall make readily available, at a fair and reasonable price to the automotive repair industry, vehicle repair procedures which allow effective emission-related diagnosis and repairs to be performed using only the SAE J1978 generic scan tool and commonly available, non-microprocessor based tools.

(6.4) As an alternative to publishing repair procedures required under section (f)(6.3), a manufacturer may publish repair procedures referencing the use of manufacturer-specific or enhanced equipment provided the manufacturer makes available to the aftermarket scan tool industry the information needed to manufacture scan tools to perform the same emission-related diagnosis and repair procedures (excluding any reprogramming) in a comparable manner as the manufacturer-specific diagnostic scan tool.

(6.5) For all 1996 and subsequent model year vehicles, manufacturers shall make available:

(A) Information to utilize the test results reported as required in section (f)(4.5) (or title *13, CCR section 1968.1 (l)(3.0)* for 1996 through 2002 model year vehicles). The information must include a description of the test and test result, associated fault codes with the test result, and scaling, units, and conversion factors necessary to convert the results to engineering units.

(B) A generic description of each of the diagnostics used to meet the requirements of this regulation. The generic description must include a text description of how the diagnostic is performed, typical enable conditions, typical malfunction thresholds, typical monitoring time, fault codes associated with the diagnostic, and test results (section (f)(4.5)) associated with the diagnostic. Vehicles that have diagnostics not adequately represented by the typical values identified above shall be specifically identified along with the appropriate typical values.

(C) Information necessary to execute each of the diagnostics used to meet the requirements of sections (e)(1) through (e)(8). The information must include either a description of sample driving patterns designed to be operated in-use or a written description of the conditions the vehicle needs to operate in to execute each of the diagnostics necessary to change the readiness status from "not complete" to "complete" for all monitors. The information shall be able to be used to exercise all necessary monitors in a single driving cycle as well as be able to be used to exercise the monitors to individually change the readiness status for each specific monitor from "not complete" to "complete".

(7) Exceptions to Standardization Requirements.

(7.1) For medium-duty vehicles equipped with engines certified on an engine dynamometer, a manufacturer may request Executive Officer approval to use both: (1) an alternate diagnostic connector, and emission-related message structure and format in lieu of the standardization requirements in sections (f)(2) and (4) that refer to SAE J1962, SAE J1978, and SAE J1979, and (2) an alternate communication protocol in lieu of the identified protocols in section (f)(3). The Executive Officer shall approve the request if:

(A) The ARB has adopted an on-board diagnostic regulation for heavy-duty vehicles and the alternate diagnostic connector, communication protocol, and emission-related message format and structure requested by the manufacturer meets the standardization requirements in the on-board diagnostic regulation for heavy-duty vehicles; or

(B) For 2004 and 2005 model year vehicles only, the alternate diagnostic connector, communication protocol, and emission-related message format and structure requested by the manufacturer meet the standardization requirements of SAE J1939 and the manufacturer has implemented features (e.g., readiness code indication via the MIL pursuant to section (f)(4.1.3)) that will allow the vehicle to be tested in a California Inspection and Maintenance test facility. If the ARB has not adopted a heavy-duty vehicle on-board diagnostic regulation by July 1, 2004, the Executive Officer shall extend the provisions of this section through the 2006 model year. The Executive Officer shall extend the provisions of this section one additional model year on each subsequent July 1 if the ARB has not adopted a heavy-duty vehicle on-board diagnostic regulation by that date.

(7.2) For 2004 model year vehicles only, wherever the requirements of sections (f)(2) and (f)(4) reflect a substantive change from the requirements of title *13, CCR sections 1968.1(e)*, (f), (k), or (l) for the 2003 model year vehicles, the manufacturer may request Executive Officer approval to continue to use the requirements of section 1968.1 in lieu of the requirements of sections (f)(2) and (f)(4). The Executive Officer shall approve the request upon determining that the manufacturer has submitted data and/or engineering evaluation that demonstrate that software or hardware changes would be required to comply with the requirements of sections (f)(2) and (f)(4) and that the system complies with the requirements of sections 1968.1(e), (f), (k), and (l).

(g) Monitoring System Demonstration Requirements for Certification

(1) General.

(1.1) Certification requires that manufacturers submit emission test data from one or more durability demonstration test vehicles (test vehicles). For applications certified on engine dynamometers, engines may be used instead of vehicles.

(1.2) The Executive Officer may approve other demonstration protocols if the manufacturer can provide comparable assurance that the malfunction criteria are chosen based on meeting emission requirements and that the timeliness of malfunction detection is within the constraints of the applicable monitoring requirements.

(1.3) For flexible fuel vehicles capable of operating on more than one fuel or fuel combinations, the manufacturer shall submit a plan for providing emission test data to the Executive Officer for approval. The Executive Officer shall approve the plan if it is determined to be representative of expected in-use fuel or fuel combinations and provides accurate and timely evaluation of the monitored systems.

(2) Selection of Test Vehicles:

(2.1.1) Prior to submitting any applications for certification for a model year, a manufacturer shall notify the Executive Officer of the test groups planned for that model year. The Executive Officer will then select the test group(s) that the manufacturer shall use as demonstration test vehicles to provide emission test data. The selection of test vehicles for production vehicle evaluation, as specified in section (j), may take place during this selection process.

(2.1.2) A manufacturer certifying one to five test groups in a model year shall provide emission test data from a test vehicle from one test group. A manufacturer certifying six to ten test groups in a model year shall provide emission test data from test vehicles from two test groups. A manufacturer certifying eleven or more test groups in a model year shall provide emission test data from test vehicles from three test groups. The Executive Officer may waive the requirement for submittal of data from one or more of the test groups if data have been previously submitted for all of the test groups.

(2.1.3) For the test vehicle(s), a manufacturer shall use a certification emission durability test vehicle(s), a representative high mileage vehicle(s), or a vehicle(s) aged to the end of the full useful life using an ARB-approved alternative durability procedure (ADP).

(3) Required Testing: Except as provided below, the manufacturer shall perform single-fault testing based on the applicable FTP test with the following components/systems set at their malfunction criteria limits as determined by the manufacturer for meeting the requirements of section (e):

(3.1) Oxygen Sensors:

(3.1.1) The manufacturer shall perform a test with all primary oxygen sensors used for fuel control simultaneously possessing a response rate deteriorated to the malfunction criteria limit. Manufacturers shall also perform a test for any other oxygen sensor parameter that can cause vehicle emissions to exceed 1.5 times the applicable standards (e.g., shift in air/fuel ratio at which oxygen sensor switches, decreased amplitude, etc.). When performing additional test(s), all primary and secondary (if applicable) oxygen sensors used for fuel control shall be operating at the malfunction criteria limit for the applicable parameter only. All other primary and secondary oxygen sensor parameters shall be with normal characteristics.

(3.1.2) For vehicles utilizing sensors other than oxygen sensors for primary fuel control (e.g., linear air-fuel ratio sensors, universal sensors, etc.), the manufacturer shall submit, for Executive Officer approval, a demonstration test plan for performing testing of all of the sensor parameters that can cause vehicle emissions to exceed 1.5 times the applicable standards. The Executive Officer shall approve the plan if it is determined that it will provide data that will assure proper performance of the diagnostics of the sensors, consistent with the intent of section (g).

(3.2)EGR System: The manufacturer shall perform a test at the low flow limit.

(3.3)VVT System: For 2006 and subsequent model year Low Emission II applications, the manufacturer shall perform a test at each target error limit and slow response limit calibrated to the malfunction criteria (e.g., 1.5 times the FTP standard) in sections (e)(13.2.1) and (13.2.2). In conducting the VVT system demonstration tests, the manufacturer may use computer modifications to cause the VVT system to operate at the malfunction limit if the manufacturer can demonstrate that the computer modifications produce test results equivalent to an induced hardware malfunction.

(3.4) Fuel System:

(3.4.1) For vehicles with adaptive feedback based on the primary fuel control sensor(s), the manufacturer shall perform a test with the adaptive feedback based on the primary fuel control sensor(s) at the rich limit(s) and a test at the lean limit(s) established by the manufacturer in section (e)(6.2.1) to detect a malfunction before emissions exceed 1.5 times the applicable standards.

(3.4.2) For vehicles with feedback based on a secondary fuel control sensor(s) and subject to the malfunction criteria in section (e)(6.2.1), the manufacturer shall perform a test with the feedback based on the secondary fuel control sensor(s) at the rich limit(s) and a test at the lean limit(s) established by the manufacturer in section (e)(6.2.1) to detect a malfunction before emissions exceed 1.5 times the applicable standards.

(3.4.3) For other fuel metering or control systems, the manufacturer shall perform a test at the criteria limit(s).

(3.4.4) For purposes of fuel system testing, the fault(s) induced may result in a uniform distribution of fuel and air among the cylinders. Non-uniform distribution of fuel and air used to induce a fault may not cause misfire. In conducting the fuel system demonstration tests, the manufacturer may use computer modifications to cause the fuel system to operate at the malfunction limit if the manufacturer can demonstrate that the computer modifications produce test results equivalent to an induced hardware malfunction.

(3.5) Misfire: The manufacturer shall perform a test at the malfunction criteria limit specified in section (e)(3.2.2). The testing is not required for diesel applications.

(3.6) Secondary Air System: The manufacturer shall perform a test at the low flow limit. Manufacturers performing only a functional check in accordance with the provisions of section (e)(5.2.2)(B) or (e)(5.2.4) shall perform a test at the functional check flow malfunction criteria.

(3.7) Catalyst System: The manufacturer shall perform a test using a catalyst system deteriorated to the malfunction criteria using methods established by the manufacturer in accordance with section (e)(1.2.6). For diesel vehicles, the manufacturer shall perform a test using a catalyst system deteriorated to the malfunction criteria in sections (e)(1.5.2)(A)(i), (B)(i), or (C)(i). For diesel vehicles with catalyst systems not subject to the malfunction criteria in section (e)(1.5.2)(A)(i), (B)(i), or (C)(i), manufacturers are; not required to perform a catalyst demonstration test.

(3.8) Heated Catalyst Systems: The manufacturer shall perform a test at the malfunction criteria limit established by the manufacturer in section (e)(2.2).

(3.9)PM Trap: The manufacturer shall perform a test using a PM trap(s) deteriorated to the malfunction criteria in sections (e)(15.2.1) or (15.2.3). For diesel vehicles with a PM trap(s) not subject to the malfunction criteria in section (e)(15.2.1) or (15.2.3), manufacturers are not required to perform a PM trap(s) demonstration test.

(3.10) Other systems: The manufacturer shall conduct demonstration tests for all other emission control components designed and calibrated to a malfunction criteria of 1.5 times any of the applicable emission standards (e.g., hydrocarbon traps, adsorbers, etc.) under the provisions of section (e)(17).

(3.11) The manufacturer may electronically simulate deteriorated components but may not make any vehicle control unit modifications (unless otherwise excepted above) when performing demonstration tests. All equipment necessary to duplicate the demonstration test must be made available to the ARB upon request.

(4) Testing Protocol:

(4.1) Preconditioning: The manufacturer shall use an applicable FTP cycle (or Unified Cycle, if approved) for preconditioning test vehicles prior to conducting each of the above emission tests. Upon determining that a manufacturer has provided data and/or an engineering evaluation that demonstrate that additional preconditioning is necessary to stabilize the emission control system, the Executive Officer shall allow the manufacturer to perform a single additional preconditioning cycle, identical to the initial preconditioning cycle, or a Federal Highway Fuel Economy Driving Cycle, following a ten minute (20 minutes for medium duty engines certified on an engine dynamometer) hot soak after the initial preconditioning cycle. The manufacturer may not require the test vehicle to be cold soaked prior to conducting preconditioning cycles in order for the monitoring system testing to be successful.

(4.2) Test Sequence:

(4.2.1) The manufacturer shall set the system or component on the test vehicle for which detection is to be tested at the criteria limit(s) prior to conducting the applicable preconditioning

cycle(s). If a second preconditioning cycle is permitted in accordance with section (g)(4.1) above, the manufacturer may adjust the system or component to be tested before conducting the second preconditioning cycle. The manufacturer may not replace, modify, or adjust the system or component after the last preconditioning cycle has taken place.

(4.2.2) After preconditioning, the test vehicle shall be operated over the applicable FTP cycle (or Unified Cycle, if approved) to allow for the initial detection of the tested system or component malfunction. This driving cycle may be omitted from the testing protocol if it is unnecessary. If required by the designated monitoring strategy, a cold soak may be performed prior to conducting this driving cycle.

(4.2.3) The test vehicle shall then be operated over the cold start and hot start exhaust tests of the applicable FTP test. If monitoring during the Unified Cycle is approved, a second Unified Cycle may be conducted prior to the FTP test.

(4.3)A manufacturer required to test more than one test vehicle (section (g)(2.1.2)) may utilize internal calibration sign-off test procedures (e.g., forced cool downs, less frequently calibrated emission analyzers, etc.) instead of official FTP test procedures to obtain the emission test data required in section (g) for all but one of the required test vehicles. The manufacturer may elect this option if the data from the alternative test procedure are representative of official FTP emission test results. Manufacturers using this option are still responsible for meeting the malfunction criteria specified in section (e) when emission tests are performed in accordance with official FTP test procedures.

(5) Evaluation Protocol:

(5.1.1) For all tests conducted under section (g), the MIL shall be illuminated upon detection of the tested system or component malfunction before the hot start exhaust test of the complete FTP test (or before the hot start portion of the last Unified Cycle, if applicable) in accordance with requirements of section (e).

(5.1.2) For all tests conducted under section (g), manufacturers may use Non-Methane Hydrocarbon (NMHC) emission results in lieu of Non-Methane Organic Gas (NMOG) emission results for comparison to the applicable FTP standards or malfunction criteria (e.g., 1.5 times the FTP standards). If NMHC emission results are used in lieu of NMOG, the emission result shall be multiplied by 1.04 to generate an equivalent NMOG result before comparison to the applicable FTP standards.

(5.1.3) If the MIL illuminates prior to emissions exceeding the applicable malfunction criteria specified in section (e), no further demonstration is required. With respect to the misfire monitor demonstration test, if a manufacturer has elected to use the minimum misfire malfunction criteria of one percent as allowed in section (e)(3.2.2)(A), no further demonstration is required if the MIL illuminates with misfire implanted at the malfunction criteria limit.

(5.1.4) If the MIL does not illuminate when the systems or components are set at their limit(s), the criteria limit or the OBD II system is not acceptable.

(A) Except for testing of the catalyst system, if the MIL first illuminates after emissions exceed the applicable malfunction criteria specified in section (e), the test vehicle shall be retested with the tested system or component adjusted so that the MIL will illuminate before emissions exceed the applicable malfunction criteria specified in section (e). If the component cannot be adjusted to meet this criterion because a default fuel or emission control strategy is used when a malfunction is detected (e.g., open loop fuel control used after an O2 sensor malfunction is determined, etc.), the test vehicle shall be retested with the component adjusted to the worst acceptable limit (i.e., the applicable monitor indicates the component is performing at or slightly better than the malfunction criteria). For the OBD II system to be approved, the MIL must not illuminate during this test and the vehicle emissions must be below the applicable malfunction criteria specified in section (e).

(B) In testing the catalyst system, if the MIL first illuminates after emissions exceed the applicable emission threshold(s) specified in section (e), the tested vehicle shall be retested with a less deteriorated catalyst system (i.e., more of the applicable engine out pollutants are converted). For the OBD II system to be approved, testing shall be continued until either of the following conditions are satisfied:

(i) The MIL is illuminated and emissions do not exceed the thresholds specified in section (e); or

(ii) The manufacturer demonstrates that the MIL illuminates within acceptable upper and lower limits of the threshold specified in section (e) for MIL illumination. The manufacturer shall demonstrate acceptable limits by continuing testing until the test results show:

a. The MIL is illuminated and emissions exceed the thresholds specified in section (e) by 10 percent or less of the applicable standard (e.g., emissions are less than 1.85 times the applicable standard for a malfunction criterion of 1.75 times the standard); and

b. The MIL is not illuminated and emissions are below the thresholds specified in section (e) by no more than 20 percent of the standard (e.g., emissions are between 1.55 and 1.75 times the applicable standard for a malfunction criterion of 1.75 times the standard).

(5.1.5) If an OBD II system is determined unacceptable by the above criteria, the manufacturer may recalibrate and retest the system on the same test vehicle. In such a case, the manufacturer must confirm, by retesting, that all systems and components that were tested prior to recalibration and are affected by the recalibration function properly under the OBD II system as recalibrated.

(6) Confirmatory Testing:

(6.1) The ARB may perform confirmatory testing to verify the emission test data submitted by the manufacturer under the requirements of section (g) comply with the requirements of section (g) and the malfunction criteria identified in section (e). This confirmatory testing is limited to the vehicle configuration represented by the demonstration vehicle(s). For purposes of section (g)(6), vehicle configuration shall have the same meaning as the term used in *40 CFR 86.082-2*.

(6.2) The ARB or its designee may install appropriately deteriorated or malfunctioning components in an otherwise properly functioning test vehicle of a test group represented by the demonstration test vehicle(s) (or simulate a deteriorated or malfunctioning component) in order to test any of the components; or systems required to be tested in section (g). Upon request by the Executive Officer, the manufacturer shall make available a vehicle and all test equipment (e.g., malfunction simulators, deteriorated components, etc.) necessary to duplicate the manufacturer's testing. The Executive Officer shall make the request within six months of reviewing and approving the demonstration test vehicle data submitted by the manufacturer for the specific test group.

(6.3) Vehicles with OBD II systems represented by the demonstration vehicle(s) may be recalled for corrective action if a representative sample of vehicles uniformly fails to meet the requirements of section (g).

(h) Certification Documentation

(1) When submitting an application for certification of a test group, the manufacturer shall submit the following documentation. If any of the items listed below are standardized for all of a manufacturer's test groups, the manufacturer may, for each model year, submit one set of documents covering the standardized items for all of its test groups.

(1.1) For the required documentation not standardized across all test groups, the manufacturer may propose to the Executive Officer that documentation covering a specified combination of test groups be used. These combinations shall be known as "OBD II groups". Executive Officer approval shall be

granted for those groupings that include test groups using the same OBD II strategies and similar calibrations. If approved by the Executive Officer, the manufacturer may submit one set of documentation from one or more representative test group(s) that are a part of the OBD II group. The Executive Officer shall determine whether a selected test group(s) is representative of the OBD II group as a whole. To be approved as representative, the test group(s) must possess the most stringent emission standards and OBD II monitoring requirements and cover all of the emission control devices within the OBD II group.

(1.2) With Executive Officer approval, one or more of the documentation requirements of section (h) may be waived or modified if the information required would be redundant or unnecessarily burdensome to generate.

(1.3) To the extent possible, the certification documentation shall use SAE J1930 terms, abbreviations, and acronyms.

(2) The following information shall be submitted as "Part 1" of the certification application. Except as provided below for demonstration data, the Executive Officer will not issue an Executive Order certifying the covered vehicles without the information having been provided. The information must include:

(2.1)A description of the functional operation of the OBD II system including a complete written description for each monitoring strategy that outlines every step in the decision making process of the monitor. Algorithms, diagrams, samples of data, and/or other graphical representations of the monitoring strategy shall be included where necessary to adequately describe the information.

(2.2)A table, in the standardized format detailed in Attachment A of ARB Mail-Out #95-20, May 22, 1995, incorporated by reference.

(2.2.1) The table must include the following information for each monitored component or system (either computer-sensed or -controlled) of the emission control system:

(A) corresponding fault code

(B) monitoring method or procedure for malfunction detection

(C) primary malfunction detection parameter and its type of output signal

(D) fault criteria limits used to evaluate output signal of primary parameter

(E) other monitored secondary parameters and conditions (in engineering units) necessary for malfunction detection

(F) monitoring time length and frequency of checks

(G) criteria for storing fault code

(H) criteria for illuminating malfunction indicator light

(I) criteria used for determining out of range values and input component rationality checks

(2.2.2) Wherever possible, the table shall use the following engineering units:

(A) Degrees Celsius (oC) for all temperature criteria

(B) KiloPascals (KPa) for all pressure criteria related to manifold or atmospheric pressure

(C) Grams (g) for all intake air mass criteria

(D) Pascals (Pa) for all pressure criteria related to evaporative system vapor pressure

(E) Miles per hour (mph) for all vehicle speed criteria

(F) Relative percent (%) for all relative throttle position criteria (as defined in SAE J1979)

(G) Voltage (V) for all absolute throttle position criteria (as defined in SAE J1979)

(H) Per crankshaft revolution (/rev) for all changes per ignition event based criteria (e.g., g/rev instead of g/stroke or g/firing)

(I) Per second (/sec) for all changes per time based criteria (e.g., g/sec)

(J) Percent of nominal tank volume (%) for all fuel tank level criteria

(2.3)A logic flowchart describing the step by step evaluation of the enable criteria and malfunction criteria for each monitored emission-related component or system.

(2.4) Emission test data, a description of the testing sequence (e.g., the number and types of preconditioning cycles), approximate time (in seconds) of MIL illumination during the test, fault code(s) and freeze frame information stored at the time of detection, corresponding SAE J1979 test results (e.g. Mode/Service $ 06) stored during the test, and a description of the modified or deteriorated components used for fault simulation with respect to the demonstration tests specified in section (g). The Executive Officer may approve conditional certification of a test group prior to the submittal of this data for ARB review and approval. Factors to be considered by the Executive Officer in approving the late submission of information identified in section (h)(2.4) shall include the reason for the delay in the data collection, the length of time until data will be available, and the demonstrated previous success of the manufacturer in submitting the data prior to certification.

(2.5) Data supporting the misfire monitor, including:

(2.5.1) The established percentage of misfire that can be tolerated without damaging the catalyst over the full range of engine speed and load conditions.

(2.5.2) Data demonstrating the probability of detection of misfire events of the misfire monitoring system over the full engine speed and load operating range for the following misfire patterns: random cylinders misfiring at the malfunction criteria established in section (e)(3.2.2), one cylinder continuously misfiring, and paired cylinders continuously misfiring.

(2.5.3) Data identifying all disablement of misfire monitoring that occurs during the FTP and US06 cycles. For every disablement that occurs during the cycles, the data should identify: when the disablement occurred relative to the driver's trace, the number of engine revolutions that each disablement was present for, and which disable condition documented in the certification application caused the disablement.

(2.5.4) Manufacturers are not required to use the durability demonstration vehicle to collect the misfire data for sections (h)(2.5.1) though (2.5.3).

(2.6) Data supporting the limit for the time between engine starting and attaining the designated heating temperature for after-start heated catalyst systems.

(2.7)A listing of all electronic powertrain input and output signals (including those not monitored by the OBD II system) that identifies which signals are monitored by the OBD II system.

(2.8)A written description of all parameters and conditions necessary to begin closed loop operation.

(2.9)A summary table identifying every test group and each of the OBD II phase-in requirements that apply to each test group.

(2.10) A written identification of the communication protocol utilized by each test group for communication with an SAE J1978 scan tool.

(2.11) A pictorial representation or written description of the diagnostic connector location including any covers or labels.

(2.12) A written description of the method used by the manufacturer to meet the requirements of section (e)(9) for PCV system monitoring including diagrams or pictures of valve and/or hose connections.

(2.13) Any other information determined by the Executive Officer to be necessary to demonstrate compliance with the requirements of this regulation.

(3) "Part 2". The following information shall be submitted by January 1st of the applicable model year:

(3.1)A listing and block diagram of the input parameters used to calculate or determine calculated load values and the input parameters used to calculate or determine fuel trim values.

(3.2)A scale drawing of the MIL and the fuel cap indicator light, if present, which specifies location in the instrument panel, wording, color, and intensity.

(4) "Part 3". The following information shall be submitted upon request of the Executive Officer:

(4.1) Data supporting the criteria used to detect a malfunction when catalyst deterioration causes emissions to exceed the applicable malfunction criteria specified in section (e).

(4.2) Data supporting the criteria used to detect evaporative system leaks.

(4.3) Any other information determined by the Executive Officer to be necessary to demonstrate compliance with the requirements of this regulation.

(i) Deficiencies

(1) For 2004 and subsequent model year vehicles, the Executive Officer, upon receipt of an application from the manufacturer, may certify vehicles even though said vehicles may not comply with one or more of the requirements of title *13, CCR section 1968.2*. In granting the certification, the Executive Officer shall consider the following factors: the extent to which the requirements of section 1968.2 are satisfied overall based on a review of the vehicle applications in question, the relative performance of the resultant OBD II system compared to systems fully compliant with the requirements of title *13, CCR section 1968.2*, and a demonstrated good-faith effort on the part of the manufacturer to: (1) meet the requirements in full by evaluating and considering the best available monitoring technology; and (2) come into compliance as expeditiously as possible. The Executive Officer may not grant certification to a vehicle in which the reported noncompliance for which a deficiency is sought would be subject to ordered recall pursuant to section 1968.5 (c)(3)(A).

(2) Manufacturers of non-complying systems are subject to fines pursuant to *section 43016 of the California Health and Safety Code*. The specified fines apply to the third and subsequently identified deficiencies, with the exception that fines shall apply to all monitoring system deficiencies wherein a required monitoring strategy is completely absent from the OBD system.

(3) The fines are in the amount of $ 50 per deficiency per vehicle for non-compliance with any of the monitoring requirements specified in sections (e)(1) through (e)(8), (e)(11), (e)(13) through (e)(15), and (e)(17), and $ 25 per deficiency per vehicle for non-compliance with any other requirement of section 1968.2. In determining the identified order of deficiencies, deficiencies subject to a $ 50 fine are identified first. Total fines per vehicle under section (i) may not exceed $ 500 per vehicle and are payable to the State Treasurer for deposit in the Air Pollution Control Fund.

(4) Manufacturers must re-apply for Executive Officer approval of a deficiency each model year. In considering the request to carry-over a deficiency, the Executive Officer shall consider the factors identified in section (i)(1) including the manufacturer's progress towards correcting the deficiency. The Executive Officer may not allow manufacturers to carry over monitoring system deficiencies for more than two model years unless it can be demonstrated that substantial vehicle hardware modifications and additional lead time beyond two years would be necessary to correct the deficiency, in which case the Executive Officer shall allow the deficiency to be carried over for three model years.

(5) Except as allowed in section (i)(6), deficiencies may not be retroactively granted after certification.

(6) Request for retroactive deficiencies

(6.1) Manufacturers may request that the Executive Officer grant a deficiency and amend a vehicle's certification to conform to the granting of the deficiencies during the first 6 months after commencement

of normal production for each aspect of the monitoring system: (a) identified by the manufacturer (during testing required by section (j)(2) or any other testing) to be functioning different than the certified system or otherwise not meeting the requirements of any aspect of section 1968.2; and (b) reported to the Executive Officer. If the Executive Officer grants the deficiencies and amended certification, their approval would be retroactive to the start of production.

(6.2) Executive Officer approval of the request for a retroactive deficiency shall be granted provided that the conditions necessary for a pre-certification deficiency determination are satisfied (see section (i)(1)) and the manufacturer could not have reasonably anticipated the identified problem before commencement of production.

(6.3) In granting the amended certification, the Executive Officer shall include any approved post-production deficiencies together with all previously approved deficiencies in computing fines in accordance with section (i)(2).

(7) Any OBD II system installed on a production vehicle that fails to conform with the certified OBD II system for that vehicle or otherwise fails to meet the requirements of section 1968.2 and has not been granted a deficiency pursuant to the provisions of section (i)(1) through (i)(6) are considered non-compliant. The vehicles are subject to enforcement pursuant to applicable provisions of the Health and Safety Code and title *13, CCR section 1968.5*.

(j) Production Vehicle Evaluation Testing

(1) Verification of Standardized Requirements.

(1.1) Requirement: For 2005 and subsequent model year vehicles, manufacturers shall perform testing to verify that all vehicles meet the requirements of section (f)(3) and (f)(4) relevant to proper communication of required emission-related messages to an SAE J1978 scan tool.

(1.2) Selection of Test Vehicles: Manufacturers shall perform this testing every model year on one production vehicle from every unique calibration within one month of the start of normal production for that calibration. Manufacturers may request Executive Officer approval to group multiple calibrations together and test one representative calibration per group. The Executive Officer shall approve the request upon finding that the software designed to comply with the standardization requirements of section (f) in the representative calibration vehicle is identical (e.g., communication protocol message timing, number of supported data stream parameters, etc.) to all others in the group and that any differences in the calibrations are not relevant with respect to meeting the criteria in section (j)(1.4).

(1.3) Test Equipment: For the testing required in section (j)(1), manufacturers shall utilize an off-board device to conduct the testing. Prior to conducting testing, manufacturers are required to request and receive Executive Officer approval of the off-board device that the manufacturer will use to perform the testing. The Executive Officer shall approve the request upon determining that the manufacturer has submitted data, specifications, and/or engineering analysis that demonstrate that the off-board device will verify vehicles will be able to perform all of the required functions in section (j)(1.4) with any other off-board device designed and built in accordance with the SAE J1978 generic scan tool specifications.

(1.4) Required Testing:

(1.4.1) The testing shall verify that the vehicle can properly establish communications between all emission-related on-board computers and any SAE J1978 scan tool designed to adhere strictly to the communication protocols allowed in section (f)(3);

(1.4.2) The testing shall further verify that the vehicle can properly communicate to any SAE J1978 scan tool:

(A) The current readiness status from all on-board computers required to support readiness status in accordance with SAE J1979 and section (f)(4.1) while the engine is running;

(B) The MIL command status while the MIL is commanded off and while the MIL is commanded on in accordance with SAE J1979 and section (f)(4.2) while the engine is running,

and in accordance with SAE J1979 and sections (d)(2.1.2) during the MIL functional check and, if applicable, (f)(4.1.3) during the MIL readiness status check while the engine is off;

(C) All data stream parameters required in section (f)(4.2) in accordance with SAE J1979 including the identification of each data stream parameter as supported in SAE J1979 (e.g., Mode/Service $ 01, PID $ 00);

(D) The CAL ID, CVN, and VIN (if applicable) in accordance with SAE J1979 and sections (f)(4.6) through (4.8);

(E) An emission-related fault code (both confirmed and pending) in accordance with SAE J1979 (including correctly indicating the number of stored fault codes (e.g., Mode/Service $ 01, PID $ 01, Data A)) and section (f)(4.4);

(1.4.3) The testing shall also verify that the vehicle can properly respond to any SAE J1978 scan tool request to clear emission-related fault codes and reset readiness status.

(1.5) Reporting of Results:

(1.5.1) The manufacturer shall notify the Executive Officer within one month of identifying any vehicle that does not meet the requirements of section (j)(1.4). The manufacturer shall submit a written report of the problem(s) identified and propose corrective action (if any) to remedy the problem(s) to the Executive Officer for approval. Factors to be considered by the Executive Officer in approving the proposed corrective action shall include the severity of the problem(s), the ability of the vehicle to be tested in an I/M program, the ability of service technicians to access the required diagnostic information, the impact on equipment and tool manufacturers, and the amount of time prior to implementation of the proposed corrective action.

(1.5.2) Upon request of the Executive Officer, a manufacturer shall submit a report of the results of any testing conducted pursuant to section (j)(1) to the Executive Officer for review.

(1.5.3) In accordance with section (i)(6), manufacturers may request Executive Officer approval for a retroactive deficiency to be granted for items identified during this testing.

(2) Verification of Monitoring Requirements.

(2.1) For 2004 and subsequent model year vehicles, within the first six months after normal production begins, manufacturers shall conduct a complete evaluation of the OBD II system of one or more production vehicles (test vehicles) and submit the results of the evaluation to the Executive Officer.

(2.2) Selection of test vehicles:

(2.2.1) Prior to submitting any applications for certification for a model year, a manufacturer shall notify the Executive Officer of the test groups planned for that model year. The Executive Officer will then select the test group(s), in accordance with sections (j)(2.2.2) and (j)(2.2.3) below, that the manufacturer shall use as test vehicles; to provide evaluation test results. This selection process may take place during durability demonstration test vehicle selection specified in section (g).

(2.2.2) A manufacturer shall evaluate one production vehicle per test group selected for monitoring system demonstration in section (g).

(2.2.3) In addition to the vehicles selected in section (j)(2.2.2) above, a manufacturer shall evaluate vehicles chosen from test groups that are not selected for monitoring system demonstration testing under section (g). The number of additional vehicles to be tested shall be equal to the number of vehicles selected for monitoring system demonstration in section (g).

(2.2.4) The Executive Officer may waive the requirements for submittal of evaluation results from one or more of the test groups if data has been previously submitted for all of the test groups.

(2.3) Evaluation requirements:

(2.3.1) The evaluation shall demonstrate the ability of the OBD II system on the selected production vehicle to detect a malfunction, illuminate the MIL, and store a confirmed fault code when a malfunction is present and the monitoring conditions have been satisfied for each individual diagnostic required by title *13, CCR section 1968.2*.

(2.3.2) The evaluation shall verify that malfunctions detected by non-MIL illuminating diagnostics of components used to enable any other OBD II system diagnostic (e.g., fuel level sensor) will not inhibit the ability of other OBD II system diagnostics to properly detect malfunctions.

(2.3.3) On vehicles so equipped, the evaluation shall verify that the software used to track the numerator and denominator for purposes of determining in-use monitoring frequency correctly increments as required in section (d)(4).

(2.3.4) Malfunctions may be mechanically implanted or electronically simulated but internal on-board computer hardware or software changes may not be used to simulate malfunctions. Emission testing to confirm that the malfunction is detected before the appropriate emission standards are exceeded is not required.

(2.3.5) Manufacturers shall submit a proposed test plan for Executive Officer approval prior to evaluation testing being performed. The test plan shall identify the method used to induce a malfunction in each diagnostic. If the Executive Officer determines that the requirements of section (j)(2) are satisfied, the proposed test plan shall be approved.

(2.3.6) Subject to Executive Officer approval, manufacturers may omit demonstration of specific diagnostics. The Executive Officer shall approve a manufacturer's request if the demonstration cannot be reasonably performed without causing physical damage to the vehicle (e.g., on-board computer internal circuit faults).

(2.3.7) For evaluation of test vehicles selected in accordance with section (j)(2.2.2), manufacturers are not required to demonstrate diagnostics that were previously demonstrated prior to certification as required in section (g).

(2.4) Manufacturers shall submit a report of the results of all testing conducted pursuant to section (j)(2) to the Executive Officer for review. This report shall identify the method used to induce a malfunction in each diagnostic, the MIL illumination status, and the confirmed fault code(s) stored.

(2.5) In accordance with section (i)(6), manufacturers may request Executive Officer approval for a retroactive deficiency to be granted for items identified during this testing.

(3) Verification and Reporting of In-use Monitoring Performance.

(3.1) Manufacturers are required to collect and report in-use monitoring performance data representative of every test group certified by the manufacturer and equipped with in-use monitoring performance tracking software in accordance with section (d)(4) to the ARB within six months from either the time vehicles in the test group were first introduced into commerce or the start of normal production for such vehicles, whichever is later. The manufacturer may propose to the Executive Officer that multiple test groups be combined to collect representative data. Executive Officer approval shall be granted upon determining that the proposed groupings include test groups using the same OBD II strategies and similar calibrations and that are expected to have similar in-use monitoring performance. If approved by the Executive Officer, the manufacturer may submit one set of data for each of the approved groupings.

(3.2) For each test group or combination of test groups, the data must include all of the in-use performance tracking data reported through SAE J1979 (i.e., all numerators, denominators, and the ignition cycle counter), the date the data was collected, the vehicle VIN, and the ECM software calibration identification number.

(3.3) Manufacturers shall submit a plan to the Executive Officer for review and approval of the sampling method, number of vehicles to be sampled, time line to collect the data, and reporting format. The

Executive Officer shall approve the plan upon determining that it provides for effective collection of data from a representative sample of vehicles that, at a minimum, is fifteen vehicles, will likely result in the collection and submittal of data within the required six month time frame, will generate data that are representative of California drivers and temperatures, and does not, by design, exclude or include specific vehicles in an attempt to collect data only from vehicles with the highest in-use performance ratios.

(3.4) Upon request of the manufacturer, the Executive Officer may for good cause extend the six month time requirement set forth in section (j)(3.1) up to a maximum of twelve months. In granting additional time, the Executive Officer shall consider, among other things, information submitted by the manufacturer to justify the delay, sales volume of the test group(s), and the sampling mechanism utilized by the manufacturer to procure vehicles. If an extension beyond six months is granted, the manufacturer shall additionally be required to submit an interim report within six months for data collected up to the time of the interim report.

(3.5) Upon request of the manufacturer, the Executive Officer may reduce the minimum sample size of fifteen vehicles set forth in section (j)(3.3) for test groups with low sales volume. In granting approval of a sampling plan with a reduced minimum sample size, the Executive Officer shall consider, among other things, information submitted by the manufacturer to justify the smaller sample size, sales volume of the test group(s), and the sampling mechanism utilized by the manufacturer to procure vehicles.

.....

1Unless otherwise noted, all section references refer to *section 1968.2 of title 13, CCR.*

2The requirements of section (f)(4.7) shall supercede the requirements set forth in title *13, CCR section 1968.1(l)(4.0)*.

Statutory Authority

AUTHORITY:

Note: Authority cited: *Sections 39600, 39601, 43000.5, 43013, 43018, 43100, 43101, 43104, 43105, 43105.5 and 43106, Health and Safety Code*. Reference: *Sections 39002, 39003, 39010, 39018, 39021.5, 39024, 39024.5, 39027, 39027.3, 39028, 39029, 39031, 39032, 39032.5, 39033, 39035, 39037.05, 39037.5, 39038, 39039, 39040, 39042, 39042.5, 39046, 39047, 39053, 39054, 39058, 39059, 39060, 39515, 39600-39601, 43000, 43000.5, 43004, 43006, 43013, 43016, 43018, 43100, 43101, 43102, 43104, 43105, 43105.5, 43106, 43150, 43151, 43152, 43153, 43154, 43155, 43156, 43204, 43211 and 43212, Health and Safety Code*.

History

HISTORY:

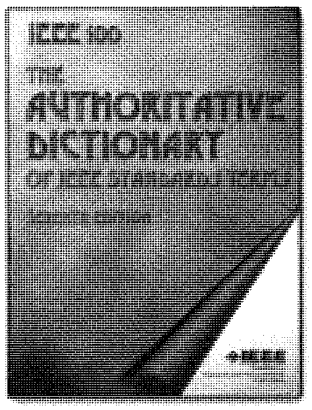
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The Authoritative Dictionary of IEEE Standards Terms

Seventh Edition



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connection-oriented confidentiality The protection of all (N)-service data units from unauthorized disclosure during communications from one (N+1)-entity to one or more (N+1)-entities for which a security association is established for the transfer of data and for the application of confidentiality service between the entities themselves and between each entity and the physical layer. (C/LM) 802.10-1998

connection-oriented integrity A service providing for the integrity of all (N)-service data on a security association and detecting any modification, insertion, deletion, or replay of any data within an entire SDU sequence. (C/LM) 802.10-1998

connection-oriented service A kind of delivery service where different virtual circuit configurations are used to transmit messages. *Synonym:* virtual circuit service. (C) 610.7-1995

connection phase A beat that begins with the assertion of the address synchronization line followed by the release of an address acknowledge line. It is used to broadcast the address and command information. Modules determine whether they wish to take part in the transaction based on this information. (C/BA) 10857-1994, 896.4-1993w, 896.3-1993w

connections In-line and tee splices that are designed to join heating cables or heating cables and power leads. (IA/PC) 515.1-1995

connections of polyphase circuits *See:* star-connected circuit; zig-zag connection of polyphase circuits; mesh-connected circuit.

connector (1) A coupling device employed to connect conductors of one circuit or transmission element with those of another circuit or transmission element. *See also:* auxiliary device to an instrument. (IM/ELM/HFIM) [40], C12.8-1981r

(2) (**wires**) A device attached to two or more wires or cables for the purpose of connecting electric circuits without the use of permanent splices. (VT/LT) 16-1955w

(3) (**splicing sleeve**) A metal sleeve, that is slipped over and secured to the butted ends of the conductors in making up a joint. (T&D/PE) [10]

(4) (**waveguides**) A mechanical device, excluding an adapter, for electrically joining separable parts of a waveguide or transmission-line system. (AP/ANT) [35]

(5) (**power cable joints**) A metallic device of suitable electric conductance and mechanical strength, used to splice the ends of two or more cable conductors, or as a terminal connector on a single conductor. Connectors usually fall into one of the following types: solder, welded, mechanical, and compression or indent. Conductors are sometimes spliced without connectors, by soldering, brazing or welding. (PE/IC) 404-1986s

(6) (**substation grounding**) A metallic device of suitable electric conductance and mechanical strength used to connect conductors. (SUB/PE) 837-1989r

(7) (**fiber optics**) *See also:* optical waveguide connector. 812-1984w

(8) *See also:* connector link. (PE/T&D) 524-1992r

connector base (motor plug) (motor attachment plug cap) A device, intended for flush or surface mounting on an appliance, that serves to connect the appliance to a cord connector. (EEC/PE) [119]

connector insertion loss *See:* insertion loss.

connector link (conductor stringing equipment) A rigid link designed to connect pulling lines and conductors together in series. It will not spin and relieve torsional forces. *Synonyms:* bullet; link; link; slug; connector; connector. (T&D/PE) 524-1992r

connector, precision *See:* precision connector.

connector, rope *See:* rope connector.

connector switch (connector) A remotely controlled switch for connecting a trunk to the called line. (EEC/PE) [119]

connector thermal capacity (substation grounding) The ability of a connector to withstand the amount of current required to produce a specified temperature on the control conductor without increasing the resistance of the connector beyond that specified in IEEE Std 837-1989. (SUB/PE) 837-1989r

connector, waveguide *See:* waveguide connector.

connect time In time-sharing computer systems, the time that a terminal or user is connected and able to communicate with a computer. *See also:* CPU time. (C) 610.10-1994w

conopulse A tracking radar that uses two simultaneous squinted beams that are rotated around the antenna boresight to produce, on a time-shared basis, monopulse angle-error signals in two orthogonal coordinates (such as azimuth and elevation). *Notes:* 1. Only two receivers are required rather than three as in the usual monopulse tracker. 2. Also called "konopulse" and "scan with compensation." (AES) 686-1997

consecutive Pertaining to the occurrence of two sequential events or items without the intervention of any other event or item; that is, one immediately after the other. (C) 610.12-1990

consecutive sequence computer A type of computer in which instructions are executed in an implicitly defined sequence unless a jump instruction specifies the storage location of the next instruction to be executed. *Contrast:* arbitrary sequence computer. (C) 610.10-1994w

consecutive spill method *See:* linear probing.

consequences The result(s) of (i.e., events that follow and depend upon) a specified event. (PE/NP) 1082-1997

conservation of radiance (fiber optics) A basic principle stating that no passive optical system can increase the quantity Ln^{-2} where L is the radiance of a beam and n is the local refractive index. Formerly called "conservation of brightness" or the "brightness theorem." *See also:* brightness; radiance. (Std100) 812-1984w

conservator (expansion tank system) (power and distribution transformers) A system in which the oil in the main tank is sealed from the atmosphere, over the temperature range specified, by means of an auxiliary tank partly filled with oil and connected to the completely filled main tank. (PE/TR) C57.12.80-1978r

conservator/diaphragm system (power and distribution transformers) A system in which the oil in the main tank is completely sealed from the outside atmosphere, and is connected to an elastic diaphragm tank contained inside a tank mounted at the top of the transformer. As oil expands and contracts within a specified temperature range the system remains completely sealed with an approximately constant pressure. (PE/TR) C57.12.80-1978r

conservator system An oil preservation system in which the oil in the main tank is sealed from the atmosphere, over the temperature range specified, by means of an ancillary tank partly filled with oil and connected to the completely filled main tank. *Synonym:* expansion tank system. (PE/TR) C57.15-1999

consist The makeup or composition (number and specific identity) of individual units on a train. (VT/RT) 1477-1998, 1475-1999, 1474.1-1999

consistency (software) The degree of uniformity, standardization, and freedom from contradiction among the documents or parts of a system or component. *See also:* traceability. (C) 610.12-1990

consistency check A check that verifies that an item of data is compatible with certain rules specified for that data. For example, one might wish to check the consistency between two data elements ORDER-DATE and DELIVER-DATE such that DELIVER-DATE may not be earlier than ORDER-DATE. *See also:* limit check; crossfooting check; range check; validity check. (C) 610.5-1990w

consol (navigation aid terms) A keyed C-W (continuous wave) short-baseline-radio navigation system operating in the L/MF (low- and medium frequency) band, generally useful to about 1500 nmi (nautical miles) (2800 kilometers [km]), and using three radiators to provide a multiplicity of overlapping lobes of dot-and-dash patterns which form equisignal hyperbolic

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SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1978 | REV. APR2002

Issued 1992-03
Revised 2002-04

Superseding J1978 FEB1998

OBD II Scan Tool — Equivalent to ISO/DIS 15031-4:December 14, 2001

This document supersedes SAE J1978 FEB1998, and is technically equivalent to ISO/DIS 15031-4:December 14, 2001, except for minor reorganization of Paragraphs 1 and 2.

Foreword—On-Board Diagnostic (OBD) regulations require passenger cars, and light and medium duty trucks, to support communication of a minimum set of diagnostic information with off-board "generic" test equipment. This document describes the minimum capabilities that must be supported by test equipment (e.g., handheld scan tools, PC based diagnostic computers, etc.) that are intended to communicate with an OBD compliant vehicle to retrieve the OBD information.

SAE J1978 was originally developed to meet U.S. OBD requirements for 1996 and later model year vehicles. ISO 15031-4 was based on SAE J1978 and was intended to meet European OBD requirements for 2000 and later model year vehicles, and added the capability to communicate on an ISO 15765-4 serial data link. This document is technically equivalent to ISO 15031-4 with U.S. specific requirements identified.

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1. *Scope*

1.1 Purpose—This SAE Recommended Practice supersedes SAE J1978 FEB1998, and is technically equivalent to ISO/DIS 15031-4:December 14, 2001.

This document is intended to satisfy the requirements of an OBD scan tool as required by U.S. On-Board Diagnostic (OBD) regulations.

The document specifies:

a. A means of establishing communications between an OBD-equipped vehicle and external test equipment,
b. A set of diagnostic services to be provided by the external test equipment in order to exercise the services defined in SAE J1979,
c. Conformance criteria for the external test equipment.

1.2 Differences from ISO Document—The ISO 15031-4 document is intended to satisfy the requirements of OBD requirements in countries other than the U.S., and includes functionality not required or not allowed in the U.S.

Notable exceptions are:

a. Proposed U.S. OBD regulations will allow ISO 15765-4 as an allowable OBD serial data link at 500 kbps only. Only those provisions of ISO 15765-4 that pertain to 500 kbps are required to be supported by an SAE J1978 diagnostic scan tool.
b. Proposed U.S. OBD regulations will not allow greater than 20 V at the SAE J1962 connector. Only the Type A connector as defined in SAE J1962 needs to be supported by an SAE J1978 diagnostic scan tool.

Differences between the documents are highlighted in the technical requirements sections of this document. Deleted text is highlighted with ~~struck through~~ and new text is highlighted with ***bold italic***.

NOTE— To maintain equivalency of the documents, a comma is used as a decimal marker for numeric values in this document.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1850 MAY2001—Class B Data Communications Network Interface.
SAE J1930—Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms - Equivalent to ISO/TR 15031-2:April 30, 2002
SAE J1962—Diagnostic Connector - Equivalent to ISO/DIS 15031-3: December 14, 2001
SAE J1979—E/E Diagnostic Test Modes - Equivalent to ISO/DIS 15031-5:April 30, 2002
SAE J2012—Diagnostic Trouble Code Definitions - Equivalent to ISO/DIS 15031-6:April 30, 2002

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2.1.2 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 7637-1:1990—Road vehicles — Electrical disturbance by conduction and coupling — Part 1: Passenger cars and light commercial vehicles with nominal 12V supply voltage — Electrical transient conduction along supply lines only
ISO 9141-2:1994—Road vehicles — Diagnostic systems — Part 2: CARB requirements for interchange of digital information
ISO 9141-2:1994/Amd.1:1996—Road vehicles - Diagnostic systems — Part 2: CARB requirements for interchange of digital information Amendment 1.
ISO 14230-4:2000—Road vehicles — Keyword protocol 2000 for diagnostic systems — Part 4: Requirements for emission-related systems
ISO/DIS 15031-4: December 14, 2001—Road vehicles — Communication between vehicle and external test equipment for emissions-related diagnostics — Part 4: External test equipment
ISO 15765-4:2001—Road vehicles — Diagnostics on Controller Area Network (CAN) – Part 4: Requirements for emissions-related systems
ISO 16750-2—Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 2: Electrical loads

2.2 Related Publication—The following publication is provided for information purposes only and is not a required part of this specification.

2.2.1 ISO PUBLICATION—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 15031-1:2001—Road vehicles — Communication between vehicle and external test equipment for emissions-related diagnostics — Part 1: General information

3. Terms and Definitions—For the purpose of this document the definitions of SAE J1930 apply.

4. Required Functions of the External Test Equipment—The following are the basic functions that the external test equipment is required to support or provide:

— Automatic hands-off determination of the communication interface used to provide OBD services on the vehicle,
— Obtaining and displaying the status and results of vehicle on-board diagnostic evaluations,
— Obtaining and displaying OBD emissions related diagnostic trouble codes (DTCs),
— Obtaining and displaying OBD emissions related current data,
— Obtaining and displaying OBD emissions related freeze frame data,
— Clearing the storage of OBD emissions related diagnostic trouble codes, OBD emissions related freeze frame data storage and OBD emissions related diagnostic tests status,
— Obtaining and displaying OBD emissions related test parameters and results as described in SAE J1979,
— Provide a user manual and/or help facility.

5. Communication Protocols—The following communication protocols shall be supported:

a. ISO 9141-2

The following specifications clarify and, if in conflict with ISO 9141-2, override any related specifications in ISO 9141-2:

— The maximum sink current to be supported by the external test equipment is 100 mA,
— The range for all tests performed relative to ISO 7637-1 is –1.0 to +40.0 V,
— The minimum bus idle period before the external test equipment shall transmit an address, shall be 300 ms.

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b. SAE J1850 41,6 kbps PWM (pulse width modulation)
c. SAE J1850 10,4 kbps VPW (variable pulse width)
d. ISO 14230-4 (Keyword protocol 2000)
e. ISO 15765-4 (CAN)

— ***NOTE: Proposed U.S. regulations will allow ISO 15765-4 as an allowable OBD serial data link at 500Kbps only. Only those provisions of ISO 15765-4 that pertain to 500 kbps are required to be supported by an SAE J1978 diagnostic scan tool.***

A fully compliant external test equipment shall support all communication protocols as specified in Section 5.

Only one protocol is allowed to be used in any one vehicle to access all legislated emission-related functions. The external test equipment is not required to support simultaneous use of protocols.

6. *Connections to the Vehicle*

NOTE— Proposed U.S. regulations will not allow greater than 20 V at the SAE J1962 connector. Only the Type A connector as defined in SAE J1962 needs to be supported by an SAE J1978 diagnostic scan tool.

Connection to the vehicle shall be made using the connector specified in SAE J1962. All data transfer between external test equipment and the vehicle shall conform to the requirements of SAE J1979.

7. *Network Access*

7.1 Automatic Determination of Communication Interface—The external test equipment shall have an "Automatic hands-off determination of the communication interface" built in to determine the communication protocol used in a given vehicle.

The tests to determine the communication interface and protocol may be performed in any order and, where possible, may be performed simultaneously. The specified sequence for each test shall be used to determine the interface to be used to access OBD services on a vehicle:

a. The electrical interface in the external test equipment for the manufacturer discretionary contact assignments shall be effectively open circuit as a default condition or state whilst this procedure is being performed.
b. The equipment shall inform the user that initialization is occurring.
c. The equipment shall, using only the following tests, attempt to determine the OBD communications protocol used by the vehicle. No user intervention is allowed during this stage.

1. Test for SAE J1850 41,6 kbps (kilobits per second) PWM (pulse width modulation):

— enable the SAE J1850 41,6 kbps PWM interface;
— send a service $01 PID $00 request message;
— if a service $01 PID $00 response message is received then SAE J1850 41,6 kbps PWM is the vehicle's OBD protocol.

2. Test for SAE J1850 10,4 kbps VPW (variable pulse width):

— enable the SAE J1850 10,4 kbps VPW interface;
— send a service $01 PID $00 request message;
— if a service $01 PID $00 response message is received then SAE J1850 10,4 kbps VPW is the vehicle's OBD protocol.

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3. Test for ISO 9141-2:

   — enable the ISO 9141-2 interface;
   — if the initialization sequence specified in ISO 9141-2 is completed successfully, then ISO 9141-2 is the vehicle's OBD protocol.

4. Test for ISO 14230-4:

   — enable the ISO 14230-4 interface;
   — if the initialization sequence specified in ISO 14230-4 is completed successfully, then ISO 14230-4 is the vehicle's OBD protocol.

5. Test for ISO 15765-4:

   — legacy vehicles previously were allowed to use the contacts now defined for CAN communication as manufacturer discretionary. The external test equipment shall ensure adequate protection from these legacy signals,
   — perform the "External Test Equipment Initialization Sequence" defined in ISO 15765-4,
   — if the initialization sequence specified in ISO 15765-4 is completed successfully, then ISO 15765-4 is the vehicle's OBD protocol.

The service $01 PID $00 request and response messages are specified in SAE J1979.

Both ISO 9141-2 and ISO 14230-4 specify a time within which a module(s) that has successfully been initialized must receive a message or the module(s) will return to the address mode. Unless the external test equipment user has indicated he/she wishes to terminate communication, once a module(s) has successfully been initialized, the external test equipment must automatically send a message, to be identified as the idle message, before this time can elapse. Any use of any response received due to the idle message is at the discretion of the external test equipment manufacturer.

For vehicles using ISO 9141-2 service $01 PID $00 request shall be used as the idle message.

For vehicles using ISO 14230-4 the service TesterPresent is the recommended way to satisfy the idle message requirement as specified in ISO 14230-4. Alternatively, the service $01 PID $00 as specified in SAE J1979 may be used.

If none of the protocol tests shown above succeeds, the equipment shall repeat all of them and advise the user:

a. That communication with the vehicle could not be established,
b. To confirm that the ignition key is in the "ON" position,
c. To check the emissions label or vehicle service information to confirm that the vehicle is OBD equipped,
d. To confirm that the external test equipment is connected to the vehicle correctly.

The equipment shall continue to repeat the protocol tests shown above until either one of them passes or the user chooses to abandon the attempt. The equipment may also indicate the number of failed initialization attempts to the user.

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7.2 **Handling of No Response from the Vehicle**—A vehicle module may fail to respond to a request message from the external test equipment because of incorrect transmission or because the module does not support that message. If a response is not received within the time-out period prescribed by the protocol, the external test equipment shall:

a. Retransmit the request message,
b. If there is still no response, transmit a service $01 PID $00 request message, in order to determine if communication with the vehicle is currently possible, and if the data desired is available,
c. If a service $01 PID $00 response is received, transmit other messages, if available, to determine whether the desired data is supported by the vehicle,
d. If the above steps fail then indicate to the user, as appropriate, that communication with the vehicle can not be performed, that communication with the module can not be performed or that the information the user has selected is unavailable.

7.3 **Handling of Multiple Responses from the Vehicle**—The external test equipment shall be capable of interfacing with a vehicle in which multiple modules support OBD requirements.

The external test equipment shall inform the user when multiple modules respond to the same request.

The external test equipment shall inform the user when multiple modules respond with different values for the same data item.

The external test equipment shall provide the user with the ability to select for display, as separate items, the responses received from multiple modules for the same data item.

7.4 **Message Structure**—Communication between the external test equipment and the vehicle consists of repeated cycles of the external test equipment issuing a request message to the vehicle module(s) and the vehicle module(s) responses. The structure of these messages is specified in SAE J1979. SAE J2012 specifies the usage of diagnostic trouble codes which may be contained in response messages.

7.5 **Diagnostic Trouble Codes Monitoring**—The external test equipment shall be capable of continuously obtaining, converting and displaying OBD emissions related diagnostic trouble codes from the vehicle. Either the diagnostic trouble code, its descriptive text or both shall be displayed. Diagnostic trouble codes and their descriptive text are specified in SAE J2012. The external test equipment shall continuously obtain and display DTCs (diagnostic trouble codes) whilst this facility is selected.

7.6 **Obtain and Display OBD Emissions Related Current Data, Freeze Frame Data, and Test Parameters and Results**—The external test equipment shall be capable of obtaining, converting, and displaying:

a. OBD emissions related current data as described in the Appendix of SAE J1979 specifying all emission-related PIDs. For each PID an external test equipment display text string and the formatting of the data value is specified (e.g., RPM: xxxxx min^{-1}),
b. OBD emissions related freeze frame data (same data display as specified in a), and
c. Test parameters and results data as described in SAE J1979. SAE J1979 details what data is available, the messages to be used to request the data, the messages to be used to return the data, the conversion values for the data and the format to be used to display the data.

When current data items are selected for display, the external test equipment will continuously request of the vehicle the data to be displayed and will display the data received in the corresponding response messages. When freeze frame or test parameters and results are selected for display, the external test equipment does not need to continuously request and display those items.

Where applicable, the external test equipment shall indicate whether a test limit is a high limit or a low limit. Where applicable, the display of test results shall also show the test ID (identifier) and component ID.

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Data from the vehicle may indicate which items are supported, in which case this information shall be made available to the user by the external test equipment. The external test equipment shall also allow users to specify requests for services, parameters, test IDs, etc. irrespective of whether the vehicle has indicated support for such items.

7.7 Code Clearing—The external test equipment shall be capable of sending a request to clear OBD emissions related diagnostic trouble codes, freeze frame data and diagnostic tests status information. The external test equipment shall require the user to confirm such a request prior to transmission.

7.8 On-Board Diagnostic Evaluations

7.8.1 COMPLETED ON-BOARD SYSTEM READINESS TESTS—Immediately after the equipment has successfully established communication with the vehicle, it shall check the status of the system readiness tests. If the supported tests have not all been completed, the equipment shall indicate to the user: "Not all supported on-board system readiness tests have been completed" or equivalent. The equipment shall also allow the user to identify any readiness tests that have not been completed.

7.8.2 SUPPORTED ON-BOARD SYSTEM READINESS TESTS—The external test equipment shall indicate to the user which of the tests specified by SAE J1979 service $01 PID $01 data B - D are supported and which of these have been completed.

7.8.3 MALFUNCTION INDICATOR LAMP - STATUS AND CONTROL—The external test equipment shall be capable of indicating if the MIL (Malfunction Indicator Lamp) has been commanded ON and if so, by which module or modules.

7.9 Use of StopCommunication Service Associated with ISO 14230-4 (optional)—When ISO 14230-4 is being used to support OBD requirements in a vehicle, the external test equipment may provide to the operator the ability to select the StopCommunication service defined for ISO 14230-4.

8. User interface

8.1 Display—The external test equipment shall be capable of displaying simultaneously at least two items of OBD emission related current data items, emissions related freeze frame data items, or emissions related diagnostic trouble codes. A list of the OBD current data and freeze frame data items, their parameter IDs, data resolution and data conversion information, units and display formats is provided in SAE J1979. The display shall be capable of displaying alphanumeric characters. The display shall at least support the SI-units as specified in SAE J1979. The unit conversions specified in SAE J1979 shall be used.

As a minimum the data values of two data items must be displayed simultaneously. A display of the parameter IDs of the data items and the IDs of the modules that supplied the data items must be easily accessible if not displayed with the data values.

The units of measurement associated with the data items shall either be:

- displayed with the data values,
- easily accessible on the display,
- readily available to the user (e.g., on the body of an external test equipment).

Having this information available in a user manual separate from the body of the external test equipment does not satisfy this requirement.

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8.2 User Input—The external test equipment shall allow the user these services as specified by SAE J1979:

a. Select between the basic functions required by OBD, e.g.:

— system readiness test status display,
— MIL (Malfunction Indicator Lamp) status and control,
— display current data,
— display freeze frame data,
— display diagnostic trouble codes,
— clear emissions related data,
— display test parameters and results,
— read vehicle identification.

b. Select for simultaneous display at least two OBD emissions related items of any one of the following categories:

— current data,
— freeze frame data,
— diagnostic trouble codes,
— test parameters and results.

c. Confirm a request to clear and/or reset OBD emissions related diagnostic information.
d. Request operation of an on board system, test or component.

Responses from multiple modules to requests for a current data item or a freeze frame data item are treated as separate data items for selection and display purposes.

9. Power Requirements

9.1 Vehicle Battery Voltage

NOTE— Proposed U.S. regulations will not allow greater than 20 V at the SAE J1962 connector. Power requirements for 24 V DC do not need to be supported by an SAE J1978 diagnostic scan tool.

9.1.1 VEHICLE BATTERY VOLTAGE FOR 12 V DC ONLY—The external test equipment shall:

— operate normally within a vehicle battery voltage range of 8,0 to 18,0 V DC,
— survive a vehicle battery voltage of up to 24,0 V DC for at least 10 minutes,
— survive, non-operationally, a reverse vehicle battery voltage of up to 24,0 V DC for at least 10 minutes.

Preferably the external test equipment will withstand cranking, in that communications and data shall not be lost during vehicle battery voltage reductions to 5,5 V for up to 0,5 s. The display need not function during this period. This is not a requirement for compliance.

9.1.2 VEHICLE BATTERY VOLTAGE FOR 24 V DC ONLY—The external test equipment shall:

— operate normally within a vehicle battery voltage range of 8,0 to 32,0 V DC,
— survive a vehicle battery voltage of up to 36,0 V DC for at least 10 minutes,
— survive, non-operationally, a reverse vehicle battery voltage of up to 36,0 V DC for at least 10 minutes.

Preferably the external test equipment will withstand cranking, in that communications and data shall not be lost during vehicle battery voltage reductions as specified in ISO 16750-2 section 4.5.3. The display need not function during this period. This is not a requirement for compliance.

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9.2 **Vehicle Battery Current Consumption**—The maximum current drawn by the external test equipment through the power contacts of the diagnostic connector shall not exceed that specified in SAE J1962 as the minimum current supplied by the vehicle.

*10. **Electromagnetic Compatibility (EMC)***—The external test equipment shall not interfere with the normal operation of vehicle modules.

The normal operation of the external test equipment shall be immune to conducted and radiated emissions present in a service environment and when connected to a vehicle.

EMC and ESD measurements and limits shall be in accordance to the standards prevailing in the country in which the tester is to be sold.

11. Conformance Testing

11.1 **General**—Conformance testing specifies the tests required to be passed in order for external test equipment to be type approved as "conforms to SAE J1978". Only external test equipment that pass all these tests may be so labelled. External test equipment shall support all the listed protocols (specified in Section 5) as allowed by legislation of the country where the equipment will be offered to the market. Equipment that pass all tests shall be labelled "Conforms to SAE J1978" and shall list the protocols supported as shown in Section 5.

The external test equipment manufacturer may optimize the Automatic Determination of Communication Interface sequence to only test for those protocols allowed by the legislation of the country.

EXAMPLE—North American legislation only allows 500 kbps data rate of ISO 15765-4 (CAN) although the standard also specifies 250 kbps. External test equipment manufacturers are allowed to only support 500 kbps in the Automatic Determination of Communication Interface software if the equipment with this software is offered to the North American market.

Validation of the conformance test is the responsibility of the equipment manufacturer and the equipment manufacturer may elect to self-certify.

The tests in this clause, shall be performed successfully five (5) consecutive times, on each sample unit to be considered passed.

Three (3) examples of at least production intent level external test equipment shall pass all these tests in order for a given version of external test equipment hardware and software to be considered passed, and that the equipment manufacturer shall ensure consistent quality of manufacture to meet the requirements of this document, to ensure consistent compatibility between external test equipment and vehicle.

Any changes to the hardware or software used in an external test equipment for the functions described in this document shall require a retest of these tests or an explanation from the external test equipment manufacturer as to why the change shall not require a retest. Where an explanation is submitted in lieu of a retest due to a change, the organization originally performing these tests shall determine whether the explanation is acceptable or whether a retest is required. Reasonable normal engineering criteria shall be used when determining whether to accept an explanation.

For every product type which is labelled as conforming to, or compatible with the requirements of SAE J1978 OBD access facilities, or other labelling to that effect, the manufacturer shall record:

a. Clear indication of the versions of product hardware, software and protocols supported,
b. The methods used to make these tests,
c. The results of the tests.

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Both proper and improper response messages will be employed during these tests. Improper responses are those that have incorrect header information, an incorrect Service Identifier, an incorrect PID, an incorrect length of the response message, or an incorrect CRC or checksum. The external test equipment must ignore all improper response messages and perform as if no response was received.

Situations involving multiple ECUs responding to a single request message, single ECUs responding with multiple response messages to a single request message and multiple ECUs responding with multiple response messages to a single request message will be tested.

The interval between the end of the request message and the beginning of the response message(s) will be varied from 0 ms up to the delay required to show a no response message indication on the external test equipment. This delay that causes the no response message indication will be compared to the value defined in SAE J1979.

The format, content, and order of messages transmitted on the data links referenced in SAE J1979 will be observed and reviewed for correctness.

The ability to obtain and report the results of the on-board system readiness tests shall be verified. The ability to report which tests the vehicle supports and which have been completed shall be verified.

The requirements described in Sections 11.3 through 11.7 (inclusive) shall be verified on each protocol specified in Section 5.

When performing these tests, observation of the indications and displays provided to the user and the signals of each protocol specified in Section 5 (bus + and bus –, K and L lines if applicable) will be the criteria for proper performance.

Testing shall be conducted at a temperature of 23 °C ± 5 °C and between 25% and 95% relative humidity.

Testing information and results must be made available to the buying public.

11.2 Determine OBD communication type—Items to be tested:

- automatic determination of interface and protocol type when the SAE J1962 connector is plugged into its mating connector in the vehicle and/or OBD support is selected, where such a selection is necessary,
- that a test of all supported OBD communication interfaces is performed at least once per scan,
- that the interface contacts related to protocols not supported by the external test equipment are not activated during the test cycle,
- that the scan of all interfaces continues until successful or until terminated by the user,
- that some indication is provided to the user that the scan of interfaces is being performed,
- that a failure to successfully find an OBD interface during a scan of all the possible interfaces is indicated to the user at the completion of each and every scan,
- that when an OBD interface is successfully found, the external test equipment automatically prompts the user for function selection,
- that the external test equipment provides and uses the facilities and/or messages specified in SAE J1979, ISO 9141-2, SAE J1850, ISO 14230-4, ISO 15765-4, and SAE J2012,
- that the external test equipment does not exceed the polling rates specified in SAE J1979,
- that the external test equipment provides the proper bias for the K and L lines as specified in ISO 9141-2 and ISO 14230-4,
- that the external test equipment performs the initialization tests according to Section 7.1 that the external test equipment supports the use of an idle message when ISO 9141-2 and ISO 14230-4 are used.

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The interface determination tests shall be performed:

- with no modules connected,
- with one ISO 9141-2 module connected,
- with one ISO 14230-4 module connected,
- with one SAE J1850 41,6 kbps PWM module connected,
- with one SAE J1850 10,4 kbps VPW module connected,
- with one ISO 15765-4 module connected.

For unsupported interfaces it is only necessary to ensure that the specific contacts related to that protocol remain open circuit and that no damage occurs to either the external test equipment or vehicle.

TABLE 1—VEHICLE CONFIGURATION AND REQUIRED RESPONSES FOR SUPPORTED PROTOCOLS

Vehicle configuration	Required response
ISO 9141-2 module connected	ISO 9141-2 session initiated and maintained
ISO 14230-4 (KWP2000) module connected	ISO 14230-4 session initiated and maintained
SAE J1850 41,6 kbps PWM module connected	SAE J1850 41,6 kbps PWM protocol selected
SAE J1850 10,4 bps VPW module connected	SAE J1850 10,4 kbps VPW protocol selected
ISO 15765-4 module connected	ISO 15765-4 protocol selected
No module connected	Operator warning issued after five retries; equipment continues to retry until operator acts to discontinue

11.3 On-Board System Readiness Test—Confirm, using each supported protocol specified in Section 5, that the external test equipment automatically requests and correctly reports the results of the supported on-board system readiness tests.

11.4 Select Functions—Confirm, using each supported protocol specified in Section 5:

- at the external test equipment offers all of the diagnostic facilities described in Section 4,
- that the user is able to navigate between these facilities.

11.5 Select and Display Items—Confirm, using each supported protocol specified in Section 5:

a. That the user is able to select and display simultaneously at least two items from any one of:

1. available DTC's,
2. current data items,
3. available freeze frame data items, and
4. test parameters and results.

b. That the module ID's and the PID's or parameter names associated with all the items mentioned above can also be displayed either (a) simultaneously with the displayed items, or (b) in some alternate method.

c. That the units-of-measurement information associated with all the possible current data items and freeze frame data items are easily available either as a part of the data display, displayed separately, or otherwise available on or with the external test equipment body itself.

d. That the external test equipment is able to handle multiple responses from the same module due to one request.

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e. That the external test equipment is able to handle responses from multiple modules due to one request.
f. That the external test equipment is able to handle multiple responses from multiple modules due to one request.
g. That the external test equipment informs the user whenever multiple modules respond to a particular request. Responses from multiple modules to a request are to be made available to the user as separate items for display.
h. That the external test equipment informs the user whenever multiple modules produce differing responses to a single request.

The criteria for successfully passing this test is to navigate between all the items and observe the results.

11.6 Confirm Requests to Clear Codes—Confirm, using each supported protocol specified in Section 5:

— that the selection of the Clear Codes function incorporates a request to the user for confirmation,
— that both yes and no responses to the request to the user to confirm the selection of the clear codes function are processed appropriately.

When performing this test, the presence or absence of DTC's shall be verified both before and after the clear codes function is selected.

11.7 General Diagnostic Communication Tests—When performing tests involving diagnostic messages, tests are to be made of the external test equipment's ability to handle an immediate response, a slow response and a response delayed longer than the maximum allowed by each of the protocols.

The external test equipment shall be able to process all responses that are received within the maximum time allowed by each protocol and indicate a no response condition to the user when the response is delayed longer than the maximum allowed by each protocol.

The external test equipment shall support the transmission of its node address as an in-frame-response during the transmission of any response messages from modules on an SAE J1850 bus and shall be able to handle both the presence and the absence of an in-frame-response during the external test equipment's transmission of request messages.

11.8 Capacitance and Impedance at the Diagnostic Connector—Confirm, using each supported protocol specified in Section 5, that the capacitance and impedance of the external test equipment, its connecting data cables and the diagnostic connector are within the limits specified in SAE J1850, ISO 9141-2, ISO 14230-4, ISO 15765-4 and SAE J1962. Measurement of these parameters shall be performed by a testing agency at their discretion following generally acceptable engineering standards.

11.9 Operating Voltage and Current Requirement—Confirm, using each supported protocol specified in Section 5:

— that the external test equipment shall correctly operate throughout the voltage range specified in the Section 9.1 and shall not require more than the maximum current specified in the Section 9.1,
— that the external test equipment shall accept without causing damage the use of supply voltages of up to the maximum survival voltage and survive reverse voltage specified in Section 9.1.

During other conformance tests, the voltage supplied to the external test equipment is to be varied throughout the specified range and a check for continuous operation performed. Also the supply current is to be compared with the limit specified.

11.10 Protocol Check—Confirm, using each supported protocol specified in Section 5, that all the request and response messages, as specified in Section 7 are properly and appropriately used by the external test equipment.

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11.11 Alphanumeric Display—Verify that the external test equipment is able to display alphanumeric characters.

11.12 User Manual and Help Facility—Verify that:

a. A user manual and/or HELP facility is available with the external test equipment;
b. The user manual and/or HELP facility at least includes:

1. Parameter specifications and service IDs as described in SAE J1979,
2. All abbreviations used by the external test equipment,
3. How to select the functions,
4. How to select items for simultaneous display,
5. How to determine the PID, item name and module ID of data returned for display,
6. How to confirm the selection of the clear codes function,
7. How to obtain and display OBD emissions related test parameters and results as described in related documentation for each protocol,
8. How multiple responses from one request are indicated,
9. How different responses to the same request are indicated,
10. What current and freeze frame data items are available through OBD.

The external test equipment shall be tested for a HELP facility and/or the availability and coverage of a user manual.

12. Notes

12.1 Marginal Indicia—*Many editorial changes and document organizational changes have been included in this document to be consistent with the equivalent ISO document, but do not affect the technical content of the document.* The change bar (I) located in the left margin is for the convenience of the user in locating areas where revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE VEHICLE ELECTRICAL AND ELECTRONICS
DIAGNOSTIC SYSTEMS STANDARDS COMMITTEE

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SAE J1978 Revised APR2002

Rationale—ISO 15031-4 was created to be referenced in OBD regulations outside of the United States, and contains the same technical content as the previous version of SAE J1978 with the following additions:

a. Provisions for ISO 15765-4 (CAN) as a diagnostic serial data link (only 500 Kbps is allowed in U.S. regulations).
b. Allowance for 24 V DC connector as defined in ISO 15031-3 (not allowed in U.S. regulations)..

This document was issued to include the same technical content, in the same order, and with the same section references as the ISO document, but includes exceptions required by proposed U.S. regulations.

NOTE— To maintain equivalency of the documents, a comma is used as a decimal marker for numeric values in this document.

Relationship of SAE Standard to ISO Standard—This document supersedes SAE J1978 FEB1998, and is technically equivalent to ISO/DIS 15031-4:December 14, 2001, except for minor reorganization of Paragraphs 1 and 2.

Application—This document is intended to satisfy the requirements of an OBD scan tool as required by U.S. On-Board Diagnostic (OBD) regulations.

The document specifies:

a. A means of establishing communications between an OBD-equipped vehicle and external test equipment,
b. A set of diagnostic services to be provided by the external test equipment in order to exercise the services defined in SAE J1979,
c. Conformance criteria for the external test equipment.

Reference Section

SAE J1850 MAY2001—Class B Data Communications Network Interface.

SAE J1930—Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms - Equivalent to ISO/TR 15031-2:April 30, 2002

SAE J1962—Diagnostic Connector - Equivalent to ISO/DIS 15031-3: December 14, 2001

SAE J1979—E/E Diagnostic Test Modes - Equivalent to ISO/DIS 15031-5:April 30, 2002

SAE J2012—Diagnostic Trouble Code Definitions - Equivalent to ISO/DIS 15031-6:April 30, 2002

ISO 7637-1:1990—Road vehicles — Electrical disturbance by conduction and coupling — Part 1: Passenger cars and light commercial vehicles with nominal 12V supply voltage — Electrical transient conduction along supply lines only

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ISO 9141-2:1994—Road vehicles — Diagnostic systems — Part 2: CARB requirements for interchange of digital information

ISO 9141-2:1994/Amd.1:1996—Road vehicles - Diagnostic systems — Part 2: CARB requirements for interchange of digital information Amendment 1.

ISO 14230-4:2000—Road vehicles — Keyword protocol 2000 for diagnostic systems — Part 4: Requirements for emission-related systems

ISO 15031-1:2001—Road vehicles — Communication between vehicle and external test equipment for emissions-related diagnostics — Part 1: General information

ISO/DIS 15031-4: December 14, 2001—Road vehicles — Communication between vehicle and external test equipment for emissions-related diagnostics — Part 4: External test equipment

ISO 15765-4:2001—Road vehicles — Diagnostics on Controller Area Network (CAN) – Part 4: Requirements for emissions-related systems

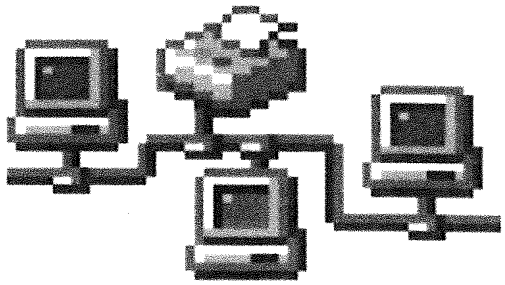
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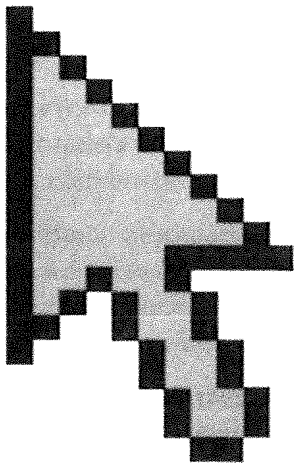
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Internet & Networking Dictionary





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Geotab v. Omega

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digital communications *n.* Exchange of communications in which all information is transmitted in binary-encoded (digital) form.

digital data service *n. See* DDS.

digital data transmission *n.* The transfer of information encoded as a series of bits rather than as a fluctuating (analog) signal in a communications channel.

digital fingerprinting *n. See* digital watermark.

digital home *n. See* smart home.

digital DNA *n.* **1.** Broadly, a reference to the bits that comprise digital information. **2.** In the gaming world, a technology called "Cyberlife" that mimics biological DNA in the creation and development of trainable creatures known as Norns. Like real DNA, digital DNA is passed from parent to offspring and determines the artificial creature's characteristics and adaptability.

digital modem *n.* **1.** A communications device that acts as the intermediary between a digital device such as a computer or terminal and a digital communications channel, such as a high-speed network line, an ISDN circuit, or a cable TV system. Although a digital modem supports standard (analog) modem protocols, it is not a "typical" modem in the sense of being a device whose primary function is to modulate (convert digital to analog) before transmission and demodulate (convert analog to digital) after transmission. It uses advanced digital modulation techniques for changing data frames into a format suitable for transmission over a digital line. *See also* terminal adapter. *Compare* modem. **2.** A 56 Kbps modem. Such a modem is not purely digital but does eliminate the traditional digital-to-analog conversion for downstream transmissions—that is, transmissions moving from the Internet to the end user. A 56 Kbps modem is also digital in that it requires a digital connection, such as T1, between the telephone company and the user's Internet Service Provider (ISP) in order to achieve its highest speed. *See also* 56-Kbps modem. **3.** A term used to distinguish all-digital communications devices, such as ISDN and cable "modems" from the more traditional analog-to-digital, phone-based modems.

Digital Network Architecture *n.* A multilayered architecture and set of protocol specifications for networks. Designed by the Digital Equipment Corporation, Digital Network Architecture is implemented in the set of products known by the name *DECnet. Acronym:* DNA. *See also* DECnet.

Digital Rights Management *n. See* DRM.

digital satellite system *n.* A high-powered satellite system with the capability to deliver high-quality transmissions of hundreds of channels directly to television receivers. A DSS broadcast begins as a digital signal sent from a service provider's station to a satellite. From there, it is directed to a satellite dish (typically 18 inches) at the user's premises. The dish next transmits the signal to a converter box, which changes it to an analog signal before sending it to the television set. *Acronym:* DSS.

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DoS *n.* Acronym for **d**enial **o**f **s**ervice attack. A computerized assault, usually planned, that seeks to disrupt Web access. A denial of service attack can occur in a number of forms. The most common form of attack is to overwhelm an Internet server with connection requests that cannot be completed. This causes the server to become so busy attempting to respond to the attack that it ignores legitimate requests for connections. One example of this type of attack, known as a SYN flood, inundates the server's entry ports with false connection messages. Another, known as the Ping of Death, sends a ping command with an oversized IP packet that causes the server to freeze, crash, or restart. Other forms of denial of service attacks include the destruction or alteration of a server's configuration data, such as router information; unauthorized access to physical components of a system; and the sending of large or invalid data that causes a system to crash or freeze. *See also* packet, Ping of Death, SYN flood.

dot *n.* **1.** In the UNIX, MS-DOS, OS/2, and other operating systems, the character that separates a file name from an extension as in TEXT.DOC (pronounced "text-dot-doc"). **2.** In computer graphics and printing, a small spot combined with others in a matrix of rows and columns to form a character or a graphic element in a drawing or design. The dots forming an image on the screen are called pixels. The resolution of a display or printing device is often expressed in dots per inch (dpi). Dots are not the same as spots, which are groups of dots used in the halftoning process. **3.** In an Internet address, the character that separates the different parts of the domain name, such as the entity name from the domain. *See also* domain (definition 3), domain name.

dot address *n.* An IP address in dotted quad form. *See also* IP address.

dot-bomb *n.* An Internet-based company or organization that has failed or downsized significantly. *See also* dot-commed.

dot-com *n.* A company doing business primarily or entirely on the Internet. The term is derived from the top-level domain, .com, at the end of the Web addresses of commercial Web sites.

dot-commed *adj.* Losing a job because of the downsizing or failure of an Internet-based company or organization. *See also* dot-bomb.

double posting *n.* In newsgroup discussions, the practice of replying to one's own posts. Because it may be seen as the digital equivalent to talking to one's self, double posting is considered an undesirable practice.

down *adj.* Not functioning, in reference to computers, printers, communications lines on networks, and other such hardware.

downlink *n.* The transmission of data from a communications satellite to an earth station.

download *vb.* In communications, to transfer a copy of a file from a remote computer to the requesting computer by means of a modem or network.

tions. Mobile IP tracks a moving host by registering the presence of the host with a foreign agent; the home agent then forwards packets to the remote network. *See also* IP.

mobile telephone switching office *n.* Computer that controls wireless phone calls. The mobile telephone switching office controls the operation of wireless cell sites, tracks calls, and transfers signals between wireless networks and traditional wired telephone systems. *Acronym:* MTSO.

modec *n.* In telecommunications, a device that generates analog modem signals digitally. The term *modec* is a combination of the terms *modem* and *codec* (coder/decoder—or hardware that can convert audio or video signals between analog and digital forms). *See also* modem (definition 2).

modem *n.* **1.** Short for **mo**dulator/**dem**odulator. A communications device that converts between digital data from a computer or terminal and analog audio signals that can pass through a standard telephone line. Because the telephone system was designed to handle voice and other audio signals and a computer processes signals as discrete units of digital information, a modem is necessary at both ends of the telephone line to exchange data between computers. At the transmit end, the modem converts from digital to analog audio; at the receiving end, a second modem converts the analog audio back to its original digital form. In order to move a high volume of data, high-speed modems rely on sophisticated methods for "loading" information onto the audio carrier—for example, they may combine frequency shift keying, phase modulation, and amplitude modulation to enable a single change in the carrier's state to represent multiple bits of data. In addition to the basic modulation and demodulation functions, most modems also include firmware that allows them to originate and answer telephone calls. International standards for modems are specified by the International Telecommunications Union, or ITU. Despite their capabilities, modems do require communications software in order to function. *Compare* digital modem. **2.** Any communications device that acts as an interface between a computer or terminal and a communications channel. Although such a device may not actually modulate or demodulate analog signals, it may be described as a modem because a modem is perceived by many users to be a black box that connects a computer to a communications line (such as a high-speed network or a cable TV system). *See also* digital modem.

modem bank *n.* A collection of modems connected to a server maintained by an ISP or the operator of a BBS or remote-access LAN. Most modem banks are configured to allow a remote user to dial a single phone number that routes calls to an available phone number on the bank. *See also* BBS (definition 1), ISP, LAN.

modem eliminator *n.* A device that enables two computers to communicate without modems. *See also* null modem.

modem ready *n. See* MR.

moderated *adj.* Subjected to review by a moderator, who may remove irrelevant or inflammatory articles or messages before redistributing them through a newsgroup, mailing list, or other messaging system.

INTERNATIONAL STANDARD

ISO 15031-4

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Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics —

Part 4: External test equipment

Véhicules routiers — Communications entre un véhicule et un équipement externe pour le diagnostic relatif aux émissions —

Partie 4: Équipement d'essai externe

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Geotab Exhibit 10
Geotab v. Omega

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15031-4 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 3, *Electric and electronic equipment*.

ISO 15031 consists of the following parts, under the general title *Road vehicles — Communication between vehicle and external test equipment for emissions-related diagnostics*:

— *Part 1: General information*

— *Part 2: Terms, definitions, abbreviations and acronyms*

— *Part 3: Diagnostic connector and related electrical circuits, specification and use*

— *Part 4: External test equipment*

— *Part 5: Emissions-related diagnostic services*

— *Part 6: Diagnostic trouble code definitions*

— *Part 7: Data link security*

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Introduction

ISO 15031 consists of a number of parts which, taken together, provide a coherent self-consistent set of specifications to facilitate emissions-related diagnostics. Each part is based on an SAE recommended practice.

This part of ISO 15031 is based on SAE J1978 FEB98, OBD Scan tool (On-board diagnosis).

ISO 15031 specifies a set of standard diagnostic services to be provided by vehicles (OBD services). This International Standard specifies a complementary set of facilities, to be provided by external test equipment, which will include scan tool facilities. These facilities provide complete, efficient and safe access to all of the public OBD (on-board diagnosis) services on any vehicle, which is compliant with ISO 15031.

Only external test equipment passing the conformance tests specified in ISO 15031-4 may claim or advertise that it meets or exceeds the requirements of ISO 15031-4.

Partially conforming external test equipment, which does not accommodate all approved protocols is permitted but shall be so marked.

ISO 15031-4 conformance allows potential purchasers to identify external test equipment which shall work correctly with a variety of vehicle types and provides assurance for external test equipment users that they shall not inadvertently cause damage, obtain incorrect results or be unable to access all available OBD (on-board diagnosis) services. Diagnostic authors who base their test strategies on ISO 15031-4 facilities do not need to concern themselves with the details of specific types of external test equipment. ISO 15031-4 provides vehicle manufacturers with a level of protection against misdiagnosis or damage to their products resulting from external test equipment unavailability or inadequacies.

ISO 15031-4 does not preclude the inclusion of additional capabilities or functions in external test equipment. However, it is the responsibility of the external test equipment designer to ensure that no such capability or function can adversely affect either an OBD-equipped vehicle, which may be connected to the equipment or the equipment itself.

ISO 15031-1 provides an introduction to the International Standard.

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Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics —

Part 4:
External test equipment

1 Scope

The document specifies:

— a means of establishing communications between an OBD-equipped vehicle and external test equipment,

— a set of diagnostic services to be provided by the external test equipment in order to exercise the services defined in ISO 15031-5,

— conformance criteria for the external test equipment.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7637-2:1990, *Road vehicles — Electrical disturbance by conduction and coupling — Part 2: Commercial vehicles with nominal 24 V supply voltage — Electrical transient conduction along supply lines only*

ISO 9141-2: 1994, *Road vehicles — Diagnostic systems — Part 2: CARB requirements for interchange of digital information*

ISO 9141-2:1994/Amd.1:1996, *Road vehicles — Diagnostic systems — Part 2: CARB requirements for interchange of digital information — Amendment 1*

ISO 11898-1, *Road vehicles — Controller area network (CAN) — Part 1: Data link layer and physical signalling*

ISO 11898-2, *Road vehicles — Controller area network (CAN) — Part 2: High-speed medium access unit*

ISO 14230-4:2000, *Road vehicles — Diagnostic systems — Keyword protocol 2000 — Part 4: Requirements for emission-related systems*

ISO TR 15031-2, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 2: Terms, definitions, abbreviations and acronyms*

ISO 15031-3, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 3: Diagnostic connector and related electrical circuits, specification and use*

ISO 15031-4, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 4: External test equipment*

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ISO 15031-5, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 5: Emissions-related diagnostic services*

ISO 15031-6, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 6: Diagnostic trouble code definitions*

ISO 15765-4, *Road vehicles — Diagnostics on Controller Area Networks (CAN) — Part 4: Requirements for emissions-related systems*

ISO 16750-2, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 2: Electrical loads*

SAE J1850:MAY2001, *Class B Data Communications Network Interface*

SAE J1939, *Recommended Practice for Serial Control and Communications Vehicle Network*

SAE J1939-11, *Physical layer, 250 kbps , twisted shielded pair*

SAE J1939-13, *Off-Board diagnostic connector*

SAE J1939-21, *Data link layer*

SAE J1939-71, *Vehicle application layer*

SAE J1939-73, *Application layer — Diagnostics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 15031-2 and SAE J1939 apply.

4 Required functions of the external test equipment

The following are the basic functions that the external test equipment is required to support or provide:

— automatic hands-off determination of the communication interface used to provide OBD services on the vehicle,

— obtaining and displaying the status and results of vehicle on-board diagnostic evaluations,

— obtaining and displaying OBD emissions-related diagnostic trouble codes (DTCs),

— obtaining and displaying OBD emissions-related current data,

— obtaining and displaying OBD emissions-related freeze frame data,

— clearing the storage of OBD emissions-related diagnostic trouble codes, OBD emissions-related freeze frame data storage and OBD emissions-related diagnostic tests status,

— obtaining and displaying OBD emissions-related test parameters and results as described in ISO 15031-5 or SAE J1939-73,

— provide a user manual and/or help facility.

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5 Communication protocols

The following communication protocols shall be supported:

a) ISO 9141-2;

The following specifications clarify and, if in conflict with ISO 9141-2, override any related specifications in ISO 9141-2:

1) The maximum sink current to be supported by the external test equipment is 100 mA.

2) The range for all tests performed relative to ISO 7637-2 is –1,0 to +40,0 V.

3) The minimum bus idle period before the external test equipment shall transmit an address, shall be 300 ms.

b) SAE J1850 41,6 kbps PWM (pulse width modulation);

c) SAE J1850 10,4 kbps VPW (variable pulse width);

d) ISO 14230-4 (Keyword protocol 2000);

e) ISO 15765-4 (CAN);

f) SAE J1939-73 (CAN).

A fully compliant external test equipment shall support all communication protocols as specified in Clause 5.

Only one protocol is allowed to be used in any one vehicle to access all legislated emission-related functions. The external test equipment is not required to support simultaneous use of different protocols.

6 Connections to the vehicle

To connect the external test equipment to the vehicle, the SAE J1939-13 connector for the SAE J1939-73 protocol shall be used and for all other protocols the ISO 15031-3 connector shall be used.

7 Network access

7.1 Automatic determination of communication interface

The external test equipment shall have an "Automatic hands-off determination of the communication interface" built in to determine the communication protocol used in a given vehicle.

Prior to connecting the external test equipment to the vehicle's diagnostic connector, the ignition key of the vehicle shall be turned to position "ON".

The tests to determine the communication interface and protocol may be performed in any order and, where possible, may be performed simultaneously. The specified sequence for each test shall be used to determine the interface to be used to access OBD services on a vehicle:

a) The electrical interface in the external test equipment for the manufacturer discretionary contact assignments shall be effectively open circuit as a default condition or state whilst this procedure is being performed.

b) The equipment shall inform the user that initialization is occurring.

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c) The equipment shall, using only the following tests, attempt to determine the OBD communications protocol used by the vehicle. No user intervention is allowed during this stage. The test equipment shall not cause bus failures such as CAN bus off.

1) Test for SAE J1850 41,6 kbps (kilobits per second) PWM (pulse width modulation):

i) enable the SAE J1850 41,6 kbps PWM interface;

ii) send a service $01 PID $00 request message;

iii) if a service $01 PID $00 response message is received, then SAE J1850 41,6 kbps PWM is the vehicle's OBD protocol.

2) Test for SAE J1850 10,4 kbps VPW (variable pulse width):

i) enable the SAE J1850 10,4 kbps VPW interface;

ii) send a service $01 PID $00 request message;

iii) if a service $01 PID $00 response message is received, then SAE J1850 10,4 kbps VPW is the vehicle's OBD protocol.

3) Fast initialization of ISO 14230-4:

i) Refer to Annex B.1 ISO 14230-4:2000.

4) 5 baud initialization of ISO 14230-4/ISO 9141-2:

i) Refer to Annex B.2 ISO 14230-4/ISO 9141-2 how to perform the 5 baud initialization and protocol detection of the ISO 14230-4 / ISO 9141-2 protocols.

5) Test for ISO 15765-4:

i) legacy vehicles previously were allowed to use the contacts now defined for CAN communication as manufacturer discretionary. The external test equipment shall ensure adequate protection from these legacy signals,

ii) perform the "External Test Equipment Initialization Sequence" defined in ISO 15765-4,

iii) if the initialization sequence specified in ISO 15765-4 is completed successfully, then ISO 15765-4 is the vehicle's OBD protocol.

6) Test for SAE J1939:

i) Once concluded that the OBD protocol is not ISO 15765-4, then proceed to the sequence to see if the vehicle is SAE J1939 OBD capable.

ii) Set CAN controller as appropriate for SAE J1939 and perform the initialization sequence specified in J1939-73.

iii) If this SAE J1939 initialization sequence is completed successfully, then SAE J1939 is the vehicle's OBD protocol.

The service $01 PID $00 request is used to identify the ISO 15765-4 protocol in step 5. Vehicles supporting OBD diagnostics with SAE J1939-73 diagnostics will not respond to this request.

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Both ISO 9141-2 and ISO 14230-4 specify a time within which a module(s) that has successfully been initialized must receive a message or the module(s) will return to the address mode. To maintain communication with the vehicle in case no service request is needed at this moment, the external test equipment shall send an idle message.

For vehicles using ISO 9141-2, service $01 PID $00 request shall be used as the idle message.

For vehicles using ISO 14230-4, the service TesterPresent is the recommended way to satisfy the idle message requirement as specified in ISO 14230-4. Alternatively, the service $01 PID $00 as specified in ISO 15031-5 may be used.

If during the initialization of the ISO 15765-4 (CAN) protocol the external test equipment receives a negative response message(s) from the emissions-related ECU(s) with the negative response code (NRC) $21 busy-RepeatRequest the external test equipment is required to perform five (5) retries (repeat request message as specified in ISO 15765-4). The reception of NRC $21 busy-RepeatRequest during the initialization indicates that an On-board diagnostic tester may be active and is currently diagnosing one or multiple emissions-related ECUs. The On-board tester and vehicle ECU(s) shall complete the in-progress communication. This may take several seconds. The external test equipment shall continue to initialize the ISO 15765-4 (CAN) protocol until it receives a positive response or aborts after five (5) seconds have expired (measured after the completion of the fifth (5th) re-try).

If none of the protocol tests shown above succeeds, the equipment shall repeat all of them and advise the user:

a) that communication with the vehicle could not be established,

b) to confirm that the ignition key is still in the "ON" position,

c) to check the emissions label or vehicle service information to confirm that the vehicle is OBD equipped,

d) to confirm that the external test equipment is connected to the vehicle correctly.

The equipment shall continue to repeat the protocol tests shown above until either one of them passes or the user chooses to abandon the attempt. The equipment may also indicate the number of failed initialization attempts to the user.

7.2 Handling of no response from the vehicle

A vehicle module may fail to respond to a request message from the external test equipment because of incorrect transmission or because the module does not support that message. If a response is not received within the time-out period prescribed by the protocol, the external test equipment shall:

a) retransmit the request message,

b) if there is still no response, transmit a service $01 PID $00 request message, in order to determine if communication with the vehicle is currently possible, and if the data desired is available,

c) if a service $01 PID $00 response is received, transmit other messages, if available, to determine whether the desired data is supported by the vehicle,

d) if the above steps fail then indicate to the user, as appropriate, that communication with the vehicle cannot be performed, that communication with the module cannot be performed or that the information the user has selected is unavailable.

7.3 Handling of multiple responses from the vehicle

The external test equipment shall be capable of interfacing with a vehicle in which multiple modules support OBD requirements.

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The external test equipment shall inform the user when multiple modules respond to the same request.

The external test equipment shall inform the user when multiple modules respond with different values for the same data item.

The external test equipment shall provide the user with the ability to select for display, as separate items, the responses received from multiple modules for the same data item.

7.4 Message structure

Communication between the external test equipment and the vehicle consists of repeated cycles of the external test equipment issuing a request message to the vehicle module(s) and the vehicle module(s) responses. The structure of these messages is specified in ISO 15031-5. ISO 15031-6 specifies the usage of diagnostic trouble codes, which may be contained in response messages. Message structures for SAE J1939 are described in SAE J1939-73 and SAE J1939-71.

7.5 Diagnostic trouble codes monitoring

The external test equipment shall be capable of continuously obtaining, converting and displaying OBD emissions-related diagnostic trouble codes from the vehicle. Either the diagnostic trouble code, its descriptive text or both shall be displayed. Diagnostic trouble codes and their descriptive text are specified in ISO 15031-6, or SAE J1939 and SAE J1939-73. The external test equipment shall continuously obtain and display DTCs (diagnostic trouble codes) whilst this facility is selected.

If the protocol is ISO 15031-5 and the response message includes a DTC number equal $0000, the data reported may not be valid and shall not be displayed.

7.6 Obtain and display OBD emissions-related current data, freeze frame data, and test parameters and results

The external test equipment shall create an internal table in its memory to maintain a list of supported PIDs/OBDMIDs/TIDs/INFOTYPEs for each ECU that responds to a service request message with the requested "Supported PID/OBDMID/TID/INFOTYPE" ($00, $20, ... $C0). If bit 0 of Data D is reported as "0", that indicates that no additional PIDs/OBDMIDs/TIDs/INFOTYPEs are supported by that ECU. If bit 0 of Data D is reported as "1", that indicates that additional PIDs/OBDMIDs/TIDs/INFOTYPEs are supported by that ECU. The external test equipment does not need to request any additional "Supported PIDs/OBDMIDs/TIDs/INFOTYPEs" if bit 0 of Data D is reported as "0" by all ECUs.

The external test equipment shall test for support of PID $4F and $50. If supported, the external test equipment shall override the data scaling of those PIDs included in the definition of ISO 15031-5 Annex B.

The external test equipment shall only display data from an ECU if that ECU indicated it supports that data item. The external test equipment shall not display data from an ECU if that ECU indicated it does not support that data item.

The external test equipment shall be capable of obtaining, converting, and displaying:

a) OBD emissions-related current data as described in ISO 15031-5 and SAE J1939-73 specifying all emission-related data. For each data item, an external test equipment display text string and the formatting of the data value is specified (e.g. RPM: xxxxx min^{-1}),

b) OBD emissions-related freeze frame data [same data display as specified in a)], and

c) test parameters and results data as described in ISO 15031-5 and SAE J1939-73. ISO 15031-5 and SAE J1939-73 details what data is available, the messages to be used to request the data, the messages to be used to return the data, the conversion values for the data and the format to be used to display the data.

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When current data items are selected for display, the external test equipment will continuously request of the vehicle the data to be displayed and will display the data received in the corresponding response messages. When freeze frame or test parameters and results are selected for display, the external test equipment does not need to continuously request and display those items.

Where applicable, the external test equipment shall indicate whether a test limit is a high limit or a low limit. Where applicable, the display of test results shall also show the test ID (identifier) and component ID.

Data from the vehicle may indicate which items are supported, in which case this information shall be made available to the user by the external test equipment. The external test equipment shall also allow users to specify requests for services, parameters, test IDs, etc. irrespective of whether the vehicle has indicated support for such items.

7.7 Code clearing

The external test equipment shall be capable of sending a request to clear OBD emissions-related diagnostic trouble codes, freeze frame data and diagnostic tests status information. The external test equipment shall require the user to confirm such a request prior to transmission.

7.8 On-board diagnostic evaluations

7.8.1 Completed on-board system readiness tests

Immediately after the equipment has successfully established communication with the vehicle, it shall check the status of the system readiness tests. If the supported tests have not all been completed, the equipment shall indicate to the user: "Not all supported on-board system readiness tests have been completed" or equivalent. The equipment shall also allow the user to identify any readiness tests that have not been completed.

7.8.2 Supported on-board system readiness tests

The external test equipment shall indicate to the user which of the tests specified by ISO 15031-5 service $01 PID $01 data B - D, or SAE J1939-73 DM5 bytes 4-8, are supported and which of these have been completed.

7.8.3 Malfunction Indicator Lamp — status and control

The external test equipment shall be capable of indicating whether the MIL (Malfunction Indicator Lamp) has been commanded ON and if so, by which module or modules.

7.9 Use of StopCommunication service associated with ISO 14230-4 (optional)

When ISO 14230-4 is being used to support OBD requirements in a vehicle, the external test equipment may provide to the operator the ability to select the StopCommunication service defined for ISO 14230-4.

8 User interface

8.1 Display

The external test equipment shall be capable of displaying simultaneously at least two items of OBD emissions-related current data items, emissions-related freeze frame data items, or emissions-related diagnostic trouble codes. A list of the OBD current data and freeze frame data items, their parameter IDs, data resolution and data conversion information, units and display formats is provided in ISO 15031-5. The display shall be capable of displaying alphanumeric characters. The display shall at least support the SI-units as specified in ISO 15031-5. The unit conversions specified in ISO 15031-5 shall be used.

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If the protocol is SAE J1939-73, then data parameters shall be displayed as specified in SAE J1939-73 using the SI-units and unit conversions. DTCs shall be displayed as specified in Annex A.

As a minimum, the data values of two data items shall be displayed simultaneously. A display of the parameter IDs of the data items and the IDs of the modules that supplied the data items shall be easily accessible if not displayed with the data values.

The units of measurement associated with the data items shall either be:

— displayed with the data values,

— easily accessible on the display, or

— readily available to the user (e.g. on the body of the external test equipment).

Having this information available in a user manual separate from the body of the external test equipment does not satisfy this requirement.

8.2 User input

The external test equipment shall allow the user these services as specified by ISO 15031-5:

a) Select between the basic functions required by OBD, e.g.:

   1) system readiness test status display,

   2) MIL (Malfunction Indicator Lamp) status and control,

   3) display current data,

   4) display freeze frame data,

   5) display diagnostic trouble codes,

   6) clear emissions-related data,

   7) display test parameters and results,

   8) read vehicle identification.

b) Select for simultaneous display at least two OBD emissions-related items of any one of the following categories:

   1) current data,

   2) freeze frame data,

   3) diagnostic trouble codes,

   4) test parameters and results.

c) Confirm a request to clear and/or reset OBD emissions-related diagnostic information.

d) Request operation of an on-board system, test or component.

Responses from multiple modules to requests for a current data item or a freeze frame data item are treated as separate data items for selection and display purposes.

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9 Power requirements

9.1 Vehicle battery voltage support

9.1.1 External test equipment supports only 12 V D.C. vehicle battery voltage

If the test tool manufacturer chooses to develop external test equipment with only 12 V D.C. vehicle battery voltage support, the following requirements shall apply:

— operate normally within a vehicle battery voltage range of 8,0 to 18,0 V D.C.,

— survive a vehicle battery voltage of up to 24,0 volts D.C. for at least 10 m,

— survive, non-operationally, a reverse vehicle battery voltage of up to 24,0 V D.C. for at least 10 m.

Preferably the external test equipment will withstand cranking, in that communications and data shall not be lost during vehicle battery voltage reductions to 5,5 V for up to 0,5 s. The display need not function during this period. This is not a requirement for compliance.

9.1.2 External test equipment supports 12 V D.C. and 24 V D.C. vehicle battery voltage

If the test tool manufacturer chooses to develop external test equipment with 12 V D.C. and 24 V D.C. vehicle battery voltage support the following requirements shall apply:

— operate normally within a vehicle battery voltage range of 8,0 to 32,0 volts D.C.,

— survive a vehicle battery voltage of up to 36,0 volts D.C. for at least 10 minutes,

— survive, non-operationally, a reverse vehicle battery voltage of up to 36,0 Volts D.C. for at least 10 minutes.

Preferably the external test equipment will withstand cranking, in that communications and data shall not be lost during vehicle battery voltage reductions as specified in ISO 16750-2. The display need not function during this period. This is not a requirement for compliance.

9.2 Vehicle battery current consumption

The maximum current drawn by the external test equipment through the power contacts of the diagnostic connector shall not exceed that specified in ISO 15031-3 as the minimum current carrying capacity supplied by the vehicle.

10 Electromagnetic compatibility (EMC)

The external test equipment shall not interfere with the normal operation of the vehicle electrical system.

The normal operation of the external test equipment shall be immune to conducted and radiated emissions present in a service environment and when connected to a vehicle.

EMC and ESD measurements and limits shall be in accordance with the standards prevailing in the country in which the tester is to be sold.

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11 Conformance testing

11.1 General

Conformance testing specifies the tests required to be passed in order for external test equipment to be type approved as "conforms to ISO 15031-4". Only external test equipment that passes all tests may be so labelled. External test equipment shall support all the listed protocols (specified in Clause 5) as allowed by national/regional legislation of the country where the equipment will be offered to the market. Equipment that passes all tests shall be labelled "Conforms to ISO 15031-4" and shall list the protocols supported as shown in Clause 5.

The external test equipment manufacturer may optimize the Automatic determination of communication interface sequence to test only for those protocols allowed by the national/regional legislation of the country.

EXAMPLE If national/regional specific legislation only allows e.g. 500 kbps data rate of ISO 15765-4 (CAN) although the standard allows 250 kbps, the external test equipment manufacturers are allowed to only support that baudrate.

Validation of the conformance test is the responsibility of the equipment manufacturer, and the equipment manufacturer may elect to self-certify.

The tests in this clause, shall be performed successfully five (5) consecutive times, on each sample unit to be considered passed.

Three (3) examples of at least production intent level external test equipment shall pass all these tests in order for a given version of external test equipment hardware and software to be considered passed, and the equipment manufacturer shall ensure consistent quality of manufacture to meet this standard, to ensure consistent compatibility between external test equipment and vehicle.

Any changes to the hardware or software used in an external test equipment for the functions described in this International Standard shall require a retest of these tests or an explanation from the external test equipment manufacturer as to why the change shall not require a retest. Where an explanation is submitted in lieu of a retest due to a change, the organization originally performing these tests shall determine whether the explanation is acceptable or whether a retest is required. Reasonable normal engineering criteria shall be used when determining whether to accept an explanation.

For every product type which is labelled as conforming to, or compatible with the requirements of ISO 15031-4 OBD access facilities, or other labelling to that effect, the manufacturer shall record:

a) clear indication of the versions of product hardware, software and protocols supported,

b) the methods used to make these tests,

c) the results of the tests.

Both proper and improper response messages will be employed during these tests. Improper responses for ISO 15031-5 are those that have incorrect header information, an incorrect Service Identifier, an incorrect PID, an incorrect length of the response message, or an incorrect CRC or checksum. Improper responses for J1939 are those that have incorrect addresses or message labelling, incorrect parameter identification, an incorrect length of the response message, or an incorrect CRC or checksum. The external test equipment must ignore all improper response messages and perform as if no response was received.

Situations involving multiple ECUs responding to a single request message, single ECUs responding with multiple response messages to a single request message and multiple ECUs responding with multiple response messages to a single request message will be tested.

The interval between the end of the request message and the beginning of the response message(s) will be varied from 0 ms up to the delay required to show a no response message indication on the external test equipment. This delay that causes the no response message indication will be compared to the value defined in ISO 15031-5 or the value defined in SAE J1939-21 specifications.

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The format, content and order of messages transmitted on the data links referenced in ISO 15031-5 and SAE J1939-73 will be observed and reviewed for correctness.

The ability to obtain and report the results of the on-board system readiness tests shall be verified. The ability to report which tests the vehicle supports and which have been completed shall be verified.

The requirements described in 11.3 through 11.7 (inclusive) shall be verified on each protocol specified in Clause 5.

When performing these tests, observation of the indications and displays provided to the user and the signals of each protocol specified in Clause 5 (bus + and bus –, K and L lines if applicable) will be the criteria for proper performance.

Testing shall be conducted at a temperature of (23 ± 5) °C and between 25 % and 95 % relative humidity.

Testing information and results shall be made available to the buying public.

11.2 Determine OBD communication type

Items to be tested:

— automatic determination of interface and protocol type when the ISO 15031-3 or SAE J1939-13 connector is plugged into its mating connector in the vehicle and/or OBD support is selected, where such a selection is necessary,

— all supported OBD communication interfaces at least once per scan,

— the interface contacts related to protocols not supported by the external test equipment are not activated during the test cycle,

— the scan of all interfaces continues until successful or until terminated by the user,

— some indication is provided to the user that the scan of interfaces is being performed,

— a failure to successfully find an OBD interface during a scan of all the possible interfaces is indicated to the user at the completion of each and every scan,

— when an OBD interface is successfully found, the external test equipment automatically prompts the user for function selection,

— the external test equipment provides and uses the facilities and/or messages specified in ISO 15031-5, ISO 9141-2, SAE J1850, ISO 14230-4, ISO 15765-4, ISO 15031-6 SAE J1939 and SAE J1939-73

— the external test equipment does not exceed the polling rates specified in ISO 15031-5 and SAE J1939-21,

— the external test equipment provides the proper bias for the K and L lines as specified in ISO 9141-2 and ISO 14230-4,

— the external test equipment performs the initialization tests according to 7.1 and the external test equipment supports the use of an idle message when ISO 9141-2 and ISO 14230-4 are used.

The interface determination tests shall be performed:

— with no modules connected,

— with one ISO 9141-2 module connected,

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— with one ISO 14230-4 module connected,

— with one SAE J1850 41,6 kbps PWM module connected,

— with one SAE J1850 10,4 kbps VPW module connected,

— with one ISO 15765-4 module connected,

— with one SAE J1939-73 module connected. (This module shall support DM5.)

For unsupported interfaces, it is only necessary to ensure that the specific contacts related to that protocol remain open circuit and that no damage occur, either to the external test equipment or vehicle.

Table 1 lists the required vehicle response dependant on the protocol in use.

Table 1 — Vehicle configuration and required responses for supported protocols

Vehicle configuration	Required response
ISO 9141-2 module connected	ISO 9141-2 session initiated and maintained
ISO 14230-4 (KWP2000) module connected	ISO 14230-4 session initiated and maintained
SAE J1850 41,6 kbps PWM module connected	SAE J1850 41,6 kbps PWM protocol selected
SAE J1850 10,4 bps VPW module connected	SAE J1850 10,4 kbps VPW protocol selected
ISO 15765-4 module connected	ISO 15765-4 protocol selected
SAE J1939-73 module connected	SAE J1939-73 protocol selected
No module connected	Operator warning issued after five retries; equipment continues to retry until operator acts to discontinue

11.3 On-board system readiness test

Confirm, using each supported protocol specified in Clause 5, that the external test equipment automatically requests and correctly reports the results of the supported on-board system readiness tests.

11.4 Select functions

Confirm, using each supported protocol specified in Clause 5:

— that the external test equipment offers all of the diagnostic facilities described in Clause 4,

— that the user is able to navigate between these facilities.

11.5 Select and display items

Confirm, using each supported protocol specified in Clause 5:

a) that the user is able to select and display simultaneously at least two items from any one of:

   1) available DTCs,

   2) current data items,

   3) available freeze frame data items, and

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4) test parameters and results;

b) that the module IDs and parameter names associated with all the items mentioned above can also be displayed either:

1) simultaneously with the displayed items, or

2) in some alternate method;

c) that the units-of-measurement information associated with all the possible current data items and freeze frame data items are easily available, either as a part of the data display, displayed separately, or otherwise available on or with the external test equipment body itself;

d) that the external test equipment is able to handle multiple responses from the same module due to one request;

e) that the external test equipment is able to handle responses from multiple modules due to one request;

f) that the external test equipment is able to handle multiple responses from multiple modules due to one request;

g) that the external test equipment informs the user whenever multiple modules respond to a particular request. Responses from multiple modules to a request are to be made available to the user as separate items for display;

h) that the external test equipment informs the user whenever multiple modules produce differing responses to a single request.

The criteria for successfully passing this test are to navigate between all the items and observe the results.

11.6 Confirm requests to clear codes

Confirm, using each supported protocol specified in Clause 5:

— that the selection of the Clear Codes function incorporates a request to the user for confirmation,

— that both yes and no responses to the request to the user to confirm the selection of the clear codes function are processed appropriately.

When performing this test, the presence or absence of DTCs shall be verified both before and after the clear codes function is selected.

11.7 General diagnostic communication tests

When performing tests involving diagnostic messages, tests are to be made of the external test equipment's ability to handle an immediate response, a slow response and a response delayed longer than the maximum allowed by each of the protocols.

The external test equipment shall be able to process all responses that are received within the maximum time allowed by each protocol and indicate a no response condition to the user when the response is delayed longer than the maximum allowed by each protocol.

The external test equipment shall support the transmission of its node address as an in-frame-response during the transmission of any response messages from modules on an SAE J1850 bus and shall be able to handle both the presence and the absence of an in-frame-response during the external test equipment's transmission of request messages.

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11.8 Capacitance and impedance at the diagnostic connector

Confirm, using each supported protocol specified in section 5, that the capacitance and impedance of the external test equipment, its connecting data cables and the diagnostic connector are within the limits specified in SAE J1850, ISO 9141-2, ISO 14230-4, ISO 15765-4, ISO 15031-3, and SAE J1939-11. Measurement of these parameters shall be performed by a testing agency at their discretion following generally accepted engineering standards.

11.9 Operating voltage and current requirement

Confirm, using each supported protocol specified in Clause 5:

— that the external test equipment shall correctly operate throughout the voltage range specified in 9.1 and shall not require more than the maximum current specified in 9.2,

— that the external test equipment shall accept without causing damage the use of supply voltages of up to the maximum survival voltage and survive reverse voltage specified in 9.1.

During other conformance tests, the voltage supplied to the external test equipment is to be varied throughout the specified range and a check for continuous operation performed. Also, the supply current is to be compared with the limit specified.

11.10 Protocol check

Confirm, using each supported protocol specified in Clause 5, that all the request and response messages, as specified in Clause 7 are properly and appropriately used by the external test equipment.

11.11 Alphanumeric display

Verify that the external test equipment is able to display alphanumeric characters.

11.12 User manual and help facility

Verify that:

a) a user manual and/or HELP facility is available with the external test equipment;

b) the user manual and/or HELP facility at least includes:

1) parameter specifications and service IDs as described in ISO 15031-5, and SAE J1939-73,

2) all abbreviations used by the external test equipment,

3) how to select the functions,

4) how to select items for simultaneous display,

5) how to determine the PID, item name and module ID of data returned for display,

6) how to confirm the selection of the clear codes function,

7) how to obtain and display OBD emissions-related test parameters and results as described in related documentation for each protocol,

8) how multiple responses from one request are indicated,

9) how different responses to the same request are indicated,

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10) what current and freeze frame data items are available through OBD.

The external test equipment shall be tested for a HELP facility and/or the availability and coverage of a user manual.

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Annex A
(informative)

Recommended external test equipment common user interface displays

A.1 General data display guidelines

The following are recommendations about the display layout and formatting of the external test equipment when data parameters, DTCs, OBD Monitor test results and vehicle/ECU identification data are to be displayed. The support of various protocols with two (2) different data parameter formats, DTC formats, and information types require general implementation guidelines for the external test equipment how to display information to the automotive technicians in a common user interface format. The examples provided in this annex neither address nor show provisions for multiple languages, e.g. reserved text string space per text string.

General data display guidelines shall be followed to achieve a common user interface format when displaying emissions-related data on an external test equipment display.

The following guidelines apply:

— Each information/data shall be displayed in conjunction with the ECU/module name or address in order to simplify the relation between functional emissions-related data and physical ECU/module.

— External test equipment with smaller type displays shall use the abbreviated terms as defined in ISO 15031-2, ISO 15031-5 and ISO 15031-6. External test equipment with larger type displays shall use the full text descriptors as defined in ISO 15031-2, ISO 15031-5 and ISO 15031-6. When SAE J1939-73 protocol is used then the text displays will follow the SAE J1939-73 descriptors.

— A consistent display layout shall be followed to ease readability.

A.2 Select menu display

The external test equipment shall provide a "Select Menu" which displays all available features depending on the supported services/diagnostic modes of the identified protocol of all emissions-related modules installed in the vehicle. The external test equipment shall only display the menu items supported by the protocol. Table A.1 — Select menu display example, provides an example as well as test menu text strings to be displayed depending on the protocol identified.

Table A.1 — Select menu display example

Select Task	ISO 15031-5	SAE J1939
Read Confirmed DTCs	applicable	applicable
Read Previously Active DTCs	not applicable	applicable
Read Pending DTCs	applicable	applicable
Review Freeze Frame Data	applicable	applicable
Current/Monitor Data Display	applicable	applicable
Clear DTC Information	applicable	applicable
OBD Monitor Data Display	applicable	applicable
Identification Data Display	applicable	applicable
Activate OBD Tests	applicable	applicable
In-Use Performance Tracking Data	applicable	applicable

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The key press or touch navigation of the "select menu" should provide scroll capability if the display size is too small to display all menu selections. By no means shall above example limit the external test equipment developers to add other features e.g. function key for each menu item or change the order or appearance of the menu items.

External test equipment manufacturer are free to implement a different menu structure to promote their test equipment.

A.3 Diagnostic trouble codes displays

A.3.1 Diagnostic trouble code summary display

The external test equipment shall be capable of continuously obtaining, converting and displaying OBD emissions-related DTCs from the vehicle. The diagnostic trouble code, its descriptive text or both shall be displayed. The same displays should be used to show "Active", "Previously Active DTCs" and "Pending DTCs".

Table A.2 — Summary of active DTC display template and example, provides a DTC list (Active, Previously Active, Pending) from all emissions-related systems/components. A sample of a DTC summary display is shown below. The left display shows a summary DTC template and the right display shows an example with DTCs stored in the vehicle's ECUs/modules.

The "Addr" column on the left displays the ECU/module address derived from the message header of the protocol (SAE J1939 address information e.g. 00 or 01 hex = Engine, 03 or 04 hex = Transmission, 0B hex = ABS). The middle column displays the ECU/module name. If the external test equipment does not know the ECU/module name which matches the ECU/module address (Addr), the hex number shall be displayed. The right column indicates the number of DTCs stored per ECU/module.

Table A.2 — Summary of active DTC display template and example

Menu item			Summary of Active DTCs		
Addr	ECU/Module descriptor	# of DTCs	Addr	ECU/Module descriptor	# of DTCs
aa	ECU/Module #1	xx	00	Engine	2
aa	ECU/Module #2	xx	03	Transmission	1
...	...	...	0B	ABS/Traction Control	0
aa	ECU/Module #n	xx			

A.3.2 Diagnostic trouble code display

A.3.2.1 ISO 15031-5/ISO 15031-6 protocol DTC display template and examples

The following sample displays provide a list of active DTCs per ECU/module. The left display shows a DTC template and the middle and right displays show examples with DTCs stored in the vehicle's ECU/module.

The DTC template should be the recommended display layout for "Active DTCs, Previously Active DTCs, and Pending DTCs".

Table A.3 — ISO 15031-5/ISO 15031-6 protocol DTC display template and examples, should be used for the ISO 15031-5/ISO 15031-6 based DTC format.

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In the upper left, the selected menu item should be displayed, e.g. "Active DTCs". In the upper right, the ECU/module name (if available) or the ECU/module address e.g. 11, 18, etc. should be displayed. The "DTC #" text string should be followed by the converted DTC number. The "Count" text string indicates the occurrence of a DTC. The occurrence count should be displayed as a three (3) digit decimal number. In the next line the DTC descriptor associated with the DTC number should be displayed as specified in ISO 15031-6. Depending on the display size and features multiple DTCs can be displayed.

Table A.3 — ISO 15031-5/ISO 15031-6 protocol DTC display template and examples

Menu item		Addr	aa	Active DTCs		Addr	11	Active DTCs		Addr	18
DTC #	xxxxx	Count	xxx	DTC #	P0118	Count	---	DTC #	P2700	Count	---
DTC descriptor (ISO 15031-6)				Engine Coolant Temperature Circuit				Transmission Friction Element "A"			
				High				Apply Time Range/Performance			
DTC #	xxxxx	Count	xxx	DTC #	P0113	Count	---				
DTC descriptor (ISO 15031-6)				Intake Air Temperature Circuit High							

A.3.2.2 SAE J1939-73 protocol DTC display template and examples

Table A.4 — SAE J1939-73 protocol DTC display template and examples, should be used for the SAE J1939-73 based DTC format.

The format and layout of the DTC display is the same as specified for the ISO 15031-5/ISO 15031-6 based protocol and DTCs. There is a minor difference in the DTC number format, which derives from a "base DTC number" (DTC circuit) and a "DTC symptom" (DTC failure type). Both values are converted into a single DTC number. The hyphen (-) separates the base DTC number from the DTC symptom. The DTC description is a concatenation of the base DTC text descriptor and the DTC symptom DTC text descriptor.

Table A.4 — SAE J1939-73 protocol DTC display template and examples

Menu item		ECU/Module		Active DTCs		Engine		Active DTCs		Transmission	
DTC #	xxxxxx-xx	Count	xxx	DTC #	110-01	Count	6	DTC #	2908-03	Count	4
DTC descriptor (SAE J1939-73)				Engine Coolant Temperature –				Transmission Boost Pressure Valve			
				Data valid but below normal operational				Actuator – Voltage Above Normal, or			
				Range – Most Severe Level				Shorted to High Source			
DTC #	xxxxxx-xx	Count	xxx	DTC #	105-02	Count	3	DTC #	604-03	Count	1
DTC descriptor (SAE J1939-73)				Intake Manifold 1 Temperature – Data				Transmission Neutral Switch – Voltage			
				Erratic, Intermittent or Incorrect				below normal, or shorted to low source			

A.4 Current/Monitor data display

A.4.1 Current/monitor data display template

As a minimum, the data values of two data items shall be displayed simultaneously. A display of the parameter abbreviation or description of the data items and the ECU's/module's address that supplied the data item(s) shall be displayed with the data values.

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Table A.5 — ISO 15031-5 and SAE J1939-73 protocol current/monitor data display template, shows the layout of the external test equipment data display. The upper row of the display should show the selected menu item e.g. "Current/Monitor Data Display". The left column displays the "Addr" which is the source of the data item. This is the ECU/module address derived from the ISO 15031-5 or SAE J1939-73 message header address information. Each parameter is comprised of a "parameter name", "current/freeze frame data", and the associated "unit" (if parameter is not state encoded).

Table A.5 — ISO 15031-5 and SAE J1939-73 protocol current/monitor data display template

Menu Item (ISO 15031-5)				Menu Item (SAE J1939-73)			
Addr	Parameter description	Data	Unit	Addr	Parameter description	Data	Unit
11	Calculated LOAD Value	xxx.x	%	00	EGR Mass Flow Rate	xxxx.x	kg/h
11	Fuel system 1 status	8 states/1 byte		00	Exhaust Gas Recirculation (EGR) Valve Control	xxx.x	%
11	Engine RPM	xxxxx	min^{-1}	00	Turbo Oil Temperature	xxxx	°C
11	Engine Coolant Temperature	xxx	°C	00	Turbocharger 1 Boost Pressure	xxxx.x	kPa
11	Misfire monitoring supported	2 states/1 bit		00	Turbocharger 1 Compressor Inlet Pressure	xxx.x	kPa
11	Misfire monitoring ready	2 states/1 bit		00	Turbocharger 1 Compressor Inlet Temperature	xxxx	°C
11	Fuel system monitoring supported	2 states/1 bit		00	Engine Test Mode Switch	4 states/2 bit	
11	Fuel system monitoring ready	2 states/1 bit		00	Exhaust Gas Oxygen Sensor Closed Loop Operation	4 states/2 bit	
11	Catalyst monitoring supported	2 states/1 bit		00	Start Enable Device 1	4 states/2 bit	
11	Catalyst monitoring ready	2 states/1 bit		00	Start Enable Device 2	4 states/2 bit	
11	Oxygen sensor monitoring supported	2 states/1 bit		03	Transmission Reverse Direction Switch	4 states/2 bit	
11	Oxygen sensor monitoring ready	2 states/1 bit		00	Particulate Trap Inlet Pressure	xxx	kPa

NOTE The above table illustrates that the format of the data for ISO 15031-5 and SAE J1939-73 can follow the same display layout approach. This table is not meant to compare the data available with one protocol versus the other.

A.4.2 ISO 15031-5 protocol current/freeze frame data display examples

Table A.6 — ISO 15031-5 protocol current/freeze frame data display examples, shows data display examples of current/freeze frame data as defined in the ISO 15031-5 specification. The smaller display on the left shows the parameter acronyms as specified in ISO 15031-2 and -5. The larger display on the right shows the full parameter descriptors as specified in ISO 15031-5. A mixture of parameters from two (2) emissions-related ECUs/modules is also shown in the same display.

Table A.6 — ISO 15031-5 protocol current/freeze frame data display examples

Current/Freeze Frame Data Display				Current/Freeze Frame Data Display			
Addr	Param. description	Data	Unit	Addr	Parameter description	Data	Unit
11	DTCFRZF	P0118		11	DTC that caused required freeze frame data storage	P0118	
11	VSS	0	km/h	11	Vehicle Speed Sensor	0	km/h
11	MIL	ON		11	Malfunction Indicator Lamp (MIL) Status	ON	
11	MIS_SUP	YES		11	Misfire monitoring supported	YES	
11	FUEL_SUP	YES		11	Fuel system monitoring supported	YES	
11	ECT	36	°C	11	Engine Coolant Temperature	36	°C
11	RPM	744	min^{-1}	11	Engine RPM	744	min^{-1}
18	CCM_SUP	YES		18	Comprehensive component monitoring supported	YES	
18	CCM_RDY	NO		18	Comprehensive component monitoring ready	NO	

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A.4.3 SAE J1939-73 protocol current/freeze frame data display examples

Table A.7 — SAE J1939-73 protocol current/freeze frame data display examples, shows data display examples of current/freeze frame data as defined in the SAE J1939-73 specification. The smaller display on the left shows the PGN (Parameter Group Number) acronyms as specified in SAE J1939-73. The larger display on the right shows the full parameter descriptors as specified in SAE J1939-73. A mixture of parameters from two (2) emissions-related ECUs/modules is also shown in the same display.

Table A.7 — SAE J1939-73 protocol current/freeze frame data display examples

Current/Monitor Data Display				Current/Monitor Data Display			
Addr	Param. description	Data	Unit	Addr	Parameter description	Data	Unit
00	DTCFRZF	110-03-05		00	DTC that caused required freeze frame data storage	110-03-05	
03	VSS	0	km/h	03	Vehicle Speed Sensor	0	km/h
00	MIL	ON		00	Malfunction Indicator Lamp (MIL) Status	ON	
00	MIS_SUP	YES		00	Misfire monitoring supported	YES	
00	FUEL_SUP	YES		00	Fuel system monitoring supported	YES	
00	ECT	36	°C	00	Engine Coolant Temperature	36	°C
00	RPM	744	min^{-1}	00	Engine RPM	744	min^{-1}
03	CCM_SUP	YES		03	Comprehensive component monitoring supported	YES	
03	CCM_RDY	NO		03	Comprehensive component monitoring ready	NO	

A.5 Clear DTC information

The display, which belongs to the "Clear DTC Information" menu item, is not specified in this annex. The layout and user interface of this display is the responsibility of the external test equipment manufacturer.

A.6 OBD I/M Readiness Monitor data display

A.6.1 OBD I/M Readiness Monitor selection and test result data display requirements

This clause provides general guidelines for the test equipment manufacturer industry on how to design the technician user interface of the external test equipment to display OBD Monitor data in combination with I/M Readiness status information in a useful manner to support the technician in making meaningful judgements.

All OBD I/M Readiness Monitor templates and displays are based on ISO 15765-4/ISO15031-5 (CAN) protocol derived data. Alternative protocols are not considered because the majority of related data is vehicle manufacturer specific. However, the guidelines provided may be used in a similar manner (e.g. Component ID should be displayed as Monitor ID and Test ID should be displayed as specified below).

When the technician has selected an OBD Monitor, a test equipment screen shall be displayed with ECU/module address, combined Malfunction Indicator Lamp (MIL) status, number of DTCs stored in this ECU, OBD I/M Readiness monitoring status information and OBD Monitor test results (test values/limits).

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Each Test ID shall be displayed with the status of 'Passed', 'Failed' or 'Not Completed'. The overall monitor status, however, should be obtained from service $01 PID $01/$41. An OBD Monitor ID shall be displayed with one or multiple Test IDs (all IDs in hexadecimal notation) and test results with test values and limits depending on the display size and capabilities. The test equipment shall provide appropriate user interface functionality to display all associated Test IDs and values, which belong to a single OBD Monitor ID. Each OBD Monitor ID shall be displayed with the overall monitor status. This information shall be obtained from service $01 PID $01/$41 for the ISO15765-4/ISO 15031-5 protocol and from DM5 and other readiness information services in SAE J1939-73 protocol.

A.6.2 OBD Monitor selection and data display template

A.6.2.1 OBD Monitor selection display template

Table A.8 — OBD I/M Readiness Monitor selection display template, should be used as a recommended guideline for the selection of an OBD Monitor. The left column of the display shows the ECU/module address. The upper row shall be used to display the selected menu item e.g. "OBD Monitor Selection". Each OBD Monitor parameter is displayed with supported status information (Yes/No). OBD Monitor groups may be created to minimize the selection list.

Table A.8 — OBD I/M Readiness Monitor selection display template

Addr	OBD Monitor Selection	
aa	Monitor name (service $01, PID $01/$41)	Status
bb	Monitor name (service $01, PID $01/$41)	Status
cc	Monitor name (service $01, PID $01/$41)	Status
dd	Monitor name (service $01, PID $01/$41)	Status
:	:	:
aa	Monitor name (service $01, PID $01/$41)	Status
bb	Monitor name (service $01, PID $01/$41)	Status

A.6.2.2 OBD Monitor selection display example

Most often, only one ECU/module will support each of the OBD I/M Readiness Monitors. The Comprehensive component monitor should be supported by all emissions-related ECUs/modules. The following example shows a list of supported and unsupported OBD I/M Readiness Monitors:

— Engine:	Misfire monitoring supported	Yes	(service $01, PID $01)
— Engine:	Fuel system monitoring supported	Yes	(service $01, PID $01)
— Engine:	Catalyst monitoring supported	Yes	(service $01, PID $01)
— Engine:	Heated catalyst monitoring supported	No	(service $01, PID $01)
— Engine:	Evaporative system monitoring supported (0.020")	Yes	(service $01, PID $01)
— Engine:	Secondary air system monitoring supported	No	(service $01, PID $01)
— Engine:	A/C system refrigerant monitoring supported	No	(service $01, PID $01)
— Engine:	Oxygen sensor monitoring supported	Yes	(service $01, PID $01)
— Engine:	Oxygen sensor heater monitoring supported	Yes	(service $01, PID $01)
— Engine:	EGR system monitoring supported	No	(service $01, PID $01)
— Engine:	Comprehensive component monitoring supported	Yes	(service $01, PID $01)
— Transmission:	Comprehensive component monitoring supported	Yes	(service $01, PID $01)

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Table A.9 — OBD I/M Readiness Monitor selection display example, is an example of how to provide OBD I/M Readiness Monitor selection to the technician. The test equipment shall provide a select capability e.g. by cursor, by function key, etc. to allow the technician to view the test results of the selected OBD I/M Readiness status and OBD Monitor.

It is recommended to show all OBD I/M Readiness Monitors, even if a monitor is not supported. This way, data can be seen even if a calibration weakness specifies a monitor, which is supported by the software but not enabled in the calibration (appropriate bit set to 'not supported'). The option to show only supported monitors can be used as well.

The left column of the display shows the ECU/module address. The upper row is used to display the selected menu item e.g. "OBD I/M Readiness Monitor Selection". Each OBD I/M Readiness Monitor parameter is displayed with supported status information (Yes/No).

Table A.9 — OBD I/M Readiness Monitor selection display example

Addr	OBD I/M Readiness Monitor Selection	Supported Status
11	Misfire monitoring supported	Yes
11	Fuel system monitoring supported	Yes
11	Catalyst monitoring supported	Yes
11	Heated catalyst monitoring supported	No
11	Evaporative system monitoring supported (0,020")	Yes
11	Secondary air system monitoring supported	No
11	A/C system refrigerant monitoring supported	No
11	Oxygen sensor monitoring supported	Yes
11	Oxygen sensor heater monitoring supported	Yes
11	EGR system monitoring supported	No
11	Comprehensive component monitoring supported	Yes
18	Comprehensive component monitoring supported	Yes

A.6.3 OBD I/M Readiness Monitor data display

A.6.3.1 OBD I/M Readiness Monitor data display template

Table A.10 — OBD I/M Readiness Monitor data display template, should be used as a recommended guideline for combination of service $01 PID $01/$41 monitor status and service $06 OBD Monitor data items as specified in ISO 15031-5 and the appropriate diagnostic message defined in SAE J1939-73. The display below shows an OBD Monitor template to display "Malfunction Indicator Lamp (MIL) Status", "Number of DTCs stored in this ECU", "OBD Monitor ID Text Descriptor" for monitoring ready, cycle enabled, cycle completed status, "Test ID(s)", Test ID(s) "Result", "Minimum Test Limit", "Test Value", "Maximum Test Limit", and the associated "data" and "unit".

The Test ID "Result" shall be calculated by the test equipment according to the following equations:

— Passed = (Minimum Test Limit <= Test Value) AND (Test Value <= Maximum Test Limit)
— Failed = (Minimum Test Limit > Test Value) OR (Test Value > Maximum Test Limit)
— Not Completed = (Minimum Test Limit = 0) AND (Test Value = 0) AND (Maximum Test Limit = 0)

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Table A.10 — OBD I/M Readiness Monitor data display template

Addr	($xx) 'Selected OBD Monitor Text Descriptor' data display	Status	
aa	Malfunction Indicator Lamp (MIL) Status	(service $01, PID $01)	
aa	Number of DTCs stored in this ECU	(service $01, PID $01)	
aa	OBD Monitor ID Text Description (monitoring ready)	(service $01, PID $01)	
aa	OBD Monitor ID Text Description (cycle enabled)	(service $01, PID $41)	
aa	OBD Monitor ID Text Description (cycle completed)	(service $01, PID $41)	
aa	Test ID	xx	Result
aa	Minimum Test Limit	xxxxx	Unit
aa	Test Value	xxxxx	Unit
aa	Maximum Test Limit	xxxxx	Unit
aa	:	:	:
aa	Test ID	xx	Result
aa	Minimum Test Limit	xxxxx	Unit
aa	Test Value	xxxxx	Unit
aa	Maximum Test Limit	xxxxx	Unit

A.6.3.2 OBD I/M Readiness Monitor data display example

This example assumes the ISO 15765-4/ISO15031-5 protocol is identified.Table A.11 — OBD I/M Readiness Monitor data display example, displays data items which were received from one emissions-related ECU/module (see Addr. 11 hex). It shows that only parts of the enabled Evaporative system are completed (e.g. which is caused by the leak size). The Evaporative system monitoring cycle can show completed based on service $01 PID $01 response data, but it is very likely that some of the Evaporative system monitoring cycle Test IDs will show "Passed"/"Failed", yet others will show "Not Completed". If service $01 PID $01 response data shows the monitor as complete, then it is done, even if not every test within that monitor has run.

The following parameters shall be displayed for the Evaporative system:

— Evaporative system monitoring ready:		YES	(service $01, PID $01)
— Evaporative system monitoring cycle enabled:		YES	(service $01, PID $41)
— Evaporative system monitoring cycle completed:		NO	(service $01, PID $41)
— Evaporative system monitor (0,020"):		3C	(service$06, Monitor ID $3C)
— Test ID:	1	Passed	(service $06, Test ID number)
— Minimum Test Limit:		0 kPa	(service $06, Minimum Test Limit Value)
— Test Value:		0.67 kPa	(service $06, Test Value)
— Maximum Test Limit:		1.74 kPa	(service $06, Maximum Test Limit Value)
— Test ID:	2	Failed	(service $06, Test ID number)
— Minimum Test Limit:		0 kPa	(service $06, Minimum Test Limit Value)
— Test Value:		0.72 kPa	(service $06, Test Value)
— Maximum Test Limit:		0.62 kPa	(service $06, Maximum Test Limit Value)
— Test ID:	3	Not Completed	(service $06, Test ID number)
— Minimum Test Limit:		0 kPa	(service $06, Minimum Test Limit Value)
— Test Value:		0 kPa	(service $06, Test Value)
— Maximum Test Limit:		0 kPa	(service $06, Maximum Test Limit Value)

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Table A.11 — OBD I/M Readiness Monitor data display example

Addr	(3C) Evaporative system monitor (0.020") data display		
11	Malfunction Indicator Lamp (MIL) Status	On	
11	Number of DTCs stored in this ECU	2	
11	Evaporative system monitor (0,020") ID	3C	
11	Evaporative system monitoring ready (0,020")	Yes	
11	Evaporative system monitoring cycle enabled (0,020")	Yes	
11	Evaporative system monitoring cycle co mpleted (0,020")	No	
11	Test ID	1	Passed
11	Minimum Test Limit	0	kPa
11	Test Value	0.67	kPa
11	Maximum Test Limit	1.74	kPa
11	Test ID	2	Failed
11	Minimum Test Limit	0	kPa
11	Test Value	0.72	kPa
11	Maximum Test Limit	0.62	kPa
11	Test ID	3	Not Completed
11	Minimum Test Limit	0	kPa
11	Test Value	0	kPa
11	Maximum Test Limit	0	kPa

A.7 Vehicle and ECU identification data display

A.7.1 Identification data display template

The following identification data display template should be used as a recommended guideline for service $09 Read vehicle information InfoTypes as specified in ISO 15031-5 and for the appropriate diagnostic message defined in SAE J1939-73.

In Table A.12 — Identification data display template, the left column of the display shows the ECU/module address. The upper row is used to display the selected menu item e.g. "Identification Data". Each row of the display should show an InfoType comprised of an "InfoType Text Descriptor" and identification "data". A space separator (ASCII 20 hex) is inserted between numbers, which consist of more than four (4) digits e.g. VIN, Calibration ID, CVN, etc. to ease readability of large numbers.

InfoTypes, which belong together, should be listed next to each other.

Table A.12 — Identification data display template

Addr	Menu item	
aa	InfoType #2	x xxxx xxxx xxxx xxxx
aa	InfoType #4	xx xxxx xxxx
aa	InfoType #6	xx xx xx xx
aa	InfoType #4	xx xxxx xxxx
aa	InfoType #6	xx xx xx xx

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A.7.2 Identification data display example

This Identification data display example shows data items which were received from two (2) emissions-related ECUs/modules (see Addr. 11, 18). The data items and numbers derive from the example section of service $09 as specified in ISO 15031-5.

In Table A.13 — Identification data display example, the display on the left is shown with abbreviated terms and the display on the right shows full descriptors as defined in ISO 15031-5.

Table A.13 — Identification data display example

Addr	ID. Data	ECU/Module	Addr	Identification Data	Engine
11	VIN	1 G1JC 5444 R725 2367	11	VIN	1 G1JC 5444 R725 2367
11	CALID#1	JMB* 3676 1500	11	Calibration ID#1	JMB* 3676 1500
11	CVN#1	1791 BC82	11	Calibration Verification Number #1	1791 BC82
11	CALID#2	JMB* 4787 2611	11	Calibration ID#2	JMB* 4787 2611
11	CVN#2	16E0 62BE	11	Calibration Verification Number #2	16E0 62BE
18	CALID#1	JMA* 4312 9911 0000	18	Calibration ID#1	JMA* 4312 9911 0000
18	CVN#1	9812 3476	18	Calibration Verification Number #1	9812 3476

A.8 Activate OBD tests

The display, which belongs to the "Activate OBD Tests" menu item, is not specified in this annex. The layout and user interface of this display are the responsibility of the external test equipment manufacturer.

A.9 In-use performance tracking data display

A.9.1 IPT (In-use performance tracking) data display template

The In-Use Performance Tracking (IPT) data items as specified in ISO 15031-5 and SAE J1939-73 shall be displayed to show the current counts of each IPT data item.

The following In-Use Performance Tracking (IPT) template should be used to display IPT data items as specified in ISO 15031-5 and SAE J1939-73.

In Table A.14 — IPT (In-use performance tracking) data display template, the left column of the display shows the ECU/module address. The upper row shall be used to display the selected menu item e.g. "In-Use Performance Tracking".

Each row displays the "IPT Data Item Text Descriptor", Number (xxxxx) and Unit.

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Table A.14 — IPT (In-use performance tracking) data display template

Addr	Menu item		
aa	IPT Data Item #1 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #2 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #3 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #4 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #5 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #6 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #7 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #8 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #9 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #10 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #11 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #12 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #13 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #14 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #15 Text Descriptor	xxxxx	Unit
aa	IPT Data Item #16 Text Descriptor	xxxxx	Unit

A.9.2 IPT (In-use performance tracking) data display example

This IPT data display example shows data items which were received from one emissions-related ECU/module (see Addr. 11). The data items and numbers derive from the example section of service $09 as specified in ISO 15031-5 or service DM20 specified in SAE J1939-73.

In Table A.15 — Display in-use performance tracking data example, the display on the left is shown with abbreviated terms and the display on the right shows full descriptors as defined in ISO 15031-5.

Table A.15 — Display in-use performance tracking data example

Addr	Menu item			Addr	In-Use Performance Tracking Data		
11	OBDCOND	1024	counts	11	OBD Monitor Conditions Encountered Counts	1024	counts
11	IGNCYCCNTR	3337	counts	11	Ignition Cycle Counter	3337	counts
11	CATCOMP1	824	counts	11	Catalyst Monitor Completion Counts Bank 1	824	counts
11	CATCOND1	945	counts	11	Catalyst Monitor Conditions Encountered Counts Bank 1	945	counts
11	CATCOMP2	711	counts	11	Catalyst Monitor Completion Counts Bank 2	711	counts
11	CATCOND2	945	counts	11	Catalyst Monitor Conditions Encountered Counts Bank 2	945	counts
11	O2SCOMP1	737	counts	11	O2 Sensor Monitor Completion Counts Bank 1	737	counts
11	O2SCOND1	924	counts	11	O2S Monitor Conditions Encountered Counts Bank 1	924	counts
11	O2SCOMP2	724	counts	11	O2 Sensor Monitor Completion Counts Bank 2	724	counts
11	O2SCOND2	833	counts	11	O2S Monitor Conditions Encountered Counts Bank 2	833	counts
11	EGRCOMP	997	counts	11	EGR/VVT Monitor Completion Condition Counts	997	counts
11	EGRCOND	1010	counts	11	EGR/VVT Monitor Conditions Encountered Counts	1010	counts
11	AIRCOMP	937	counts	11	AIR Monitor Completion Condition Counts (Sec. Air)	937	counts
11	AIRCOND	973	counts	11	AIR Monitor Conditions Encountered Counts (Sec. Air)	973	counts
11	EVAPCOMP	68	counts	11	EVAP Monitor Completion Condition Counts	68	counts
11	EVAPCOND	97	counts	11	EVAP Monitor Conditions Encountered Counts	97	counts

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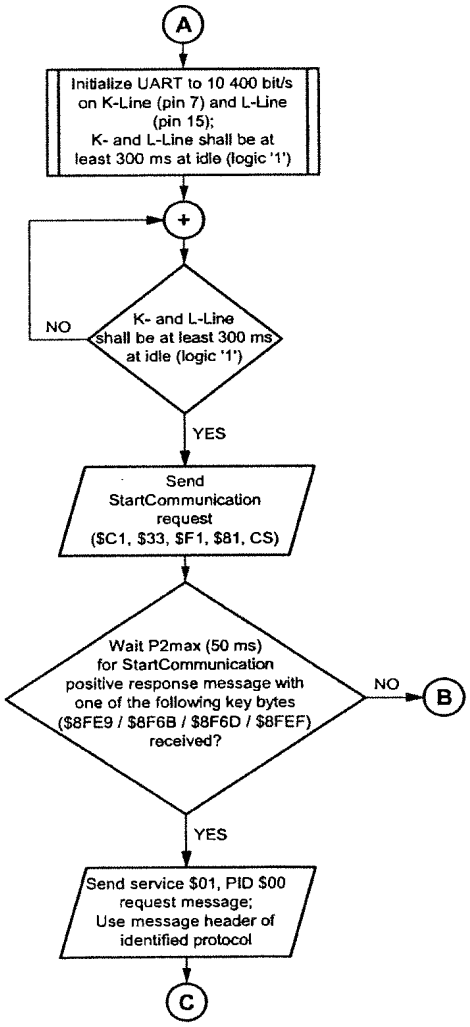
Annex B
(normative)

Initialization and identification of ISO 14230-4/ISO 9141-2 protocols

This annex describes the principle initialization of ISO 14230-4/ISO 9141-2 to be performed by the external test equipment.

B.1 ISO 14230-4 – Fast initialization

ISO 14230-4 specifies two (2) different methods of initializing the protocol. This section specifies the "Fast Initialization" sequence. The external test equipment expects the ISO 14230-4 protocol being supported by the server/ECU. Figure B.1 — Fast initialization of ISO 14230-4 Keyword protocol 2000, specifies the external test equipment "Fast Initialization" sequence of ISO 14230-4 protocol.



Key

A start fast initialization

B protocol is NOT ISO 14230-4 with fast initialization support

C protocol is ISO 14230-4 with fast initialization support

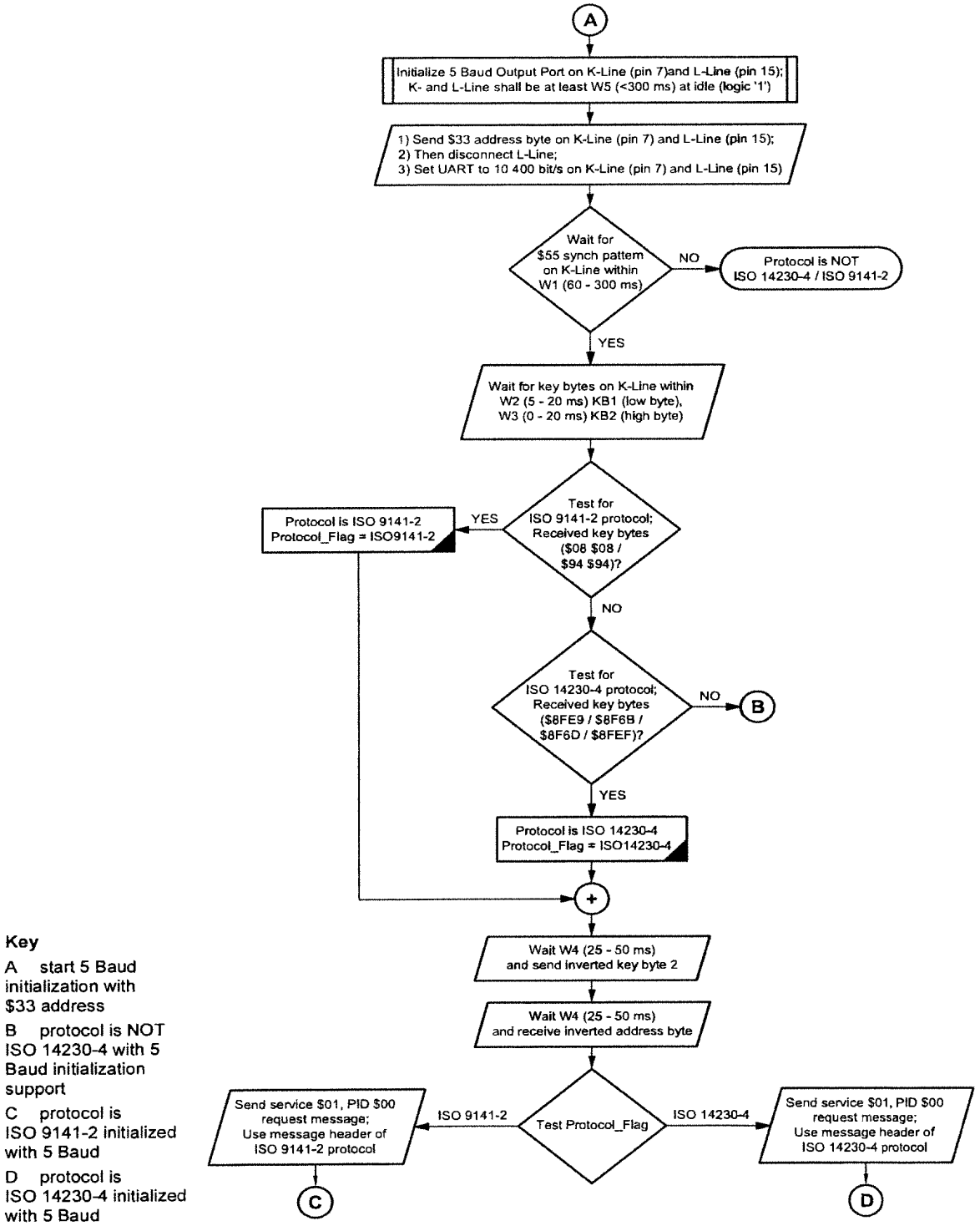
Figure B.1 — Fast initialization of ISO 14230-4 Keyword protocol 2000

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B.2 ISO 14230-4 / ISO 9141-2 - 5 baud initialization

This section specifies the "5 Baud Initialization" sequence of ISO 14230-4/ISO 9141-2. The external test equipment expects either the ISO 14230-4 or the ISO 9141-2 protocol being supported by the server/ECU. Figure B.2 — 5 Baud initialization of ISO 14230-4 / ISO 9141-2 protocol, specifies the external test equipment "5 Baud Initialization" sequence of ISO 9141-2/ISO 14230-4 protocols.

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Key

A start 5 Baud initialization with $33 address

B protocol is NOT ISO 14230-4 with 5 Baud initialization support

C protocol is ISO 9141-2 initialized with 5 Baud

D protocol is ISO 14230-4 initialized with 5 Baud

Figure B.2 — 5 Baud initialization of ISO 14230-4 / ISO 9141-2 protocol

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B.3 Key bytes indicating support of ISO 15031-5 services

Each K-Line protocol ISO 14230-4 and ISO 9141-2 support several key bytes, which indicate to the external test equipment which header and timing parameter set shall be used for subsequent communication.

B.3.1 ISO 14230-4 protocol defined key bytes

For legislated diagnostics ISO 14230-4 and ISO 9141-2 are allowed on the K-Line. Table B.1 — ISO 14230-4 key bytes, specifies the key bytes to be supported by the external test equipment.

Table B.1 — ISO 14230-4 key bytes

Key byte #2 High Byte	Key byte #1 Low Byte	Description	Normal timing
0x8F	0xE9	Key byte = 2025_{10}: 3 byte header including target and source address	P1 = 0 – 20 ms P2 = 25 – 50 ms P3 = 55 – 5000 ms P4 = 0 – 20 ms
0x8F	0x6B	Key byte = 2027_{10}: 3 byte header including target and source address, with or without additional length byte	
0x8F	0x6D	Key byte = 2029_{10}: 1 byte header or 3 byte header including target and source address	
0x8F	0xEF	Key byte = 2031_{10}: 1 byte header or 3 byte header including target and source address, with or without additional length byte	

The key bytes inform the external test equipment about the message format (header type), which shall be used by the server/ECU and external test equipment for all consecutive message exchange.

The following apply to an emissions-related server/ECU:

— all emissions-related servers/ECUs in a vehicle shall implement the identical key bytes in order to exchange emissions-related information with the same request and response message format,

— emissions-related servers/ECUs may have different key bytes if installed in a different family of vehicles even if the server/ECU hardware and principle communication software derives from a similar vehicle family,

— the request and response message format for enhanced diagnostic communication in emissions-related servers/ECUs shall use the identical key bytes as implemented for emissions-related diagnostics as reported during the initialization,

— if the initialization sequence specified in ISO 9141-2 and ISO 14230-2 is completed successfully, then ISO 9141-2 or ISO 14230-4 shall be the vehicle's OBD protocol.

B.3.2 ISO 9141-2 protocol defined key bytes

Table B.2 — ISO 9141-2 key bytes specifies the key bytes, to be supported by the external test equipment.

Table B.2 — ISO 9141-2 key bytes

Key byte #2 High Byte	Key byte #1 Low Byte	Description	Timing parameter
0x08	0x08	Key byte = $1\ 032_{10}$: this key byte informs the external test equipment that the server(s)/ECU(s) shall wait at least P_2min = 25 ms when sending a response message	P1 = 0 – 20 ms **P2 = 25 – 50 ms** P3 = 55 – 5 000 ms P4 = 0 – 20 ms
0x94	0x94	Key byte = $2\ 580_{10}$: this key byte informs the external test equipment that the server(s)/ECU(s) may send the response message immediately (P_2min = 0 ms) after receiving a request message	P1 = 0 – 20 ms **P2 = 0 – 50 ms** P3 = 55 – 5 000 ms P4 = 0 – 20 ms

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B.4 Examples of byte flow and timing measured on the K-Line

The following tables show traces on the K-Line of ISO 14230-4 protocol with fast and 5 baud initialization and ISO 9141-2 protocol to show the bytes which are the same and which are different.

B.4.1 Byte flow and timing example of ISO 14230-4 with fast initialization

This example shows a K-Line data acquisition between external test equipment and a vehicle equipped with two (2) emissions-related servers/ECUs (ECM and TCM). The external test equipment uses the fast initialization of ISO 14230-4 Keyword protocol 2000. After the successful initialization, the external test equipment requests supported PIDs (PID $00) of service $01 as specified in ISO 15031-5.

The left column in Table B.3 — Byte flow and timing example of ISO 14230-4 with fast initialization, shows the time between bytes (stop bit of last byte and start bit of next byte). The next column shows the bytes as recorded on the K-Line. The 3rd column shows the "Msg. Type" (message type) either "Request" or "Response". The column on the right includes a description of each byte.

Table B.3 — Byte flow and timing example of ISO 14230-4 with fast initialization

Fast initialization with $33 address		Msg. Type	Description of data bytes
Time in ms between bytes	Byte in hex		
N/A	N/A		Wake-up pattern
N/A	C1	Request	Functional addressing, length = 1 data byte
7,4	33		Target address (emissions-related ECUs)
7,3	F1		Source address (external test equipment/OBD Scan Tool)
7,5	81		Service Identifier of StartCommunication request message
7,2	66		Checksum
28,4	83	Response #1	Physical addressing, length = 3 data bytes
3,2	F1		Target address (external test equipment/OBD Scan Tool)
3,6	11		Source address ECM
3,4	C1		Service Identifier of StartCommunication positive response message
3,1	E9		Key byte #1 (Low byte): 2025 decimal
3,2	8F		Key byte #2 (High byte): 2025 decimal
3,5	BE		Checksum
35,1	83	Response #2	Physical addressing, length = 3 data bytes
5,2	F1		Target address (external test equipment/OBD Scan Tool)
5,6	18		Source address TCM
5,4	C1		Service Identifier of StartCommunication positive response message
5,1	EF		Key byte #1 (Low byte): 2031 decimal
5,2	8F		Key byte #2 (High byte): 2031 decimal
5,5	CB		Checksum
71,6	C2	Request	Functional addressing, length = 1 data byte
6,2	33		Target address
6,2	F1		Source address (external test equipment/OBD Scan Tool)
6,2	01		Service request $01
6,2	00		PID $00 (request supported PIDs)
6,2	E7		Checksum

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Table B.3 (*continued*)

Fast initialization with $33 address		Msg. Type	Description of data bytes
Time in ms between bytes	Byte in hex		
29,4	86	Response #1	Header response
3,2	F1		Target address (external test equipment/OBD Scan Tool)
3,6	11		Source address ECM
3,4	41		Service response $41, PID $00
3,1	00		Echo of PID $00 (request supported PIDs)
3,2	BF		Supported PID data byte #1 (support for PIDs 01, 03-08)
3,5	BF		Supported PID data byte #2 (support for PIDs 09, 0B-10)
3,4	A8		Supported PID data byte #3 (support for PIDs 11, 13, 15)
3,3	91		Supported PID data byte #4 (support for PIDs 19, 1C, 20)
3,7	80		Checksum
35,1	86	Response #1	Header response
5,2	F1		Target address (external test equipment/OBD Scan Tool)
5,6	18		Source address TCM
5,4	41		Service response $41, PID $00
5,1	00		Echo of PID $00 (request supported PIDs)
5,2	80		Supported PID data byte #1 (support for PID 01)
5,5	01		Supported PID data byte #2 (support for PID 0D)
5,4	00		Supported PID data byte #3 (no support for PIDs 11-18)
5,3	00		Supported PID data byte #4 (no support for PIDs 19-20)
5,6	51		Checksum
130,7	C2	Request	Next Request
:	:		:
:	:		:

B.4.2 Byte flow and timing example of ISO 14230-4 / ISO 9141-2 protocol

This example shows a K-Line data acquisition between external test equipment and a vehicle equipped with two (2) emissions-related servers/ECUs (ECM and TCM). Both protocols, ISO 14230-4 and ISO 9141-2 are shown in parallel to illustrate differences and commonalities. The external test equipment uses the 5 Baud initialization without knowing which protocol is supported on the K-Line. After the interpretation of the key bytes the external test equipment inverts the key byte #2 and sends it to the vehicle. The vehicle servers/ECUs respond with the inverted 5 baud address byte. After the successful initialization the external test equipment requests supported PIDs (PID $00) of service $01 as specified in ISO 15031-5.

ISO 14230-4: The left column in Table B.4 — Byte flow and timing example of ISO 14230-4 / ISO 9141-2 protocol, shows the time between bytes (stop bit of last byte and start bit of next byte). The next column shows the bytes as recorded on the K-Line.

ISO 9141-4: The third column in Table B.4 — Byte flow and timing example of ISO 14230-4 / ISO 9141-2 protocol, shows the time between bytes (stop bit of last byte and start bit of next byte). The fourth column shows the bytes as recorded on the K-Line.

The fifth column shows the "Msg. Type" (message type) either "Request" or "Response". The column on the right includes a description of each byte.

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Table B.4 — Byte flow and timing example of ISO 14230-4 / ISO 9141-2 protocol

5 Baud initialization with $33 address				Msg. Type	Description of data bytes
ISO 14230-4		ISO 9141-2			
Time in ms between bytes	Byte in hex	Time in ms between bytes	Byte in hex		
173,5	55	186,4	55	N/A	Synchronization byte at 10400 bit/s
10,0	E9	10,1	08	N/A	ISO 14230-4: Key byte #1 (Low byte): 2025 decimal ISO 9141-2: Key byte #1 (Low byte): 1032 decimal
10,0	8F	10,1	08	N/A	ISO 14230-4: Key byte #2 (High byte): 2025 decimal ISO 9141-2: Key byte #2 (Low byte): 1032 decimal
31,0	70	31,0	F7	N/A	Inverted Key byte #2
29,0	CC	29,3	CC	N/A	Inverted 5 baud address byte
71,6	C2	70,8	68	Request	1st header byte
10,2	33	10,2	6A		2nd header byte
10,2	F1	10,2	F1		Source address (external test equipment/OBD Scan Tool)
10,2	01	10,2	01		Service request $01
10,2	00	10,2	00		PID $00 (request supported PIDs)
10,2	E7	10,2	C4		Checksum
37,5	86	39,1	48	Response #1	1st header byte
3,0	F1	3,0	6B		2nd header byte
3,4	11	3,4	11		Source address ECM
3,4	41	3,4	41		Service response $41, PID $00
3,1	00	3,1	00		Echo of PID $00 (request supported PIDs)
3,2	BF	3,2	BF		Supported PID data byte #1 (support for PIDs 01, 03-08)
3,5	BF	3,5	BF		Supported PID data byte #2 (support for PIDs 09, 0B-10)
3,4	A8	3,4	A8		Supported PID data byte #3 (support for PIDs 11, 13, 15)
3,3	91	3,3	91		Supported PID data byte #4 (support for PIDs 19, 1C, 20)
3,7	80	3,7	BC		Checksum
41,5	86	41,5	48	Response #1	1st header byte
3,0	F1	3,0	6B		2nd header byte
5,6	18	5,6	18		Source address TCM
5,4	41	5,4	41		Service response $41, PID $00
5,1	00	5,1	00		Echo of PID $00 (request supported PIDs)
5,2	80	5,2	80		Supported PID data byte #1 (support for PID 01)
5,5	01	5,5	01		Supported PID data byte #2 (support for PID 0D)
5,4	00	5,4	00		Supported PID data byte #3 (no support for PIDs 11-18)
5,3	00	5,3	00		Supported PID data byte #4 (no support for PIDs 19-20)
5,6	51	5,6	1A		Checksum
130,7	C2	130,7	C2	Request	Next Request
:	:	:	:		:
:	:	:	:		:

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Yongwan Park
Fumiyuki Adachi
Editors

Enhanced Radio Access Technologies for Next Generation Mobile Communication



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Geotab v. Omega

Enhanced Radio Access Technologies for Next Generation Mobile Communication

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CHAPTER 1

OVERVIEW OF MOBILE COMMUNICATION

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Abstract: Following chapter introduces the mobile communication, gives a short history of wireless communication evolution, and highlights some application scenarios predestined for the use of mobile devices. Cellular and wireless based systems related to different generations of mobile communication, including GSM, IS-95, PHS, AMPS, D-AMPS, cdma2000 and WCDMA are also described by this Chapter. Much attention in this chapter is given to express the wireless based networks, such as Wi-Fi and WiBro/WiMax, and wireless broadcasting systems, including DMB, DVB-H, and ISDB-T. We conclude the chapter with the future vision of mobile communication evolution

Keywords: mobile communication; wireless communication; first generation (1G); second generation (2G); thirdgeneration (3G); IMT-2000; UMTS; WCDMA; cdma2000; TDSCDMA; IEEE 802.11; WiFi-; IEEE 802.15; Bluetooth; UWB; WiBro; WiMax; wireless broadcasting; DMB; DVB-H; ISDB-T; OFDMA; MC DS-CDMA

1. INTRODUCTION TO MOBILE COMMUNICATION SYSTEM

To this day, there have been three different generations of mobile communication networks. First-generation of (1G) wireless telephone technologies are the analog cell phone standards that were introduced in the 80s and continued until being replaced by **2G** digital cell phones in 1990s. Example of such standards are **NMT** (Nordic Mobile Telephone), used in Nordic countries, **NTT** system in Japan, and the **AMPS** (Advanced Mobile Phone System) operated in the United States. The second-generation (**2G**) technology is based on digital cellular technology. Examples of the 2G are the Global System for Mobile Communications (**GSM**), Personal Digital Cellular (**PDC**), and North American version of CDMA standard (**IS-95**). The third generation (**3G**) started in October 2001 when **WCDMA** network was launched in Japan. The services associated with 3G provide the ability to transfer both voice data (a telephone call) and non-voice data (such as downloading information, exchanging email, and instant messaging).

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Technology	1G	2G	2.5G	3G	3.5G	4G
Standard	AMPS, TACS, NMT, ETC.	TDMA, CDMA, GSM, PDC	GPRS, EDGE, 1×RTT	WCDMA, CDMA2000	HSDPA WiBro(Mobile WiMax)	Single standard
Implementation	1984	1991	1999	2002	2006	2010
Data Rate	1.9Kbps	14.4Kbps	384Kbps	2Mbps	10 ~ 50Mbps	100Mbps ~ 1Gbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	CDMA, OFDMA	CDMA, OFDMA, ?
Service	Analog voice, synchronous data to 9.5 Kbps	Digital voice, Short messages	Higher capacity, packetized data	Higher capacity, broadband data up to 2Mbps	Portable Internet, High speed Wireless Internet, multimedia	Higher capacity, completely IP oriented, multimedia, data up to 1Gbps



Figure 1. Mobile communication generations

Figure 1 illustrates a brief overview on each generation. More detail information about mobile communication evolution steps is given in section 2.

The advances in cellular systems, wireless LANs, wireless MANs, personal area networks (PANs), and sensor networks are bound to play a significant role in the people communication manner in the future. It is expected that in the following years most of the access part of the Internet will be wireless. Increasing capacity and data rate of mobile communication systems enable to develop extended applications and services. **Figure 2** demonstrates some application environments and modern services focusing on South Korea and Japan's markets and technology trends. The current and awaited mobile services in these countries can be viewed as follows:

E-mail: This is a killer application regardless of the mobile network generation. The e-mail applications both send a message to other mobile phone or to anyone who has an Internet e-mail address. Mobile terminals also can receive e-mail. Low cost and fully compatibility with normal Internet e-mail makes this service popular among the mobile Internet users.

Web Browsing: Although mobile browsing is not popular everywhere today, it is very likely that within next ten years from now, mobile phone users will connect to Internet and use a mobile browser as an everyday tool. But this requires that the mobile browsing user experience improves: connection speed, number of services, and usability must increase, while cost per byte must decrease. While 2G networks allow predominantly text-based HTML browsing, 2.5G and 3G mobile terminals with TFT displays with 262,144 colors enables mobile users to browse Internet contents with high quality.

Two candidates aimed to enabling the Web browsing application to be built with wireless technology. One of them is Wireless Application Protocol (WAP) which was designed to provide services equivalent to a Web browser with some mobile-specific additions, being specifically designed to address the limitations of very small portable devices. The Japanese *i-mode* system is the other major competing wireless data protocol. WAP was hyped at the time of its introduction, leading users to expect WAP to have the performance of the Web. In terms of speed, ease of use, appearance, and interoperability, the reality fell far short of expectations. This led

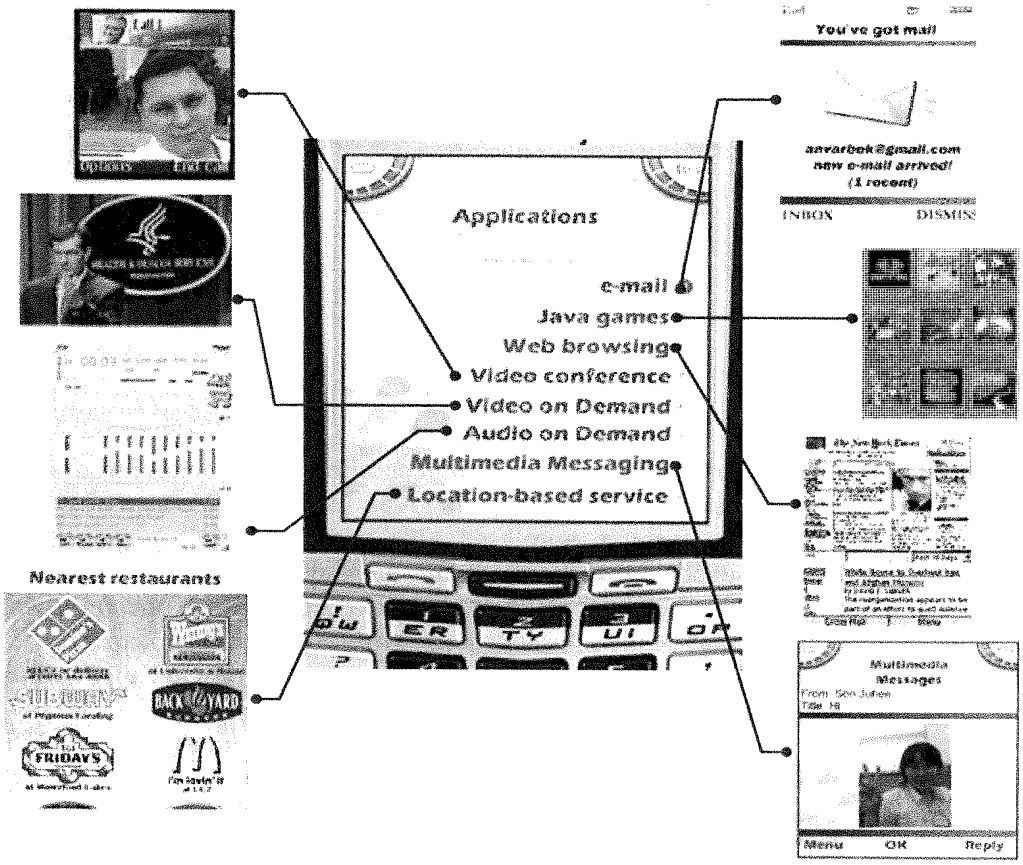


Figure 2. Mobile applications

to the wide usage of sardonic phrases such as "Worthless Application Protocol", "Wait And Pay", and so on. While WAP did not succeed, *i-mode* soon became a tremendous success. *i-mode* phones have a special *i-mode* button for the user to access the start menu. There are numerous official sites – and even more unofficial ones – that can be made available by anyone, using HTML and with access to a standard Web server. As of June 2005, *i-mode* has 45 million customers in Japan and over 5 million in the rest of the world.

Multimedia Messaging Service (MMS) is a technology for transmitting not only text messages, but also various kinds of multimedia content (e.g. images, audio, and/or video clips) over wireless telecommunications networks. MMS-enabled mobile phones enable mobile users to compose and send messages with one or more multimedia parts. Mobile phones with built-in or attached cameras, or with built-in MP3 players are very likely to also have an MMS messaging client – a software program that interacts with the mobile subscriber to compose, address, send, receive, and view MMS messages.

Java Application: Most recent mobile devices are able to run wide variety of Java-based applications. It was expected that Java capable phones will be used for financial services and other e-commerce businesses, but however main Java-based applications are the video games. NTT DoCoMo was the first carrier globally to introduce Java to mobile phones and for games on mobile phones. Since the start of *i-mode* in February 1999, the global development of mobile games has been pioneered and is driven by *i-mode* games. Java runs atop a Virtual Machine (called the KVM) which allows reasonable, but not complete, access to the functionality of the underlying phone. This extra layer of software provides a solid barrier of protection which seeks to limit damage from erroneous or malicious software. It also allows Java applications to move freely between different types of phone (and other mobile device) containing radically different electronic components, without modification.

Videoclip/Music Download: Current 3G networks allow mobile users to download video and audio content with enhanced speeds of up to 384 Kbps. Recent mobile devices with built in multimedia players and high resolution displays can access to rich content of video clips, movie trailers, music files, news highlights and so on.

Video phone: Visual phone service which is capable of both audio and video duplex transmission is a typically on the top of the 3G networks. This service utilizes a circuit switch connection with 64 Kbps.

Location-dependent services: Contemporary mobile networks offer the opportunity to employ recently developed position-determining devices and to offer many new and interesting location-dependent services. In many cases it is important for an application to know something about the location or the user might need location information for further activities. In 2001 Japanese company NTT DoCoMo launched the first location-dependent Web browsing service. The service delivers mobile users a broad range of location-specific Web content. The location estimation accuracy depends on cell size and the associated base station. The mobile user can gain access to cell-range information such as restaurants, hotels, shopping centers, and download relevant maps. On April 2004 Korean SK Telecom also launched the commercial Location-Based Service, called "Becktermap". Unlike existing Location-Based Services that show the location by downloading a complete map like a photo, the Becktermap service directly draws a map with a specific location on the cellular screen. It does this by downloading its configuration information from base stations or a Global Positioning System. This service includes weather conditions at the location, discount information at department stores, nearby restaurant information, and the changing location information of the pedestrian.

Future location based service systems will use both GPS and network information, and will support the interoperability between outdoor (GPS, Cellular, etc.) and indoor (based on WLAN, UWB, etc.) localization and tracking systems.

Figure 3 shows the mobile communication services and applications evolution towards 3G. Today's mobile users already comprise some, but future users will comprise many mobile communication systems and mobility aware applications.

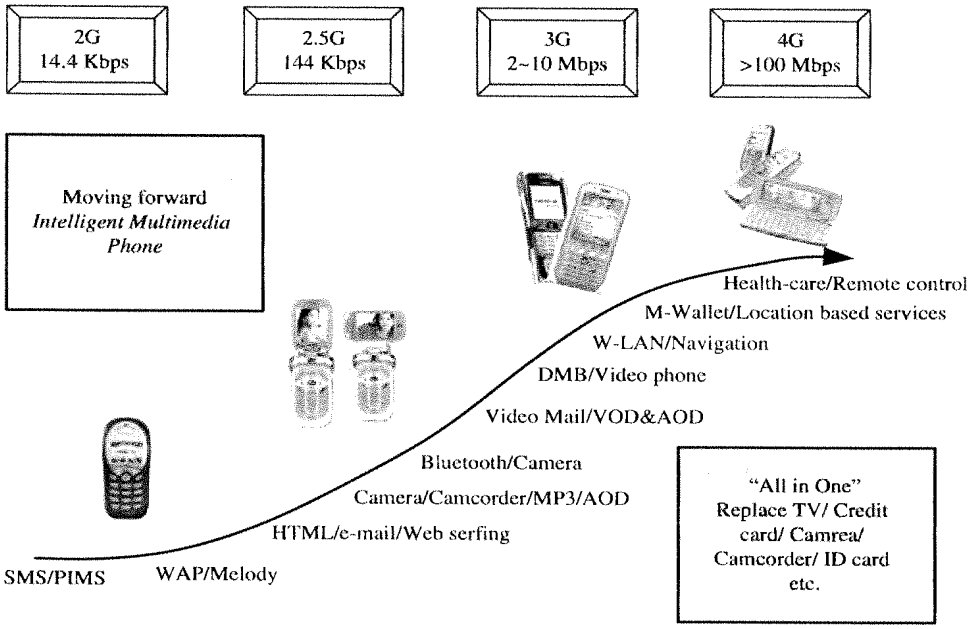


Figure 3. Mobile applications and services evolution

Music, news, road conditions, weather and financial reports, business information, infotainment and others are received via digital audio broadcasting (DAB) with 1.5 Mbps. DMB (Digital Multimedia Broadcasting) allows to transmit data, radio and TV to mobile devices. For personal communication a UMTS phone might be available offering voice and data connectivity with 384 Kbps. Satellite communications can be used for remote areas, while the current position of mobile user is determined using GPS.

In the next generation the cell phone will be an important mobile platform for daily life tools. The machine-to-machine services such as remote control of vendor machines, home-security, commuter pass, delivery tracking, and telemetry are now becoming commercially available, and it is reasonable to expect that this application area will grow into a significant component of next generation services.

The major standardization bodies that play an important role in defining the specifications for the mobile technology are:

- ITU (*International Telecommunication Union*): International organization within the United Nations, where governments and the private sector coordinate global telecom networks and services. One of the sectors of ITU, *ITU-T* produces the quality standards covering all the fields of telecommunications. More than 1500 specialists from telecommunication organizations and administrations around the world participate in the work of the Radiocommunication Sector of ITU (*namely ITU-R*). ITU's *IMT-2000* (*International Mobile Telecommunications-2000*) global standard for 3G wireless communications has opened the way to enabling innovative applications and services (e.g. multimedia entertainment,

infotainment and location-based services, among others). The new concept from the ITU for mobile communication systems with capabilities which go further than that of IMT-2000 is *IMT-Advanced*, previously known as "*systems beyond IMT-2000*". For more detail information refer to ITU homepage by http://www.itu.int/home/index.html.

- IEEE (*Institute of Electrical and Electronics Engineers*) is one of the leading standards-making organizations in the world. IEEE performs its standards making and maintaining functions through the IEEE Standards Association (IEEE-SA). IEEE standards affect a wide range of industries including: power and energy, information technology (IT), telecommunications, nanotechnology, information assurance, and many more. One of the more notable IEEE standards is the *IEEE 802 LAN/MAN* group of standards which includes the:
  - 802.3 *Ethernet standard,*
  - 802.11 *Wireless Local Area Networks (Wi-Fi),*
  - 802.15 *Wireless Personal Area Networks (Bluetooth, ZigBee, Wireless USB),*
  - 802.16 *Broadband Wireless Access (WiMax, Mobile WiMax/WiBro),*
  - 802.20 *Mobile Broadband Wireless Access (suspended until I October 2006),* etc.

For more information about *IEEE* and *802 LAN/MAN* group refer to http://www.ieee.org/ and http://www.ieee802.org/ Web pages, respectively.

- ETSI (*European Telecommunication Standard Institute*) is an independent, non-profit, standardization organization of the telecommunications industry (equipment makers and network operators) in Europe, with worldwide projection. ETSI has been successful in standardizing the GSM cell phone system and the TETRA professional mobile radio system. Owing to the technical and commercial success of the GSM, this body plays an important role in the development of 3G mobile systems. See http://www.etsi.org/ for detailed information.
- *ARIB* (The Association of Radio Industries and Businesses) was chartered by the Minister of Posts and Telecommunications of Japan as a public service corporation on May 15, 1995. Established in response to several trends such as the growing internationalization of telecommunications, the convergence of telecommunications and broadcasting, and the need for promotion of radio-related industries, this body is playing an important role in the 3G development. ARIB Web page located at http://www.arib.or.jp/english/.
- TTA (*Telecommunications Technology Association*) is a Korean IT standards organization that develops new standards and provides one-stop services for the establishment of IT standards as well as testing and certification for IT products. One of the successful standards approved by TTA is the TTA PG302, the standard for 2.3 GHz Portable Internet (*WiBro*). For further information see TTA organization Web site at http://tta.or.kr/English/.
- 3GPP (*Third Generation Partnership Project*) was created to maintain overall control of the specification design and process for 3G networks. The scope of 3GPP is to make a globally applicable 3G mobile phone system specification within the scope of the ITU's IMT-2000 project. The 3GPP is an

international collaboration of a number of telecommunications standards bodies to standardize UMTS (*Universal Mobile Telecommunications System*). The original scope of 3GPP was to produce globally applicable Technical Specifications and Technical Reports for a 3rd Generation Mobile System based on evolved GSM core networks and the radio access technologies that they support. The current Organizational Partners are Japanese (*ARIB and TTC*), Chinese (*CCSA*), European (*ETSI*), American (*ATIS*) and Korean (*TTA*). 3GPP Web site located at http://www.3gpp.org/ .

- 3GPP2 is the other major 3G standardization organization, which promotes the cdma2000 system. In the world of IMT-2000, this proposal is known as IMT-MC. The major difference between 3GPP and 3GPP2 approaches into the air specification development is that 3GPP has specified a completely new air interface without any constraints from the past, whereas 3GPP2 has specified a system that is backward compatible with IS-95 systems. Official Web page of 3GPP2 organization is http://www.3gpp2.org/.

Next in this chapter we discuss the aforesaid mobile communication generations in detail and describe the services and applications suitable for mobile communication systems.

2. EVOLUTION OF MOBILE COMMUNICATION SYSTEMS

For a better understanding of today's wireless communication systems and developments, we will present a short history of wireless communications. The name, which is closely connected with the success of wireless communication, is that **Guglielmo Marconi**. In 1895, he gave the first demonstration of **wireless telegraphy**. Six years later in 1901 the first transatlantic transmission followed. The first radio broadcast took place in 1906 when **Reginald A. Fessenden** transmitted voice and music for Christmas. Within the next years huge work has been made, and in 1915 the first **wireless transmission** was set up between New York and San Francisco. Since, all this done using long wave transmission, sender and receiver still needed huge antennas and high transmission power (up to 200 kW).

The situation was resolutely changed with the **discovery of short waves** in 1920 by Marconi. Since then became possible to send short radio waves around the world bouncing at the ionosphere. After the Second World War governments started to invest in development of wireless communication projects. In 1958 Germany launches the first analogue wireless network named **A-Netz**, using 160 MHz carrier frequency. Connection setup was only possible from the mobile station, no handover, i.e., changing of the base station, was possible. System had coverage of 80 percent and 11,000 customers. In 1972 **B-Netz** followed in Germany, using the same 160 MHz. This network could initiate the connection setup from a station in the fixed telephone network, but, the current location of the mobile receiver had to be known. In 1979, B-Netz had 13,000 customers and needed a heavy sender and receiver, typically built into cars.

At the same time, the Northern European countries of Denmark, Finland, Norway and Sweden agreed upon the **Nordic Mobile Telephone (NMT)** system. NMT is based on analog technology (first generation or 1G) and two variants exist: **NMT-450** and **NMT-900**. The numbers indicate the frequency bands uses. NMT-900 was introduced in 1986 because it carries more channels than the previous NMT-450 network. The cell sizes in an NMT network range from 2 km to 30 km. With smaller ranges the network can serve more simultaneous callers; for example in a city the range can be kept short for better service. NMT used full duplex transmission, allowing for simultaneous receiving and transmission of voice. Car phone versions of NMT used transmission power of up to 15 watt (NMT-450) and 6 watt (NMT-900), handsets up to 1 watt. NMT had automatic switching (dialing) and handover of the call built into the standard from the beginning. Additionally, the NMT standard specified billing as well as national and international roaming.

In 1979 NTT introduced the analog mobile phone system using frequency division multiplexing (FDMA) and operating at 800MHz band. NTT system aimed to provide nationwide service by introducing the cellular architecture, location registration and handoff. In 1983 Bell Labs officially introduced the analog mobile phone system standard **Advanced Mobile Phone System (AMPS),** using FDMA and working at 850 MHz. Though analog is no longer considered advanced at all, AMPS introduced the relatively seamless cellular switching technology, that made the original mobile radiotelephone practical, and was considered quite advanced at the time. Using FDMA, each cell site would transmit on different frequencies, allowing many cell sites to be built near each other. However it had the disadvantage that each site did not have much capacity for carrying calls. It also had a poor security system which allowed people to force a phone's serial code to use for making illegal calls.

The boundary line between 1G and 2G systems is obvious: it is the analog/digital split. The 2G systems have much higher capacity than the 1G systems. One frequency channel is simultaneously divided among several users, either by code or time division. There are four main standards for 2G: *Global System for Mobile* (GSM), *Digital AMPS* (D-AMPS), code-division multiple access (CDMA, IS-95), and *Personal Digital Cellular* (PDC).

PDC is the Japanese 2G standard. Originally it was known as *Japanese Digital Cellular (**JDC**)*, but the name was changed to PDC to make system more attractive outside Japan. However, this renaming did not bring about the desired result, and this standard is commercially used only in Japan. PDC operates in two frequency bands, 800 MHz and 1,500 MHz. It has both analog and digital modes. PDC has been very popular system in Japan.

Another, popular Japanese 2G system is **Personal Handy-phone System (PHS)**, also marketed as the **Personal Access System (PAS)**, is a mobile network system operating in the 1880-1930 MHz frequency band. PHS is, essentially, a cordless telephone with the capability to handover from one cell to another. PHS cells are small, with transmission power a maximum of 500mW and range typically measures in tens or at most hundreds of meters, as opposed to the multi-kilometer ranges of

GSM. Originally developed by NTT Laboratory in Japan in 1989 and far simpler to implement and deploy than competing systems like PDC or GSM, the commercial services have been started by 3 PHS operators (NTT-Personal, DDI-Pocket and ASTEL) in Japan in 1995. However, the service has been pejoratively dubbed as the "poor man's cellular" due to its limited range and roaming capabilities in Japan. Recently, PHS has been reconsidered again in Japan as a cost-effective solution to providing broadband services of data rate up to 64Kbps, which is much faster than any other 2G systems. Also in other Asian countries, e.g., China, PHS has been deployed in addition to 2G cellular systems.

In accordance with the general idea of European Union, the European countries decided to develop a pan-European phone standard in 1982. The new system aimed to:

- use a new spectrum at 900 MHz;
- allow roaming throughput Europe;
- be fully digital;
- offer voice and data service.

The "**Groupe Speciale Mobile**" **(GSM)** was founded for this new development. From 1982 to 1985 discussions were held to decide between building an analog or digital system. After multiple field tests, a digital system was adopted for GSM. The next task was to decide between a narrow or broadband solution. In May 1987, the narrowband time division multiple access (TDMA) solution was chosen. In 1989, ETSI took over control and by 1990 the first GSM specification was completed, amounting to over 6,000 pages of text. Commercial operation began in 1991 with Radiolinja in Finland. GSM differs significantly from its predecessors in that both signaling and speech channels are digital, which means that it is considered a second generation (2G) mobile phone system. This first version GSM, now called global system for mobile communication, works at 900 MHz and uses 124 full-duplex channels. GSM offers full international roaming, automatic location services, authentication, encryption on the wireless link, and a relatively high audio quality. GSM is by far the most successful and widely used 2G system. Originally designed as a Pan-European standard, it was quickly adopted all over the world.

It was soon discovered that the analog AMPS in the US and digital GSM at 900 MHz in Europe are not sufficient for the high user densities in cities. These triggered off the search for more able systems. While the Europeans agreed to use the GSM in the new 1800 MHz band **(DCS 1800)**, in the US, different companies developed three different new, more bandwidth-efficient technologies to operate side-by-side with AMPS in the same frequency band. This resulted in three incompatible systems, the analog narrowband AMPS (IS-88), and the two digital systems D-AMPS (IS-136) and CDMA (IS-95).

D-AMPS (also known as US-TDMA) is used in the Americas, Israel, and in some Asian countries. D-AMPS uses existing AMPS channels and allows for smooth transition between digital and analog systems in the same area. Capacity was increased over the preceding analog design by dividing each 30 kHz channel

pair into three time slots (TDMA) and digitally compressing the voice data, yielding three times the call capacity in a single cell. A digital system also made calls more secure because analog scanners could not access digital signals.

The first **CDMA**-based digital cellular standard **IS-95** (Interim Standard 95) is pioneered by Qualcomm. The brand name for IS-95 is ***cdmaOne***. IS-95 is also known as TIA-EIA-95. CDMA or "code division multiple access" is a digital radio system that transmits streams of bits (PN Sequences). CDMA permits several users to share the same frequencies. Unlike TDMA, a competing system used in GSM, all transmitters can be active all the time, because network capacity does not directly limit the number of active users. Since larger numbers of users can be served by smaller numbers of cell-sites, CDMA-based standards have a significant economic advantage over TDMA-based standards, or the oldest cellular standards that used FDMA.

In 1993 South Korea adopts CDMA, although some experts worried Korea would lag behind with the launch of the then-untested CDMA network, while the world was commercializing the GSM standard. The decision to adopt CDMA technology turned a new page in Korea's telecommunications history. In January 1996, Korea successfully launched the world's first commercial operation of CDMA network in Seoul and its neighboring cities. Since then, CDMA has become the fastest-growing of all wireless technologies, with over 100 million subscribers worldwide. In addition to supporting more traffic, CDMA brings many other benefits to carriers and mobile users, including better voice quality, broader coverage and stronger security. IS-95 is the only CDMA standard so far to be operated commercially as a 2G system.

Note that quite often when the 2G is discussed, *digital cordless systems* are also mentioned. In 1991, ETSI adopted the standard **Digital European cordless telephone** (**DECT**) for digital cordless telephony. DECT works at a spectrum of 1880–1900 MHz with a range of 100–500m. 120 duplex channels can carry up to 1.2 Mbps for data transmission. Several new features, such as voice encryption and authentication, are built-in. Today, DECT has been renamed *digital enhanced cordless telecommunications*.

2.5 Generation (2.5G) is a designation that broadly includes all advanced upgrades for the 2G networks. 2.5G provides some of the benefits of 3G (e.g. it is packet-switched) and can use some of the existing 2G infrastructure in GSM and CDMA networks. **Figure 4** demonstrates the evolution of cellular based systems from 2G towards 4G. **General Packet Radio Service (GPRS)** is a 2.5G technology used by GSM operators. Some protocols, such as **EDGE** (**Enhanced Data Rates for Global Evolution**) for GSM and **CDMA2000 1x-RTT** for CDMA, can qualify as "3G" services (because they have a data rate of above 144 Kbps), but are considered by most to be 2.5G services because they are several times slower than "true" 3G services.

With **GPRS** technology, the data rates can be pushed up to 115 Kbps, or even higher. It provides moderate speed data transfer, by using unused TDMA channels in the GSM network. Originally there was some thought to extend GPRS to cover

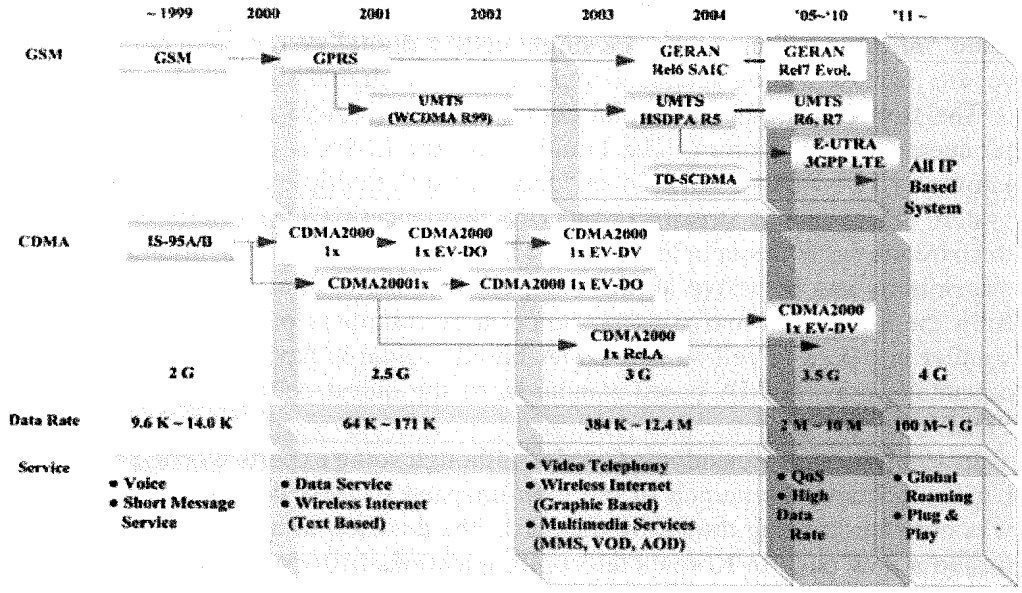


Figure 4. Mobile communication systems evolution towards 4G

other standards, but instead those networks are being converted to use the GSM standard, so that it is the only kind of network where GPRS is in use. First it was standardized by ETSI but now that effort has been handed onto the 3GPP. GPRS is packet switched, and thus it does not allocate the radio resources continuously but only when there is something to be sent. A consequence of this is that packet switched data has a poor bit rate in busy cells. The theoretical limit for packet switched data is approx. 160.0 Kbps (using 8 time slots). A realistic bit rate is 30–80 Kbps, because it is possible to use max 4 time slots for downlink. GPRS is especially suitable for non-real-time applications, such as e-mail and Web surfing. It is not well suited for real-time applications, as the resource allocations in GPRS is connection based and thus it cannot guarantee an absolute maximum delay.

A change to the radio part of GPRS called **EDGE** (sometimes called EGPRS or Enhanced GPRS) allows higher bit rates of between 160 and 236.8 Kbps (theoretical maximum is 473.6 Kbps for 8 timeslots). Although EDGE requires no hardware changes to be made in GSM core networks, base stations must be modified. EDGE compatible transceiver units must be installed and the base station subsystem (BSS) needs to be upgraded to support EDGE. New mobile terminal hardware and software is also required to decode/encode the new modulation and coding schemes and carry the higher user data rates to implement new services.

CDMA2000 1xRTT, the core CDMA2000 wireless air interface standard, is known by many terms: 1x, 1xRTT, IS-2000, CDMA2000 1X, and cdma2000 (lowercase). The designation "1xRTT" (1 times Radio Transmission Technology) is used to identify the version of CDMA2000 radio technology that operates in a

pair of 1.25-MHz radio channels (one times 1.25 MHz, as opposed to three times 1.25 MHz in 3xRTT as shown in **Figure 5**). 1xRTT almost doubles voice capacity over IS-95 networks. Although capable of higher data rates, most deployments have limited the peak data rate to 144 Kbps. While 1xRTT officially qualifies as 3G technology, 1xRTT is considered by some to be a 2.5G (or sometimes 2.75G) technology. This has allowed it to be deployed in 2G spectrum in some countries which limit 3G systems to certain bands.

Year 1998 marked the beginning of mobile communication using satellites with the **Iridium** system. The Iridium satellite constellation is a system of 66 active communication satellites in low earth orbit and uses 1.6 GHz band for communication with the mobile phone. The system was originally to have 77 active satellites, and was named for the element iridium, which has atomic number 77. Iridium allows worldwide voice and data communications using handheld devices. Iridium communications service was launched on November 1, 1998 and went into bankruptcy on August 13, 1999. Its financial failure was largely due to insufficient demand for the service. The increased coverage of terrestrial cellular networks (e.g. GSM) and the rise of roaming agreements between cellular providers proved to be fierce competition. Nowadays the system is being used extensively by the U.S. Department of Defense for its communication purposes through the DoD Gateway in Hawaii. The commercial Gateway in Tempe, Arizona provides voice, data and paging services for commercial customers on a global basis. Typical customers include maritime, aviation, government, the petroleum industry, scientists, and frequent world travelers. Iridium Satellite LLC claims to have approximately 142,000 subscribers as of December 31, 2005.

In 1999 IEEE published several powerful WLAN standards. One of them is **802.11b Wi-Fi** standard offering 11 Mbps at 2.4 GHz. 802.11b products appeared on the market very quickly, since 802.11b is a direct extension of the DSSS (Direct-sequence spread spectrum) modulation technique defined in the original

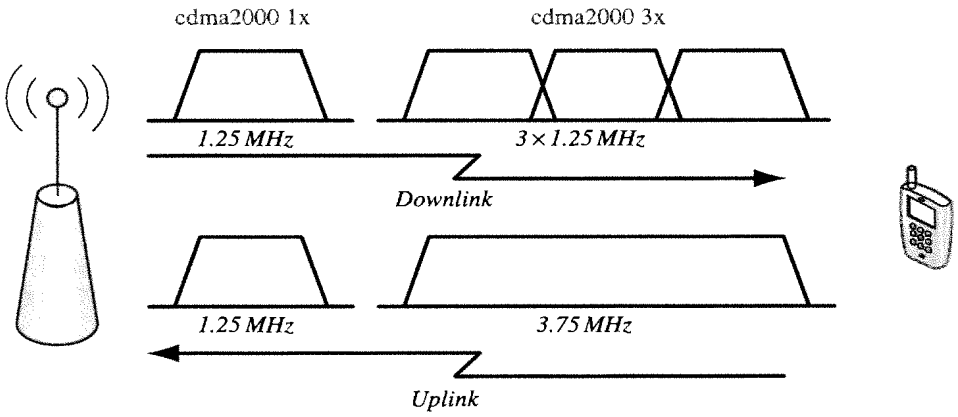


Figure 5. Relationship between 1x and 3x modes in spectrum usage

standard. Hence, chipsets and products were easily upgraded to support the 802.11b enhancements. The dramatic increase in throughput of 802.11b (compared to the original standard) along with substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology. The same spectrum is used by **Bluetooth**, a short-range technology to set-up wireless personal area networks (PANs) with gross data rates less than 1 Mbps. Bluetooth is an industrial specification for PANs, also known as **IEEE 802.15.1**. Bluetooth provides a way to connect and exchange information between devices like personal digital assistants (PDAs), mobile phones, laptops, PCs, printers and digital cameras via a secure, low-cost, globally available short range radio frequency.

The rapid development of mobile communication systems was one of the most notable success stories of the 1990s. The 2G systems began their operation at the beginning of the decade, and since then they have been expanding and evolving continuously. In 2000 there were 361.7 million GSM and more than 100 million CDMA subscribers worldwide. Main disadvantage of 2G systems was that the standards for developing the networks were different for different parts of the world. Hence, it was decided to have a network that provides services independent of the technology platform and whose network design standards are same globally. Thus, **3G** was born. To understand the background to the differences between 2G and 3G systems, we need to look at the new requirements of the 3G systems which are listed below:

- Bit rates up to 2 Mbps;
- Variable bit rate to offer bandwidth on demand;
- Multiplexing of services with different quality requirements on a single connection, e.g. speech, video and packet data;
- Delay requirements from delay-sensitive real time traffic to flexible best-effort packet data;
- Quality requirements from 10% frame error rate to 10^{-6} bit error rate;
- Co-existence of 2G and 3G systems and inter-system handovers for coverage enhancements and load balancing;
- Support asymmetric uplink and downlink traffic, e.g. Web browsing causes more loading to downlink than to uplink;
- High spectrum efficiency;
- Co-existence of FDD and TDD modes.

ITU started the process of defining the standard for 3G systems, referred to as **IMT-2000**. In 1998 Europeans agreed on the **Universal Mobile Telecommunications System (UMTS)** as the European proposal for the 3G systems. UMTS uses Wideband-CDMA (**WCDMA**) as the underlying standard, is standardized by the 3GPP, and represents the European/Japanese answer to the ITU IMT-2000 requirements for 3G systems.

IMT-2000 offers the capability of providing value-added services and applications on the basis of a single standard. The system envisages a platform for distributing converged fixed, mobile, voice, data, Internet, and multimedia services. One of its key visions is to provide seamless global roaming, enabling users to

move across borders while using the same number and handset. IMT-2000 also aims to provide seamless delivery of services, over a number of media (satellite, fixed, etc...). It is expected that IMT-2000 will provide higher transmission rates: a minimum speed of 2Mbps for stationary or walking users, and 348 Kbps in a moving vehicle.

3. MODERN CELLULAR COMMUNICATION SYSTEMS

In 2001 the 3G systems started with the **FOMA** service in Japan, with several field trials in Europe and with **cdma2000** in South Korea. The first country which introduced 3G on a large commercial scale was Japan. In 2005 about 40% of subscribers use 3G networks only, and 2G is on the way out in Japan. It is expected that during 2006 the transition from 2G to 3G will be largely completed in Japan, and upgrades to the next 3.5G stage with maximum around 14 Mbps data rate is underway.

3G technologies are an answer to the ITU's IMT-2000 specification. Originally, 3G was supposed to be a single, unified, worldwide standard, but in practice, there are two main competing technologies, WCDMA and cdma2000. Also there is another 3G standard called TD-SCDMA, developing by the Chinese Academy of Telecommunications Technology (CATT).

This section describes the stated above 3G systems, lists their main parameters and gives information about their evolutions, like HSDPA/HSUPA for WCDMA and 1x EV-DO/EV-DV for cdma2000 systems.

3.1 WCDMA/HSDPA/HSUPA

WCDMA (Wideband Code Division Multiple Access) is a type of 3G cellular network. WCDMA is the technology behind the 3G UMTS standard and is allied with the 2G GSM standard. WCDMA was developed by NTT DoCoMo as the air interface for their 3G network. Later NTT DoCoMo submitted the specification to the ITU as a candidate for the international 3G standard known as IMT-2000. The ITU eventually accepted WCDMA as part of the IMT-2000 family of 3G standards. Later WCDMA was selected as the air interface for UMTS, the 3G successor to GSM.

WCDMA is a wideband Direct-sequence Code Division Multi Access (DS-CDMA) system. Compared to the first DS-CDMA based standard, IS-95, WCDMA uses a three times larger bandwidth equal to 5 MHz, as a result using 3.84 Mcps chip rate. Higher chip rate of 3.84 Mcps enables higher bit rate and provides more multipath diversity than the chip rate of 1.2288 Mcps (IS-95), especially in urban cells. In order to support high bit rates up to 2 Mbps, WCDMA supports the use of variable spreading factor and multicode connections.

WCDMA supports highly variable user data rates and the Bandwidth on Demand (BoD) is well supported. Although, the user data rate is constant during each 10 ms frame, the data capacity among the users can change from frame to frame. WCDMA

utilizes fast closed loop power control in both uplink and downlink. Fast power control in the downlink improves link performance and enhances downlink capacity. However, this requires new functionalities in the mobile, such as SIR (signal-to-interference ratio) estimation and outer-loop power control. Also, WCDMA supports both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) operation modes. In the FDD mode, separate 5 MHz carrier frequencies are used for uplink and downlink respectively, whereas in TDD only 5 MHz is time-shared between the uplink and downlink. WCDMA supports the operation of asynchronous base stations, so that there is no need for a global time reference such as GPS. Deployment of indoor and micro base stations is easier when no GPS signal needs to be received.

In standardization forums, WCDMA technology has emerged as the most widely adopted 3G air interface. Its specification has been created in 3GPP. Within 3GPP, WCDMA is called Universal Terrestrial Radio Access (UTRA) FDD and TDD, the name WCDMA being used to cover both FDD and TDD operation. Further, experience from 2G systems like GSM and cdmaOne has enabled improvements to be incorporated in WCDMA. Focus has also been put on ensuring that as much as possible of WCDMA operators' investments in GSM equipment can be reused. Examples are the re-use and evolution of the core network, the focus on co-siting and the support of GSM handover. In order to use GSM handover the subscribers need dual mode handsets.

Inter-frequency handovers are considered important in WCDMA, to maximize the use of several carriers per base station. In cdmaOne inter-frequency measurements are not specified, making inter-frequency handovers more difficult. Also, WCDMA includes transmit diversity mechanism to improve the downlink capacity to support asymmetric capacity requirements between downlink and uplink.

WCDMA supports up to 1920 Kbps data transfer rates (and not 2 Mbps as previously expected), although at the moment users in the real networks can expect performance up to 384 Kbps – in Japan, its evolved version High Speed Down Link Packet Access (HSDPA) will be deployed in 2006 to provide mobile users with higher rate packet services than WCDMA. HSDPA and High Speed Up Link Packet Access (HSUPA) will enable high-speed wireless connectivity comparable to wired broadband. HSDPA/HSUPA enables individuals to send and receive email with large file attachments, play real-time interactive games, receive and send high-resolution pictures and video, download video and music content or stay wirelessly connected to their office PCs – all from the same mobile device.

HSDPA refers to the speed at which individuals can receive large data files, the "downlink." In this respect it extends WCDMA in the same way that EV-DO extends CDMA2000. HSDPA provides a smooth evolutionary path for UMTS networks allowing for higher data capacity (up to 14.4 Mbps in the downlink). It is an evolution of the WCDMA standard, designed to increase the available data rate by a factor of 5 or more. HSDPA defines a new WCDMA channel, the high-speed downlink shared channel (HS-DSCH) that operates in a

different way from existing WCDMA channels, but is only used for downlink communication to the mobile.

HSUPA (high-speed uplink packet access) refers to the speed at which individuals can send large data files, the "uplink." HSUPA extremely increases upload speeds up to 5.76 Mbps. HSUPA is expected to use an uplink enhanced dedicated channel (E-DCH) on which it will employ link adaptation methods similar to those employed by HSDPA. Similarly to HSDPA there will be a packet scheduler, but it will operate on a request-grant principle where the MSs request a permission to send data and the scheduler decides when and how many MSs will be allowed to do so. In HSUPA, unlike in HSDPA, soft and softer handovers will be allowed for packet transmissions. Similar to HSDPA, HSUPA is considered **3.75G.**

HSDPA considerably improves the 3G end-user data experience by enhancing downlink performance. HSDPA significantly reduces the time it takes a mobile user to retrieve broadband content from the network. A reduced delay is important for many applications such as interactive games. In general, HSDPA allows a more efficient implementation of "interactive" and "background" Quality of Service (QoS) classes as standardized by 3GPP. HSDPA high data rates also improve the use of streaming applications, while lower roundtrip delays will benefit Web browsing applications. In addition, HSDPA's improved capacity opens the door for new and data-intensive applications that cannot be fully supported with Release 99 because of bandwidth limitations.

3.2 cdma2000/1xEV-DO/1xEV-DV

The other significant 3G standard is **cdma2000**, which is an outgrowth of the earlier 2G CDMA standard IS-95. cdma2000's primary proponents are outside the GSM zone in the Americas, Japan and Korea. cdma2000 is managed by 3GPP2, which is separate and independent from UMTS's 3GPP. The various types of transmission technology used in cdma2000 include 1xRTT, cdma2000-1xEV-DO and 1xEV-DV. cdma2000 offers data rates of 144 Kbps to over 3 Mbps. It has been adopted by the International Telecommunication Union - ITU. Arguably the most successful introduction of cdma2000 3G systems is South Korean SK Telecom, which has more than 20 million 3G subscribers. In October 2000, they debuted the world's first commercial CDMA 1x service; and in February 2002, they released the first commercial CDMA 1xEV-DO service, which achieves data rates up to 2.4 Mbps.

Same as IS-95 cdma2000 1x uses one times the chip rate of 1.2288 Mcps. However, in addition, the cdma2000 also supports Spreading Rate 3 (or 3x), which is used when higher data rate transmissions are required. Spreading Rate 3 has two implementation options: DSSS (Direct-sequence spread spectrum) or MCSS (multicarrier spread-spectrum).

On the downlink of the MC system three narrowband 1x carriers, each with 1.25 MHz, are bundled to form a multicarrier transmission with approximately 3.75 MHz (3x) bandwidth. On the uplink, cdma2000 3x system uses the DSSS option, which allows the mobile to directly spread its data over a wider bandwidth

using a chip rate of 3.6864 Mcps. To harmonize with other 3G systems such as UMTS WCDMA, a Spreading Rate 3 signal can have 625 kHz of guard band on each side resulting in a total 5 MHz RF bandwidth. Although currently, there do not seem to be commercial commitments for actual adopting the MC mode, but instead the focus has been more on the further development of narrowband operation, wider bandwidth options such as 6x, 9x, and 12x are under consideration for even higher data rate applications.

Launched in South Korea in **2002, cdma2000 1xEV-DO** (1x Evolution-Data Optimized, originally 1x Evolution-Data Only), is an evolution of cdma2000 1x with High Data Rate (HDR) capability added and where the forward link is time-division multiplexed. This 3G air interface standard is denoted as IS-856. 1xEV-DO is capable of delivering data ar speeds comparable to wireline broadband. By dividing radio spectrum into separate voice and data vhannels, cdma2000 1xEV-DO, which uses a 1.25 MHz data channel, improves network efficiency and eliminates the chance that an increase in voice traffic would cause data speeds to drop.

cdma2000 1xEV-DO in its latest revision, Rev. A, supports downlink data rates up to 3.1 Mbps and uplink data rates up to 1.8 Mbps in a radio channel dedicated to carrying high-speed packet data. 1xEV-DO Rev. A was first deployed in Japan and will be deployed in North America in 2006. The Rev. 0 that is currently deployed in North America has a peak downlink data rate of 2.5 Mbps and a peak uplink data rate of 154 Kbps.

cdma2000 1xEV-DV (1x Evolution-Data/Voice), is another piece of the 3G CDMA roadmap. Promising efficient, high speed packet data capabilities added to cdma2000 1x circuit-switched voice capability, cdma2000 1xEV-DV supports downlink (forward link) data rates up to 3.1 Mbps and uplink (reverse link) data rates of up to 1.8 Mbps. 1xEV-DV can also support concurrent operation of legacy 1x voice users, 1x data users, and high speed 1xEV-DV data users within the same radio channel.

In 2005, Qualcomm put the development of EV-DV on an indefinite halt, due to lack of carrier interest, mostly because both Verizon Wireless and Sprint are using EV-DO.

3.3 TD-SCDMA

TD-SCDMA (Time Division-Synchronous Code Division Multiple Access) is a 3G mobile telecommunications standard, being pursued in the People's Republic of China by the Chinese Academy of Telecommunications Technology (CATT).

TD-SCDMA uses TDD, in contrast to the FDD scheme used by WCDMA. By dynamically adjusting the number of timeslots used for downlink and uplink, the system can more easily accommodate asymmetric traffic with different data rate requirements on downlink and uplink than FDD schemes. Since it does not require paired spectrum for downlink and uplink, spectrum allocation flexibility is also increased. Also, using the same carrier frequency for uplink and downlink means that the channel condition is the same on both directions, and the base station can

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Table 1. Modern cellular systems main parameter

Parameter	WCDMA	cdma2000	TD-SCDMA
Multiple access	DS-CDMA	1x: DS-CDMA; **3x:** MC-CDMA	TDMA, CDMA, FDMA
Carrier spacing	5 MHz	1x: 1.25 MHz; 3x: 3.75 MHz	1.6 MHz
Chip rate	3.84 Mcps	1x: 1.2288 Mcps; 3x: 3.6864 Mcps	1.28 Mcps
Data rate	up to 1920 Kbps (up to 10 Mbps using HSDPA)	153.6 Kbps, up to 2.4 Mbps with EV-DO and 5.2 Mbps with EV-DV	up to 2 Mbps
Duplexing method	FDD/TDD	FDD	TDD
Power control frequency	1500 MHz	800 Hz in uplink/downlink	Downlink and uplink
BS synchronization	Asynchronous	Synchronous	Synchronous
Frame length	10 ms	5 ms, 10 ms, 20 ms	10 ms
Spreading factors	Variable SF from 4 to 512	4~256 UL	1, 2, 4, 8 and 16
Data modulation	QPSK/ dual-channel QPSK	BPSK/QPSK	QPSK or 8PSK
Antenna processing	DL transmit diversity (Space-Time Coding)	DL transmit diversity (Space-Time Spreading)	Smart antenna with beamforming

OMEGA EXHIBIT 2038

deduce the downlink channel information from uplink channel estimates, which is helpful to the application of beamforming techniques.

TD-SCDMA also uses TDMA in addition to the CDMA used in WCDMA. This reduces the number of users in each timeslot, which reduces the implementation complexity of multiuser detection and beamforming schemes, but the non-continuous transmission also reduces coverage (because of the higher peak power needed), mobility (because of lower power control frequency) and complicates radio resource management algorithms.

The "S" in TD-SCDMA stands for "synchronous", which means that uplink signals are synchronized at the base station receiver, achieved by continuous timing adjustments. This reduces the interference between users of the same timeslot using different codes by improving the orthogonality between the codes, therefore increasing system capacity, at the cost of some hardware complexity in achieving uplink synchronization. The standard has been adopted by 3GPP since Rel-4, known as "UTRA TDD 1.28Mcps Option".

We conclude this section by listing the main parameters of modern cellular based networks in **Table 1**.

4. WIRELESS DATA SERVICES

While many of the classical mobile phone systems converged to IMT-2000 systems (with cdma2000 and WCDMA/UMTS), the Wireless Local Area Networks (WLAN) area developed more or less independently.

WLAN is expected to continue to be an important form of connection in many business areas. The market is expected to grow as the benefits of WLAN are recognized. It is estimated that the WLAN market will have been 0.3 billion US dollars in 1998 and 1.6 billion dollars in 2005. So far WLANs have been installed in universities, airports, and other major public places. Decreasing costs of WLAN equipment has also brought it to many homes.

Early development of WLANs included industry-specific solutions and proprietary protocols, but at the end of the 1990s these were replaced by standards, primarily the various versions of IEEE 802.11 (Wi-Fi). An alternative ATM-like 5 GHz standardized technology, HIPERLAN, has not succeeded in the market, and with the release of the faster 54 Mbps 802.11a (5 GHz) and 802.11g (2.4 GHz) standards, almost certainly never will.

In this section we discuss the most succeed wireless network standards such as IEEE 802.11a/b/g Wi-Fi and IEEE 802.15 family standards including Bluetooth, ZigBee and Wireless USB. Much attention in this chapter is paid to high speed wireless Internet services such as WiBro and WiMax.

4.1 IEEE 802.11 Family Standards

IEEE 802.11, the Wi-Fi standard, denotes a set of WLAN standards developed by working group 11 of the IEEE LAN/MAN Standards Committee (IEEE 802). The

802.11 family currently includes six over-the-air modulation techniques that all use the same protocol. The most popular (and prolific) techniques are those defined by the *b*, *a*, and *g* amendments to the original standard. 802.11b and 802.11g standards use the 2.4 GHz band. Because of this choice of frequency band, 802.11b and 802.11g equipment can incur interference from microwave ovens, cordless telephones, Bluetooth devices, and other appliances using this same band. The 802.11a standard uses the 5 GHz band, and is therefore not affected by products operating on the 2.4 GHz band.

The **802.11a** amendment to the original standard was ratified in 1999. The 802.11a standard uses the same core protocol as the original standard, operates in 5 GHz band, and uses a 52-subcarrier orthogonal frequency-division multiplexing (OFDM) with a maximum raw data rate of 54 Mbps, which yields realistic net achievable throughput in the mid-20 Mbps. The data rate is reduced to 48, 36, 24, 18, 12, 9 then 6 Mbps if required.

Since the 2.4 GHz band is heavily exploited, using the 5 GHz band gives 802.11a the advantage of less interference. However, this high carrier frequency also brings disadvantages. It restricts the use of 802.11a to almost line of sight, necessitating the use of more access points; it also means that 802.11a cannot penetrate as far as 802.11b since it is absorbed more readily, other things (such as power) being equal.

802.11a products started shipping in 2001, lagging 802.11b products due to the slow availability of the 5 GHz components needed to implement products. 802.11a was not widely adopted overall because 802.11b was already widely adopted, because of 802.11a's disadvantages, because of poor initial product implementations, making its range even shorter, and because of regulations.

802.11b products appeared on the market very quickly, since 802.11b is a direct extension of the DSSS modulation technique defined in the original standard. Hence, chipsets and products were easily upgraded to support the 802.11b enhancements. The dramatic increase in throughput of 802.11b (compared to the original standard) along with substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology.

802.11b is usually used in a point-to-multipoint configuration, wherein an access point communicates via an omni-directional antenna with one or more clients that are located in a coverage area around the access point. Typical indoor range is 30 m at 11 Mbps and 90 m at 1 Mbps. Extensions have been made to the 802.11b protocol (e.g., channel bonding and burst transmission techniques) in order to increase speed to 22, 33, and 44 Mbps, but the extensions are proprietary and have not been endorsed by the IEEE. Many companies call enhanced versions "802.11b+". These extensions have been largely obviated by the development of 802.11g, which has data rates up to 54 Mbps and is backwards-compatible with 802.11b.

In June 2003, a third modulation standard was ratified: **802.11g**. This flavor works in the 2.4 GHz band (like 802.11b) but operates at a maximum raw data rate of 54 Mbps, or about 24.7 Mbps net throughput like 802.11a. 802.11g hardware will work with 802.11b hardware. Details of making *b* and *g* work well together occupied much of the lingering technical process. In older networks, however, the

presence of an 802.11b participant significantly reduces the speed of an 802.11g network. The modulation scheme used in 802.11g is OFDM for the data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. The maximum range of 802.11g devices is slightly greater then that of 802.11b devices, but the range in which a client can achieve full (54 Mbps) data rate speed is much shorter than that of 802.11b. The 802.11g standard swept the consumer world of early adopters starting in January 2003, well before ratification. The corporate users held back and Cisco and other big equipment makers waited until ratification. By summer 2003, announcements were flourishing. Most of the dual-band 802.11a/b products became dual-band/tri-mode, supporting a, b, and g in a single mobile adaptor card or access point. Despite its major acceptance, 802.11g suffers from the same interference as 802.11b in the already crowded 2.4 GHz range. Devices operating in this range include microwave ovens, Bluetooth devices, and cordless telephones.

In January 2004 IEEE announced that it had formed a new **802.11n** Task Group to develop a new amendment to the 802.11 standard for wireless local-area networks. The real data throughput is estimated to reach a theoretical 540 Mbit/s (which may require an even higher raw data rate at the physical layer), and should be up to 100 times faster than 802.11b, and well over 10 times faster than 802.11a or 802.11g. It is projected that 802.11n will also offer a better operating distance than current networks.

802.11n builds upon previous 802.11 standards by adding MIMO (multiple-input multiple-output). MIMO uses multiple transmitter and receiver antennas to allow for increased data throughput through spatial multiplexing and increased range by exploiting the spatial diversity, perhaps through coding schemes like Alamouti coding.

The Enhanced Wireless Consortium (EWC) was formed to help accelerate the IEEE 802.11n development process and promote a technology specification for interoperability of next-generation WLAN products.

According to the IEEE 802.11 Working Group Project Timelines, the 802.11n standard is not due for final approval until July 2007.

Table 2 summarizes this section and list main parameters of 802.11 standards family.

Table 2. IEEE 802.11 family standards major parameters

	802.11	802.11a	802.11b	802.11g	802.11n
Release Date	1997	1999	1999	2003	Expected mid.2007
Frequency band	2.4 GHz	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz
Data Rate (typical)	1 Mbps	25 Mbps	6.5 Mbps	25 Mbps	200 Mbps
Data rate (max)	2 Mbps	54 Mbps	11 Mbps	54 Mbps	540 Mbps
Range (indoor)	30 meters	10 meters	30 meters	30 meters	50 meters
Transmission	FHSS, DSSS, IR	DSSS with CCK	OFDM	OFDM, CCK DSSS+ DB(Q)PSK	MIMO-OFDM

4.2 IEEE 802.15 Family Standards

15th working group of the IEEE 802 specializes in Wireless PAN (Personal Area Network) standards. It includes four task groups, numbered from 1 to 4.

Task group 1 or **802.15.1** derived a WPAN standard based on **Bluetooth** specification, which is the simple choice for convenient, wire-free, short-range communication between devices. It is a globally available standard that wirelessly connects mobile phones, portable computers, cars, stereo headsets, MP3 players, and more (**Figure 6**). Bluetooth was designed to fill a range of use cases or applications. To improve interoperability, Bluetooth Profiles were written to make sure that the application level works the same way across different manufacturers' products.

Bluetooth radios operate in the unlicensed ISM band at 2.4 GHz using 79 channels between 2.402 GHz to 2.480 GHz (23 channels in some countries). The range for Bluetooth communication is 10 meters with a power consumption of 0dBm (1mW).

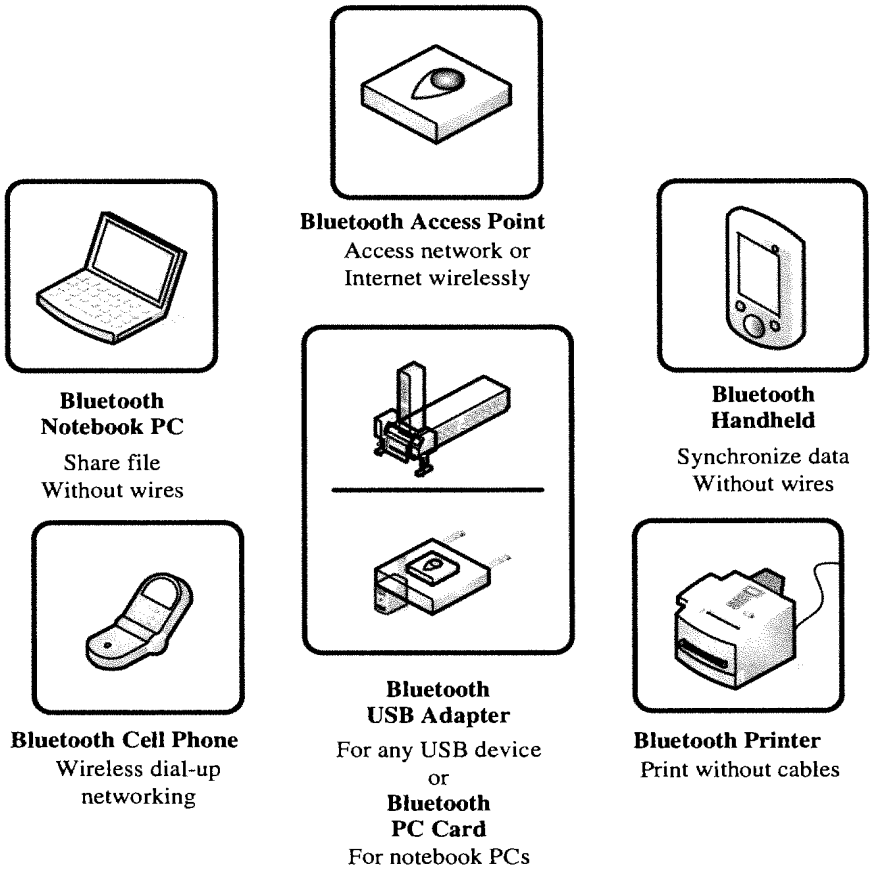


Figure 6. Bluetooth devices

This distance can be increased to 100 meters by amplifying the power to 20dBm. The Bluetooth radio system is optimized for mobility.

The name Bluetooth was born from the 10th century king of Denmark, King Harold Blaatand (whose surname is sometimes written as Bluetooh), who engaged in diplomacy which led warring parties to negotiate with each other. The inventors of the Bluetooth technology thought this a fitting name for their technology which allowed different devices to talk to each other.

The Bluetooth specification was first developed by Ericsson (now Sony Ericsson), and was later formalized by the Bluetooth Special Interest Group (**SIG**). The SIG was formally announced on May 20, 1999. It was established by Sony Ericsson, IBM, Intel, Toshiba and Nokia, and later joined by many other companies as Associate or Adopter members.

Bluetooth technology already plays a part in the rising Voice over IP (VOIP) scene, with Bluetooth headsets being used as wireless extensions to the PC audio system. As VOIP becomes more popular, and more suitable for general home or office users than wired phone lines, Bluetooth may be used in Cordless handsets, with a base station connected to the Internet link.

In March 2006, the Bluetooth Special Interest Group (SIG) announced its intent to work with UWB (ultra-wideband) manufacturers to develop a next-generation Bluetooth technology using UWB technology and delivering UWB speeds. This will enable Bluetooth technology to be used to deliver high speed network data exchange rates required for wireless VOIP, music and video applications.

The IEEE **802.15.3** High Rate Task Group (TG3) for WPANs is chartered to draft and publish a new standard for high-rate (20Mbit/s or greater) WPANs. Besides a high data rate, the new standard will provide for low power, low cost solutions addressing the needs of portable consumer digital imaging and multimedia applications. Another member of 802.15 family is the IEEE 802.15 High Rate Alternative PHY Task Group (TG3a) or **802.15.3a** is working to define a project to provide a higher speed **Ultra-wideband (UWB)** PHY enhancement amendment to 802.15.3 for applications which involve imaging and multimedia.

Ultra-Wideband (UWB) is a recently allocated unlicensed spectrum (3.1–10.6 GHz) that provides an efficient use of scarce radio bandwidth while enabling both high data rate personal-area network wireless connectivity as well as long-range, low data rate applications. UWB was previously defined as an impulse radio, but the industry now views it as an available bandwidth set with an emissions limit that enables coexistence without harmful interference.

Due to its extremely short range, UWB is limited to the same sort of devices that Bluetooth is used for. The main advantage to using Ultra-wideband as opposed to Bluetooth is, as the name implies, bandwidth speed. Excepting any interference, a UWB device could theoretically achieve transfer speeds of up to 1 Gbps (today's Bluetooth devices have a theoretical limit of 3Mbps). The ranges of applications for these kinds of speeds are staggering even given the range limitations of UWB.

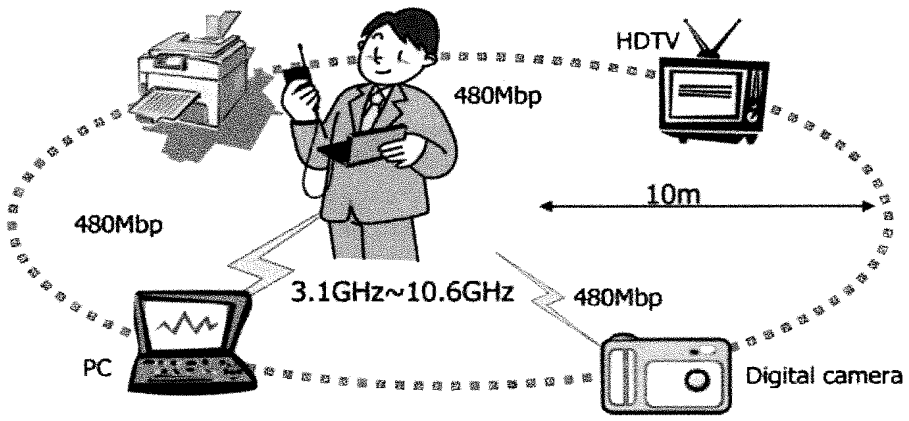


Figure 7. UWB applications example

As **Figure 7** indicates, UWB is a potential market includes a broad spectrum of products and applications. One typical scenario is promising wireless data connectivity between a host and associated peripherals such as keyboards, mouse, printer, scanner, and so on. A UWB link functions as a 'cable replacement' with transfer data rate requirements that range from 1000 Kbps for wireless mouse to 100 Mbps for rapid file sharing or download of images/graphic files. Additional driver applications relate to streaming of digital media content between consumer electronics appliances, such as digital TVs, VCRs, CD/DVD players, MP3 players and so on. In summary UWB is seen as having potential for applications that to date have not been fulfilled by other wireless short-range technologies currently available, such as, 802.11 LANs or Bluetooth PANs.

One of the technologies fully utilizing the advantages of UWB is the **Wireless USB (WUSB)**. WUSB is a new wireless extension to USB intended to combine the speed and security of wired technology with the ease-of-use of wireless technology. WUSB is based on ultra wideband wireless technology defined by WiMedia (***IEEE 802.15.3a***), which operates in the range of 3.1–10.6 GHz.

Wireless USB supports the 480 Mbps data rate over a distance of two meters. If the speed is lowered to 110 Mbps, UWB will go a longer distance (up to 10 meters). WUSB supports so-called dual-role devices, which in addition to being a WUSB client device, can function as a host with limited capabilities. For example, a digital camera could act as a client when connected to a computer, and as a host when transferring pictures directly to a printer.

WUSB will be used in devices that are now connected via regular USB cables, such as game controllers, printers, scanners, digital cameras, MP3 players, hard disks and flash drives, but it is also suitable for transferring parallel video streams.

4th and last member of IEEE 802.15 family is the **IEEE 802.15.4** was chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. This standard specifies operation in the unlicensed 2.4 GHz, 915 MHz and 868 MHz ISM bands. The raw, over-the-air data rate is

250 Kbps per channel in the 2.4 GHz band, 40 Kbps per channel in the 915 MHz band, and 20 Kbps in the 868 MHz band. Transmission range is between 10 and 75 meters.

ZigBee is the most succeed technology based on 802.15.4 standard. ZigBee's current focus is to define a general-purpose, inexpensive, self-organizing, mesh network that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, interactive toys, smart badges, remote controls, and home automation, etc. (**Figure 8**). The resulting network will use very small amounts of power so individual devices might run for a year or two using the originally installed battery.

We summarize the IEEE 802.15 based standards major parameters in **Table 3**.

4.3 WiBro/Mobile WiMax (IEEE 802.16e)

In February 2002, Korean government allocated 100 MHz bandwidth of 2.3GHz spectrum band for **WiBro** (Wireless Broadband) system. WiBro allows subscribers to use high-speed Internet more cheaply and more widely, even when moving at speeds of about 60 km (37 miles) per hour. WiBro base stations will offer an aggregate data throughput of 30 to 50 Mbps and cover a radius of 1–5 km allowing for the use of portable Internet usage within the range of a base station. From testing during the APEC Summit in Pusan in late 2005, the actual range and bandwidth were quite a bit lower than these numbers. The technology will also offer Quality of Service. The inclusion of QoS allows for WiBro to stream video content and other loss-sensitive data in a reliable manner. The WiBro system was developed as a regional and potentially international alternative to 3.5G systems, which delivers

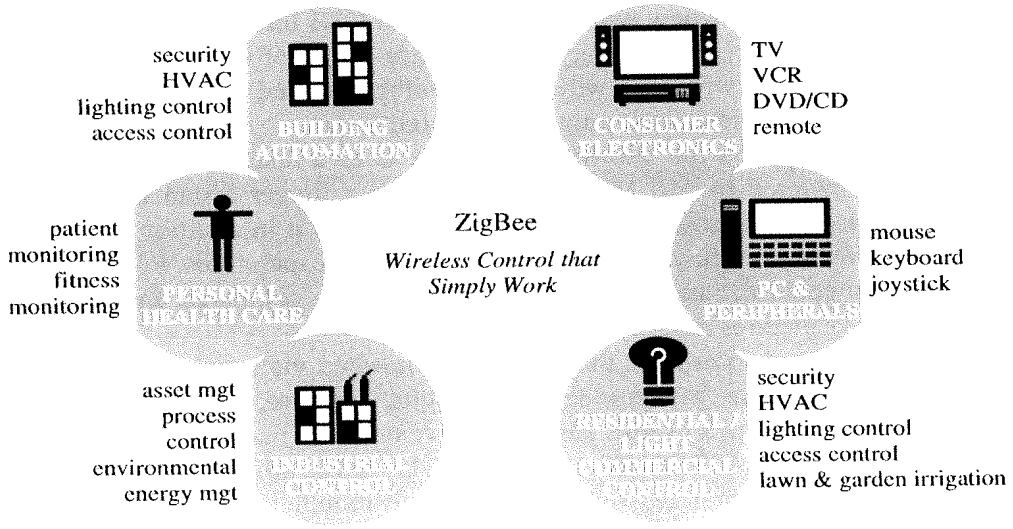


Figure 8. ZigBee applications example

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Table 3. 802.15 based standards

Key features	Bluetooth 802.15.1[a]	802.15.3[b]	802.15.3a UWB/HR[c]	802.15.4 ZigBee[d]
Status of standard	Approved	Approved	Under discussion	Approved
Operating Frequency	2.4-2.4835 GHz ISM band	2.4-2.4835 GHz ISM band	3.1-10.6 GHz	868-868.6 MHz 2.4-2.4835 GHz ISM band
Max. data rate	1 Mbps	QPSK: 11Mbps 64QAM:55mbps	110Mbps (<10m) 200Mbps (4m) 480Mbps (2m)	250Kbps 40Kbps 20Kbps
Max. range	10m (opt. 100m)	10 m	10 m	30 m
Modulation	GFSK	D-QPSK, 16-,32-,64QAM	BPSK, QPSK	BPSK, QPSK
Spreading	DS-FH	N/A	Multiband OFDM or DS-SS	DS-SS
Max. transmit power	0 dBm 20 dBm for 100m	100 mW	-41.3 dBm/MHz 0.562 mW	20 mW
Cost	$5	Unknown	$20~	$2.50

[a] http://www.bluetooth.com
[b] http://www.ieee802.org/15/pub/TG3.html
[c] http://www.ieee802.org/15/pub/TG3a.html
[d] http://www.zigbee.com

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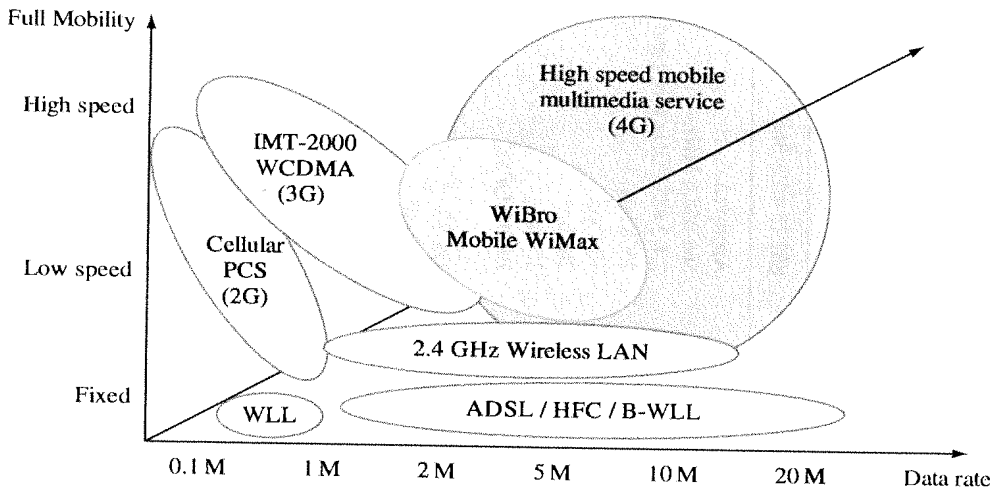


Figure 9. WiBro service location

superior spectral efficiency and end-user throughput than today's 3G networks, and acts as a transition to 4G (**Figure 9**).

Table 4 lists the major parameters and radio access requirements for WiBro system. WiBro adopts OFDMA/TDD for multiple-access and duplex schemes, and aims to provide a high data rate wireless Internet access with PSS (Personal Subscriber Stations) under the stationary or mobile environment, regardless of the place and time. WiBro supports the various types of wireless multimedia applications and various types of multimedia-enabled terminals such as handsets, notebook, PDA or smart phone. Depending on urban environment WiBro service supports different cell types with different cell radius. Pico- and micro-cell radiuses equal to 100 m and 400 m, respectively, whereas macro-cell service coverage is up to 1 km. System supports mobile users at a velocity of up to 60 km/h, although last trials showed that this parameter can be upgraded up to 100 km/h.

These all appear to be the stronger advantages over another wireless broadband access standard called **WiMax (Worldwide Interoperability for Microwave Access)**. Formed in April 2001 to promote conformance and interoperability of the standard IEEE 802.16, the WiMax Forum describes WiMAX as "*a standards-based*

Table 4. WiBro system major parameters and radio access requirements

Major system parameters		Radio access requirements	
Duplexing	TDD	Frequency reuse factor	1
Multiple Access	OFDMA	Mobility	<100 Km/h
Frequency band	2.3 GHz	Service coverage	<1 Km
System Bandwidth	10 MHz	Throughput	Max. DL/UL=3/1 Mbps Min. DL/UL=512/128 Kbps
Sampling frequency	10 MHz	Handoff	<150 ms

technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL."

Given the lack of self developed momentum as a standard, WiBro has joined WiMAX and agreed to harmonize with the similar IEEE 802.16-2005 standard, formerly named but still best known as **802.16e** or **Mobile WiMAX** standard, which is approved in December, 2005.

The WiMAX mobility standard is an improvement on the modulation schemes stipulated in the original (fixed) WiMAX standard. It allows for fixed wireless and mobile Non Line of Sight (NLOS) applications primarily by enhancing the OFDMA (Orthogonal Frequency Division Multiple Access). From **Table 5** you can see that WiBro is fully compatible with Mobile WiMax.

Currently the only competitor of WiBro/Mobile Wimax is the HSDPA, which enables WCDMA operators to increase peak data download speeds fivefold. **Table 6** compares the main parameters of both, HSDPA and Mobile WiMax systems. It is

Table 5. Comparison between WiMax and WiBro systems

Items	WiMax (fixed) 802.16d	802.16e	
		Mobile WiMax	WiBro
Frequency (GHz)	3.5, 5.8	2.3, 2.5, 3.5, etc.	2.3
Bandwidth (MHz)	3.5, 7, 10, 14	3.5, 7, 8.75, 10, 14	10
Duplex method	TDD/FDD	TDD	TDD
Multiple access	TDMA	OFDMA	OFDMA

Table 6. HSPDA vs. Mobile WiMAX

Attribute	HSDPA	Mobile WiMAX
Base standard	WCDMA	IEEE 802.16e
Duplex method	FDD	TDD (FDD opt.)
DL multiple access	CDM-TDM	OFDM
UL multiple access	CDMA	OFDMA
Channel BW	5 MHz	Scalable: 4.375, 5, 8.75, 10 MHz
BS-to-BS distance	2.8 km	2.8 km
Modulation DL	QPSK/16QAM	QPSK/16QAM/64QAM
Modulation UL	BPSK/QPSK	QPSK/16QAM
Coding	CC, Turbo	CC, Turbo
Peak data rate	DL:14 Mbps UL: 2 Mbps	46(1:1)~54(3:1) Mbps (DL/UL combined (32,14), (46,8))
H-ARQ	Fast 6-channel Asycnhronous CC	Multi-channel Asynchronous CC
Scheduling	Fast in DL	Fast in UL and DL
Handoff	Network initiated hard	Network optimized hard
Tx diversity and MIMO	Simple open & closed loop	STBC, SM

expected that in areas where HSDPA becomes widely available, like Western Europe, and where well-suited spectrum for 802.16e is rare, the window of opportunity for mobile WiMax will be quite limited. However the scalable architecture, high data throughput and low cost deployment make WiBro/Mobile WiMAX a leading solution for wireless broadband services. The high data throughput enables efficient data multiplexing and low data latency. Attributes essential to enable broadband data services including data, streaming video and VoIP with high quality of service (QoS).

In June 2006 SK Telecom and KT launched the world first commercial WiBro service in Korea. Market research results shows that by the end of year 2006 it is expected about 610 thousand subscribers join the WiBro network, and within the next few years number of WiBro users increases rapidly. The scalable architecture, high data throughput and low cost deployment make WiBro/Mobile WiMAX a leading solution for wireless broadband services. The high data throughput enables efficient data multiplexing and low data latency. Attributes essential to enable broadband data services including data, streaming video and VoIP with high quality of service (QoS).

5. WIRELESS BROADCASTING SERVICES

The rushing trend of digital revolution has resulted in personalized and mobile communication service and created a new stream of personalized and mobile TV broadcasting service. Mobile digital broadcast TV combines the two best-selling consumer products in history—TVs and mobile phones. Mobile digital TV (DTV) is already becoming a delivery mechanism for TV broadcasts, bringing new interactivse content to a new generation of customers that wants both communications and entertainment – all in one place.

Like all new technologies, there are several different standards for mobile DTV around the world. These include three primary open standards developed by industry associations with contributions from multiple players in the mobile DTV marketplace:

- DMB (digital media broadcast) has deployed today in Korea with several handsets already in-market to support the standard and is expanding to Europe and other parts of Asia.
- DVB-H (digital video broadcast-handheld) is quickly gaining ground with trials in Europe, the U.S. and parts of Asia.
- ISDB-T (integrated services digital broadcast-terrestrial) is the standard in Japan.

Digital Multimedia Broadcasting – a digital transmission system for sending data, radio and TV to mobile devices such as mobile phones. It can operate via satellite (**S-DMB**) or terrestrial (**T-DMB**) transmission (**Figure 10**). DMB is based on the Eureka 147 DAB standard.

In May 2005, SK Telecom (South Korea) launched a satellite DMB (S-DMB) service that delivers high-quality video broadcasts to a mobile phone or car-based

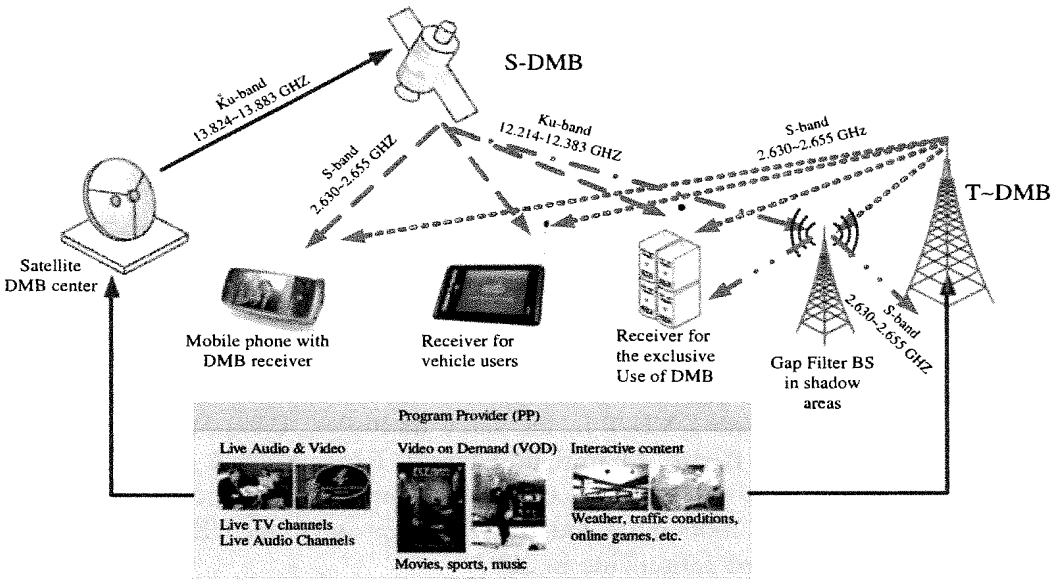


Figure 10. S-DMB and T-DMB services working principle

video entertainment system. SK Telecom is initially delivering 11 video channels, 25 audio channels, and 3 data channels. In S-DMB service customers can receive the signal transmitted by the satellite directly from most areas on the ground. However, there are some shadow areas such as subways, tunnels, inside buildings, etc. However, the signal receiving areas can be extended by installing Gap Fillers (Base Stations) in those shadow areas.

S-DMB utilizes Ku-Band (13.824~13.883GHz) between the Signal Transmission Center and satellite (the 144th degree of east longitude), and S-Band (2.630~2.655 GHz, 25MHz) is utilized between satellite (Or Gap Filler) and the terminals. Further, Ku-Band (12.214~12.239GHz) is used between satellite and Gap Filler (Base Station). The S-DMB service adopts the same Code Division Multiplexing (CDM) technology as the mobile phone service. Thus it is the most appropriate for signal reception in a mobile environment. This can also guard against multiple channel interferences that cause reductions in signal receiving quality within the mobile environment.

T-DMB is an ETSI standard (TS 102 427 and TS 102 428). Currently, DMB is in use in a number of countries. South Korea, in particular, started T-DMB service in December 1, 2005. Some T-DMB trials are currently planned around Europe:

- Germany will launch T-DMB for the world cup 2006
- France currently makes a trial in Paris
- Switzerland and Italy prepare a trial for 2006
- UK launch a trial for 2006

Main competitor of DMB system in mobile TV field is the **DVB-H** system. DVB-H is a technical specification for bringing broadcast services to handheld receivers

and was formally adopted as ETSI standard EN 302 304 in November 2004 and has some similarities with the competing mobile TV standard DMB. DVB-H is the latest development within the set of DVB transmission standards. DVB-H technology adapts the successful DVB-T system for digital terrestrial television to the specific requirements of handheld, battery-powered receivers. DVB-H can offer a downstream channel at high data rates which can be used standalone or as an enhancement of mobile telecoms networks which many typical handheld terminals are able to access anyway.

DVB-H is designed to work in the following bands:

- VHF-III (174–230 MHz, or a portion of it)
- UHF-IV/V (470–830 MHz, or a portion of it)
- L –band (1.452–1.492 GHz)

DVB-H can coexists with DVB-T in the same multiplex. DVB-H trials are now underway in Helsinki, Berlin, Oxford, Pittsburgh, Paris, Madrid, Sydney, South Africa, The Hague, Delhi, Bern and Erlangen. Commercial launches of DVB-H services are expected in 2006 in Finland, Italy, Albania and in the USA. In Germany, DVB-H will be launched nationwide in 2007.

Another system that provides a digital TV to mobile users is Japanese **ISDB-T**. ISDB-T was adopted in commercial transmissions in Japan in December 2003. It comprises a market of about 100 million television sets. ISDB-T had 10 million subscribers by the end of April 2005. ISDB-T was pointed out as the most flexible of all for better answering the necessities of mobility and portability. It is most efficient for mobile and portable reception.

ISDB-T is characterized by the following features:

- ISDB-T can transmit a HDTV (High Definition Television) channel and a mobile phone channel within the 6 MHz bandwidth usually reserved for TV transmissions.
- ISDB-T allows switching to two or three SDTV (Standard Definition Television) channels instead of one HDTV channel (multiplexing SDTV channels).
- ISDB-T provides interactive services with data broadcasting.
- ISDB-T supports Internet access as a return channel that works to support the data broadcasting. Internet access is also provided on mobile phones.
- ISDB-T allows HDTV to be received on moving vehicles at over 100 km/h.
- 1seg is a mobile terrestrial digital audio/video broadcasting service in Japan. The 1seg can be received on mobile phones moving at a speed over 400 km/h.

Mobile DTV is coming to a phone. It's true that the technology will likely first take off in urban centers with heavy commuters and with teenagers and the younger population. But merging a mobile phone with a TV is something that everyone can understand. And with our universal hunger for information and connectivity, mobile DTV presents the perfect opportunity for users to stay informed and up to date on what is happening in the news, with their favorite sports team and even their favorite reality TV show or soap opera.

We finalize this section by comparing the main parameters of major digital broadcasting services in **Table 7**.

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Table 7. Comparison of beyond 3G and 4G systems

Key features	WiBro	3G LTE	IEEE 802.20	4G
Spectrum	2.3 GHz	2.5~2.6 GHz		3~5 GHz
Bandwidth	10 MHz (20 MHz)	5MHz, 10MHz, 15MHz, 20MHz	5MHz, 10MHz, 15MHz, 20MHz	5~100 MHz
Multiple Access	OFDMA/TDD	OFDMA/FDD, TDD;SC-FDMA,	OFDMA/FDD, TDD	OFDMA, MC-CDMA, ???
Service	Portable Internet/ High-speed Wireless Internet	High-speed mobile service	High-speed mobile service	Ubiquitous Broadband Convergence
Peak Data Rate	30/50 Mbps@ 3 km/h	100 Mbps@ 3 km/h	100 Mbps@ 3 km/h	120 Mbps@ 100 km/h 1/3 Gbps@ 3km/h
Mobility	~120 km/h	~350 km/h	~350 km/h	~350 km/h
Remarks	WiBro-II: better performance compared to 3G LTE and 802.20	Similar to 802.20	Supported by QUALCOMM	High coverage, QoS
Service starting time	WiBro: 09.2005 WiBro Evol.: 12. 2007.	July 2007	Suspected until Oct. 2006	2010~2015

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Parameter	DMB	MediaFLO	DVB-H	ISDB-T
Deploying countries	South Korea, Europe	USA	USA, Europe	Japan
Video/Audio codec	H.264/MPEG4	H.264/MPEG2	H.264/MPEG2	H.264/MPEG2
Channel BW/Rate	6MHz/9.2Mbps	5~8MHz/ 11.2Mbps	8MHz/ 15Mbps	6MHz/ 23Mbps
Modulation	OFDM	OFDM	OFDM	OFDM
Available channels	11 TV and 25 radio	19 TV and 10 radio	8 TV and 12 radio	-/-

6. FUTURE MOBILE COMMUNICATION SYSTEMS

While the current third generation systems still heavily rely on classical telephone technology in the network infrastructure, future systems will offer users the choice of many different networks based on the Internet. No one knows exactly when and how this common platform will be available. Companies have to make their money with 3G systems first. However, already Japanese company NTT DoCoMo is talking about the introduction of **4G**. 4G technology stands to be the future standard of wireless devices. The NTT DoCoMo is testing 4G communications under brand name super 3G (or 3.9G) at 100 Mbps while moving, and 1 Gbps while stationary. NTT DoCoMo plans on releasing the first commercial network in 2010. **Figure 11** shows a mobile communication roadmap. Despite the fact that current wireless devices seldom utilize full 3G capabilities, there is a basic attitude that if the pipeline is provided then services for it will follow. In general, a generation is defined by the result of technology changes over a 10–15 year time frame. Thus,

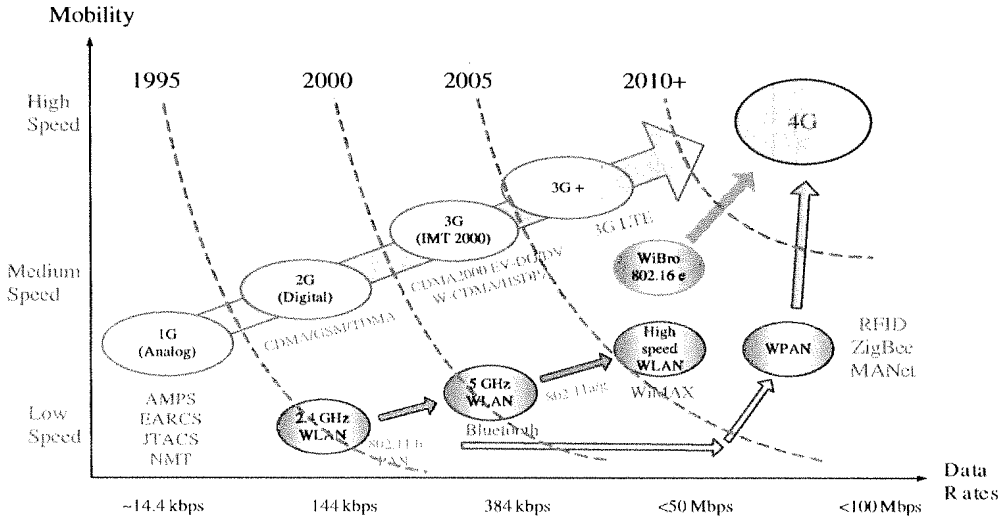


Figure 11. Mobile communication roadmap

4G would refer to whatever is deployed in the 2010–2015 period, assuming 3G deployment spans the 2000–2005 period. Typically, this means a new air-interface with higher data rates in the least, and some see change in the way data transport is handled end-to-end.

Currently, different international organizations such as, ITU-R, ITU-T, 3GPP, 3GPP2 are discussing visions of systems beyond 3G. The major drivers for these systems are the increasing demand for personal mobile communications with respect to performance, applications, traffic, and easy to use. Users are expecting mobile IP applications comparable to the home, a variety of services and applications with a wide spread of usage patterns, data rates and traffic volume. Despite there are different organizations working on 4G development, however all of them define the key issues of 4G systems as accessing information anywhere, anytime, with a seamless connection to a wide range of information, data, pictures, audio, video, and so on.

The term 4G is used broadly to include several types of broadband wireless access communication systems, not only cellular systems. The 4G systems not only will support the next generation of mobile services, but also will support the fixed wireless networks. 4G systems will have broader bandwidth, higher data rate, and smoother and quicker handoff and will focus on seamless service across a multitude of wireless systems and networks.

The future infrastructures of 4G will consist of a set of various networks using IP as a common protocol so that users will be able to choose every application and environment. Currently All-IP network has been tipped as the most probable technology to be synonymous with 4G systems.

The first motivation for an All-IP network is that currently it is the best architectural choice to enable a wide variety of innovative and commercially lucrative services. A second reason is that the relative technical simplicity of the basic IPs, as well as the ability of IP itself to act as a unifying abstraction or waist that hides and divides the complexity of the protocol stack, also helps to make application development for IP networks easier. This has resulted in the rapid development and deployment of a large number of Internet applications, such as, e-mail, messaging, gaming and content distribution. Simplified All-IP network example shown in **Figure 12.**

ITU is currently proposed a new concept called IMT-Advanced, which is responsible for the overall system aspects with capabilities which go further than that of IMT-2000.

The new capabilities of these IMT-Advanced systems are envisaged to handle a wide range of supported data rates according to economic and service demands in multi-user environments with target peak data rates of up to approximately 100 Mbps for high mobility such as mobile access and up to approximately 1 Gbps for low mobility such as nomadic/local wireless access, which enables the favorable conditions to develop the multimedia based services. For example with 1 Gbps data rate mobile subscribers can download the 100 mp3 music files in 2.4 seconds, one 800 Mb movie file in 5.6 seconds, and 20Mbps rate HDTV signal in 12.5 seconds.

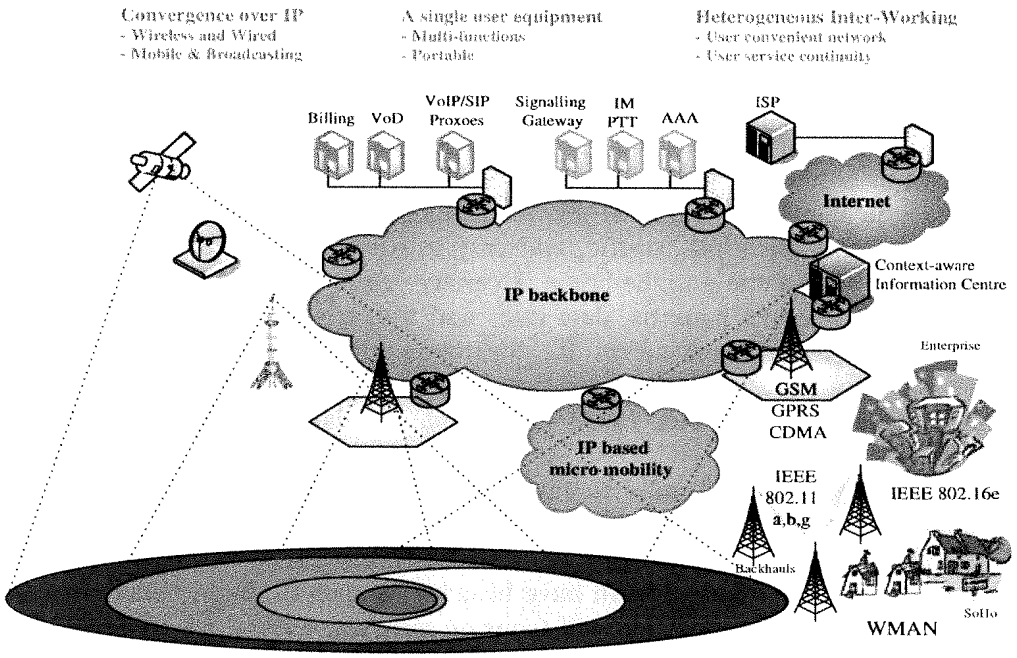


Figure 12. All-IP network example

To support this wide variety of services, it may be necessary for IMT-Advanced to have different radio interfaces and frequency bands for mobile access for highly mobile users and for new nomadic/local area wireless access.

One of the strong migration paths toward IMT-Advanced is 3G LTE (Long Term Evolution) concept proposed by 3GPP. LTE aims to ensure the continued competitiveness of the 3GPP technologies for the future, and focuses on enhancement of UTRA and optimization of the UTRAN architecture. Followings are the LTE requirements for 4G systems:

- Radio Access Network Latency: Significantly reduced latency
- Mobility:
  - Optimized for low mobile speed, higher mobile speed supported with high performance (up to 350 km/h)
  - Voice and other real-time services via Packet Service Domain with at least same quality as supported by 3GPP R6 over the whole of the speed range
- Co-existence and interworking with 3GPP Radio Access Technology
- Mobility between 3GPP and non-3GPP systems
- Peak data rate:
  - max 100 Mbps@20 MHz (DL) and 50 Mbps@20 MHz (UL)
  - DL: 2 receiver antennas with up to 16-QAM, UL: 1 transmitting antenna with 16-QAM
  - Spectrum efficiency: 3 to 4 times 3GPP r6 HSDPA (5bps/Hz), 2 to 3 times R6 enhanced UL (2.5 bps/Hz)

  - Scalable bandwidth: 1.25, 2.5, 5, 10, 15, 20 MHz
- Coverage
  - up to 5 km: performance targets should be met
  - up to 30 km: slight degradations of performance
  - up to 100 km: should not be precluded by the specifications
- Efficient (enhanced) E-UTRAN architecture and smooth migration
- Efficient support for transmission of higher layers
- Reduced complexity: minimization of the number of options.

Although, currently there are several solutions proposed by different vendors to meet the 4G requirements, only few of them can be defined as predominant candidates (**Figure 13**).

Below some of these technologies are described:

- *Multiple access schemes*: OFDMA, MC-CDMA, SC-FDMA
  - Strong desire of OFDMA for DL and SC-FDMA for UL by most companies
- *Modulation and coding*
  - Adaptive Modulation and Coding (AMC).
  - Hybrid Automatic Repeat Request (H-ARQ)
- *Duplex technique*
  - Hybrid Division Duplexing (considering both, TDD and FDD schemes)
- *Inter-cell interference avoiding* at cell edge
  - Interference randomization proposed by RITT, CATT, and others.
  - Interference cancellation method proposed by Panasonic and ETRI
  - Interference coordination/avoidance methods by Siemens, Alcatel and ETRI.
- *MIMO* (Multi Antenna Techniques)
  - 31 proposed MIMO technologies by different vendors (Samsung, Qualcomm, Motorola, NTT DoCoMo, etc.)

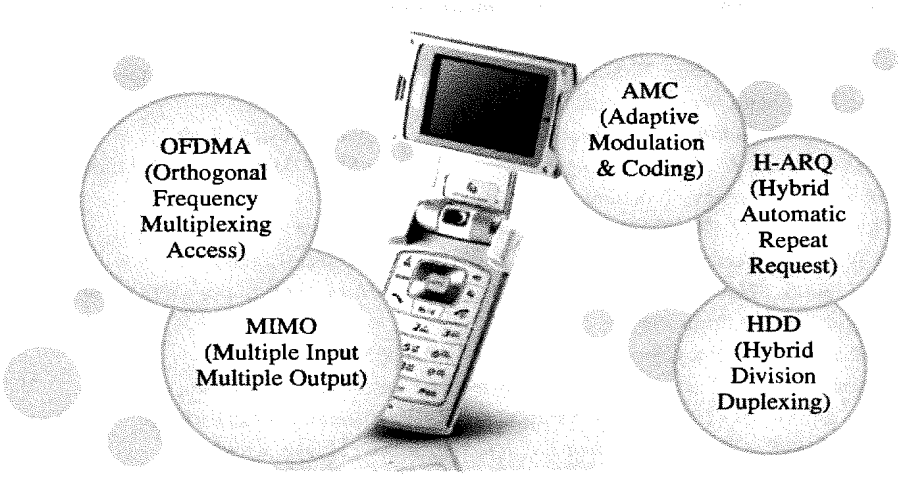


Figure 13. Solutions for next generation mobile communications

- *Cell search schemes*
  - Hot topic and intensive discussion currently
- *Bandwidth scalability*: SCH/BCH position at 20 MHz bandwidth
- *Random access* schemes: synchronized RACH, non-synchronized RACH, TFSTD (Time-Frequency Switching Transmit Diversity) for RACH.
  - Hot topic and intensive discussion currently.

We finalize this chapter by giving the main parameters of beyond 3G and 4G systems in **Table 7**

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CHAPTER 2

RADIO ACCESS TECHNIQUES

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Abstract: This chapter describes the key features of radio access techniques. Introducing the main multiple access methods such as FDMA, TDMA, however much attention in this chapter is paid to CDMA. Especially Section 2 gives the detailed information on CDMA concept, spreading process and spreading codes used by different CDMA standards. Also key factors of CDMA based systems such as handover processing, power control, frequency reuse factor and system capacity are also given by this section. At the end of the chapter we discuss the basics of multi-carrier transmission, introducing such multi-carrier modulation schemes as OFDM, OFDMA, MC-CDMA, MC DS-CDMA and MC CS-CDMA

Keywords: TDMA, FDMA, CDMA, PN sequence, Walsh code, spreading, despreading, frequency reuse factor, sectorization gain, power control, handover, MRC, EGC, Rake receiver, multi-carrier, OFDM, OFDMA, MC-CDMA, MC DS-CDMA, MC CS-CDMA

1. INTRODUCTION TO MULTIPLE ACCESS TECHNIQUES

In communications, a channel access method is used to share a communications channel or physical communications medium between multiple users. The goal in the design of cellular systems is to be able to handle as many calls as possible in a given bandwidth with some reliability. In a mobile cellular system, each mobile station (MS) can distinguish a signal from, the serving base station (BS) and differentiate the signals from neighboring BSs. To accommodate a number of users, many traffic channels need to be made available. In principle there are three different ways to allow access to the channel: frequency, time, and code division multiplexing and is addressed by three multiple access techniques. Next we introduce these techniques – frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA).

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1.1 Frequency Division Multiple Access

If a system employs different carrier frequencies to transmit the signal for each user, it is called FDMA system. FDMA subdivides the total bandwidth into N_c narrowband sub-channels which are available during the whole transmission time. This requires bandpass filters with sufficient stop band attenuation. The concept of FDMA is shown in

Figure 1, three different users are assigned different frequency bands, transmitting own data at the same time duration. In order to cope with frequency deviations of local oscillators and to minimize interference from adjacent channels, a sufficient guard band is left between two adjacent spectra.

Figure 2 shows the simple example of how FDMA works. Couples of users are talking each other at the same time, but separated in frequency domain. While message "OK" is transmitted by the Frequency Channel 1, message "ME" is transmitted by Frequency Channel 2.

The main advantages of FDMA are in its low required transmit power, robustness against multipath fading and easy frequency planning. However, its drawbacks in cellular system might be the implementation of N_c modulators and demodulators at the BS, sensitivity to narrow band interference and bandwidth leakage due to guard bands.

FDMA has been widely adopted in analog systems for portable and automobile telephones. FDMA technique also successfully exploited in GSM cellular system. 124 channels, in GSM 900 and 374 channels in GSM 1800, each 200 kHz wide, are used for FDMA.

1.2 Time Division Multiple Access

TDMA is a popular multiple access technique, which is used in several international standards. TDMA splits a single carrier wave into time slots and distributes the slots among multiple users. As shown in

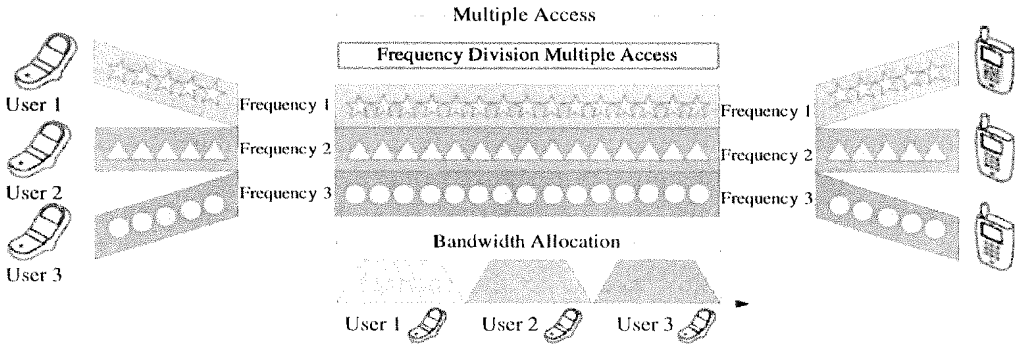


Figure 1. Concept of FDMA

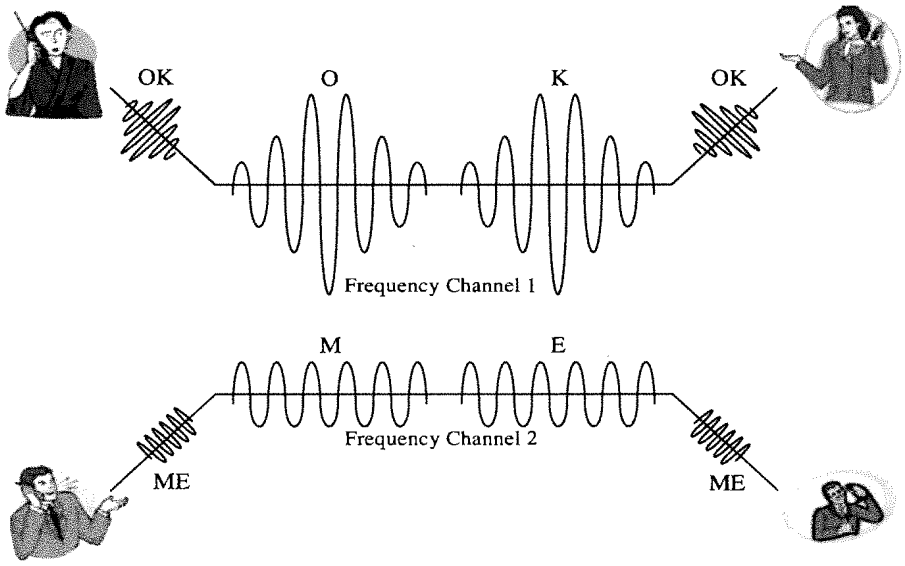


Figure 2. Example of FDMA working principle

Figure 3, three different users sharing the same frequency spectrum, but separated in time domain. The users transmit in rapid succession, one after the other, each using their own timeslot. This allows multiple users to share the same transmission medium (e.g. radio frequency) whilst using only the part of its bandwidth they require.

Figure 4 demonstrates TDMA working principle, two couple of users talking via using of same frequency channel, but separated by different time slots. While

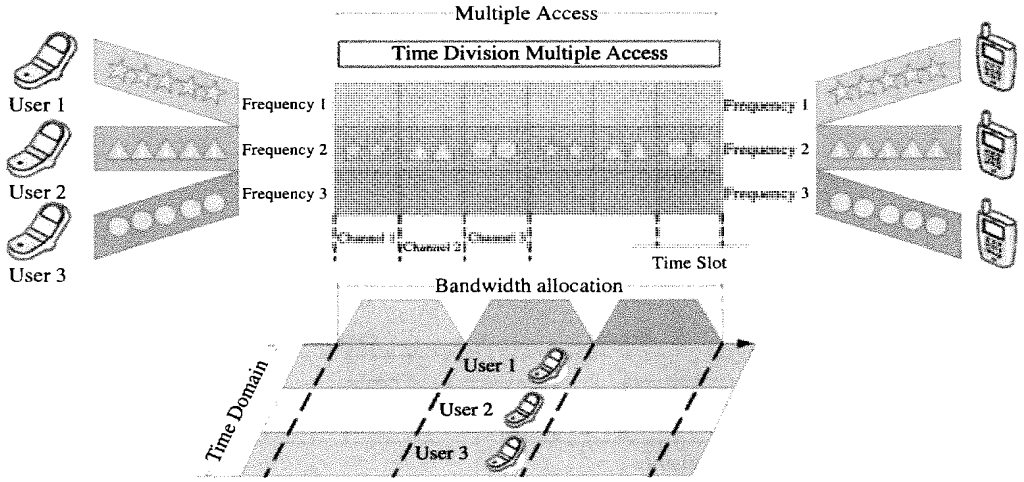


Figure 3. Concept of TDMA

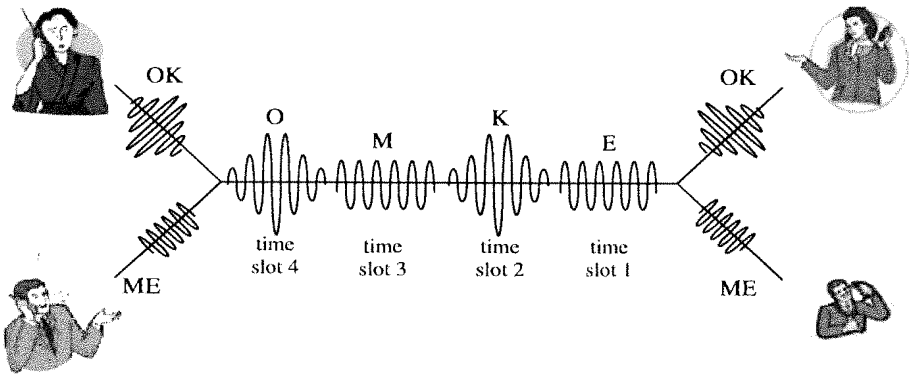


Figure 4. Example of TDMA working principle

message "OK" occupies 2nd and 4th time slots, message "ME" is transmitted during the 1st and 3rd time slots.

TDMA system may be in two modes: FDD (Frequency division duplex) and TDD (Time division duplex). FDD and TDD are the techniques used to separate uplink and downlink channels signals. Channel structures of TDMA/FDD and TDMA/TDD systems are illustrated in **Figures 5** and **6**, respectively.

Time division duplex has a strong advantage in the case where the asymmetry of the uplink and downlink data speed is variable. As the amount of uplink data increases, more bandwidth can be allocated to that and as it shrinks it can be taken away. Another advantage is that the uplink and downlink radio paths are likely to be very similar in the case of a slow moving system. This means that techniques such as beamforming work well with TDD systems.

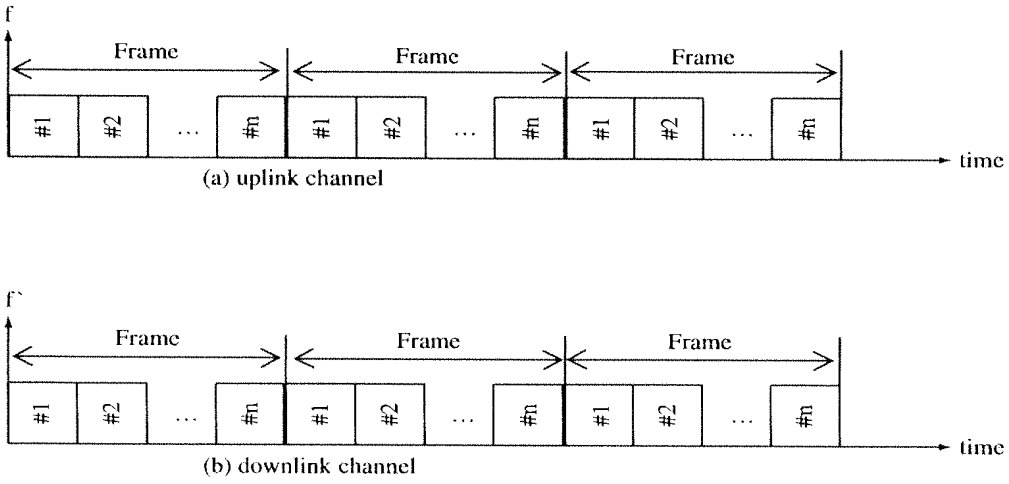


Figure 5. Structure of uplink and downlink channels in a TDMA TDD system

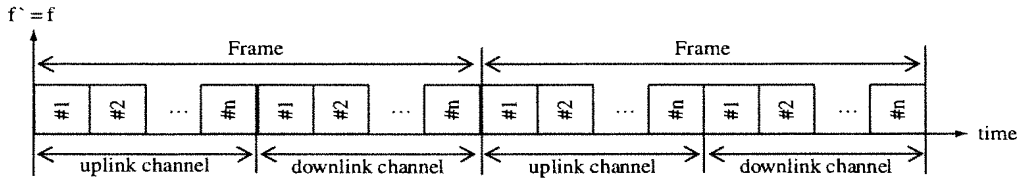


Figure 6. Structure of uplink and downlink channels in a TDMA TDD system

In FDD the uplink and downlink sub-bands are said to be separated by the "frequency offset". Frequency division duplex is much more efficient in the case of symmetric traffic. In this case TDD tends to waste bandwidth during switchover from transmit to receive, has greater inherent latency, and may require more complex and more power-hungry circuitry.

Another advantage of FDD is that it makes radio planning easier and more efficient since base stations do not "hear" each other (as they transmit and receive in different sub-bands) and therefore will normally not interfere each other. With TDD systems, care must be taken to keep guard bands between neighboring base stations (which decreases spectral efficiency) or to synchronize base stations so they will transmit and receive at the same time (which increases network complexity and therefore cost, and reduces bandwidth allocation flexibility as all base stations and sectors will be forced to use the same uplink/downlink ratio).

A major advantage of TDMA is that the radio part of the mobile only needs to listen and broadcast for its own timeslot. For the rest of the time, the mobile can carry out measurements on the network, detecting surrounding transmitters on different frequencies. Disadvantages of TDMA system are high transmit power, sensitivity to multipath and difficulty in frequency planning.

TDMA technique mostly used in digital cellular standards, such as, GSM, PDC, D-AMPS, and others. TDMA is also used extensively in satellite systems, local area networks and physical security systems. While early efforts to incorporate TDMA into UMTS failed, leaving UMTS as a purely CDMA technology, China still continue pursuing TD-SCDMA (time division synchronous CDMA) for the next generation mobile system.

1.3 Code Division Multiple Access

CDMA is a form of multiplexing and a method of multiple access that does not divide up the channel by time (as in TDMA), or frequency (as in FDMA), but instead encodes data with a certain code associated with a channel and uses the constructive interference properties of the signal medium to perform the multiplexing.

As shown in **Figure 7** in CDMA system, different spread-spectrum codes are assigned to each user, and multiple users share the same frequency, at the same time, but are separated from each other via use of a set of orthogonal codes, thus, codes 1010 and 1100 are assigned to User 1 and User 2, respectively, whereas User 3 exploits code 1001 for spreading. In the receiver side original data can be

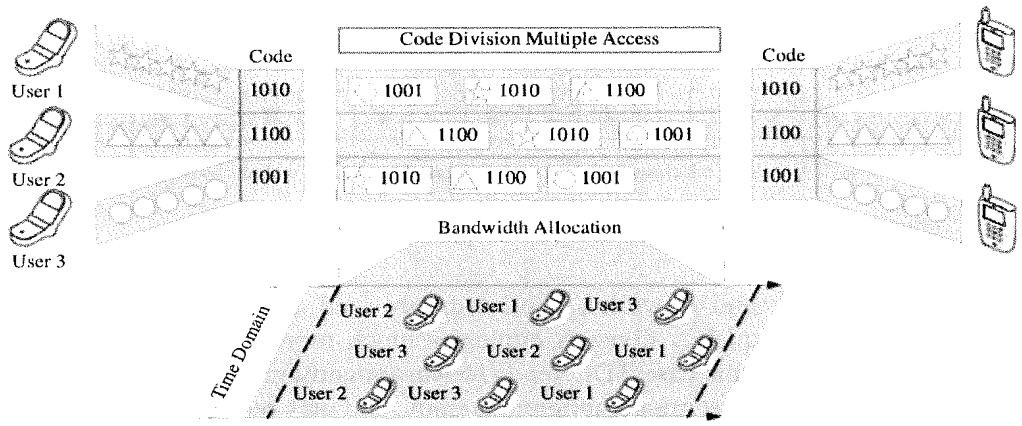


Figure 7. Concept of CDMA

recovered only if the receiver knows the code that used to spread received data. Otherwise, received signals will be identified as interference or noise from other users.

Figure 8 shows the example of CDMA working principle. Both of the messages, "OK" and "ME" transmitted simultaneously in the same frequency channel, but separated by different codes.

CDMA system is based on spread spectrum technology, which provides some advantages which are primarily of interest in secure communication systems, e.g., low probability of intercept or robustness to jamming. In a spread spectrum communication system users employ signals which occupy a significantly larger bandwidth than the symbol rate. Bandwidth spreading is accomplished before the transmission through the use of a code that independent of the transmitted data. The same code is used to demodulate the data at the receiving end.

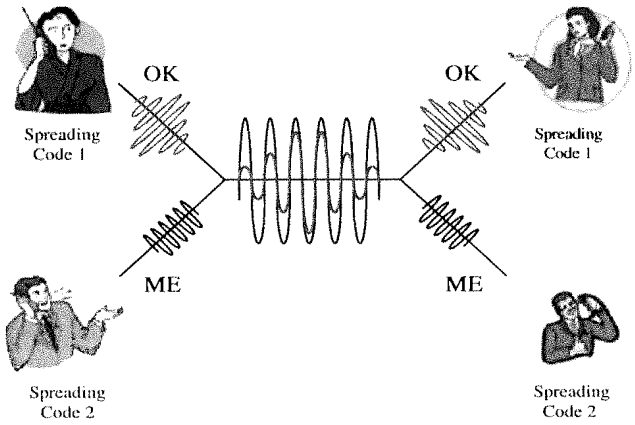


Figure 8. Example of CDMA working principle

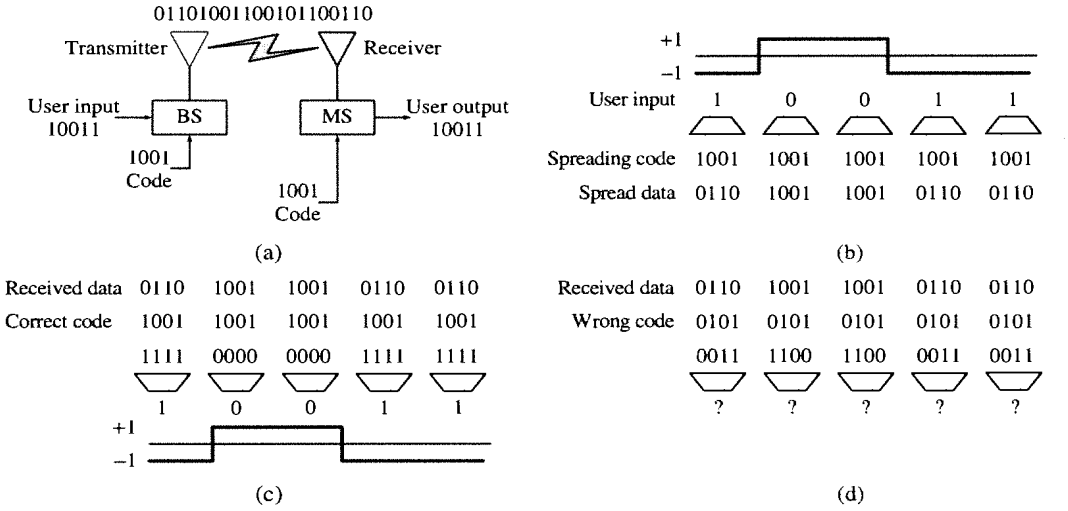


Figure 9. CDMA working principle, (a) general scheme, (b) spreading process, (c) despreading using correct code, (d) despreading using wrong code

Figure 9 gives more detail explanation of spreading and dispreading process. In **Figure 9a** general spreading-despreading process is shown, user input data 10011 is spread by sequence 1001 which results in spread data 0110 1001 1001 0110 0110, this process is given by **Figure 9b**. Next, if encoded sequence is received by correct, destined user original data can be recovered easily via using of correct, spreading code (1001), which is shown in **Figure 9c** As shown in **Figure 9d** in case when spread data is received by wrong user, original data cannot be recovered without knowledge about correct spreading sequence.

Nowadays CDMA is most widely used multiple access scheme and integrated into almost all 3G mobile phone systems like WCDMA (UMTS) and cdma2000. Compared to other schemes CDMA has the advantage of a soft handover and soft capacity. Soft capacity in CDMA systems describes the fact that CDMA systems can add more and more users to a cell with tradeoff the QoS (Quality of Service) in system, i.e. there is no hard limit. Also CDMA can be used in combination with FDMA/TDMA access schemes to increase the capacity of a cell and frequency planning in CDMA systems is much easier compared to the TDMA/FDMA schemes. However there are several disadvantages within the CDMA system, such as, complexity of receivers compared to FDMA/TDMA based networks, needs more complicated power control for senders due to the *near-far problem* (see Section 2.3).

2. CDMA BASED SINGLE CARRIER RADIO ACCESS

Code division multiple access communication is rapidly replacing time- and frequency-division methods as the cornerstone of wireless communication and mobile radio. Above we have discussed multiple access techniques, including

CDMA, in brief. In this section we describe the CDMA based single carrier radio access technique in detail, since it is now attracting the most attention as a core technology for the next-generation mobile communication system.

2.1 The CDMA Concept

In CDMA systems all users transmit in the same bandwidth simultaneously, but are separated from each other via the use of a set of spreading sequences (codes). There are two basic types of CDMA implementation methodologies: *direct sequence (DS)* systems and *frequency hopping (FH)*.

The concept of DS CDMA is shown in **Figure 10**. As illustrated in **Figure 10** each user's narrowband signal is spread over a wider bandwidth. This wider bandwidth is greater than the minimum bandwidth required to transmit the information. Each user's narrowband signal is spread by a different wideband code. Each of the codes is orthogonal to one another, and channelization of simultaneous users is achieved by the use of this set of spreading codes. All the spread wideband signals of different users are added together to form a composite signal, which is transmitted over the radio channel in the same frequency band. The resulting composite signal has a noiselike spectrum, and in fact can be intentionally made to look like noise to all but the intended radio receiver. The receiver is able to distinguish among the different users by using a copy of the original code. The receiver separates the desired user out of the composite signal by correlating the composite signal with original code. All the users with codes that do not match the code of the desired users are rejected.

Figure 11 shows concept of FH CDMA system. In a FH method, a pseudo-random sequence is used to change the radio signal frequency, across a broad frequency band in a random fashion. A spread-spectrum modulation implies that the radio transmitter frequency hops from channel to channel in a predetermined but pseudorandom manner. The RF signal is dehopped at the receiver end via frequency synthesizer controlled by a pseudorandom sequence generator synchronized to the transmitter's pseudorandom sequence generator. If the rate change of the carrier frequency is greater than the symbol rate, then the system is referred to as a *fast frequency hopping system*. In **Figure 12a** there are several frequency hops during the one data symbol, hence this system refers to *fast frequency hopping*. Fast FH

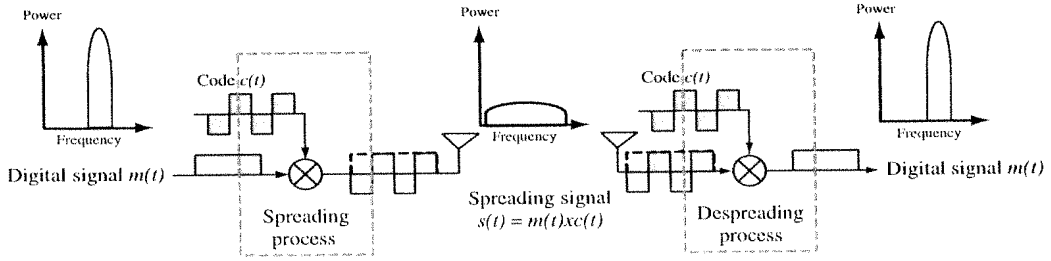


Figure 10. Concept of DS-CDMA

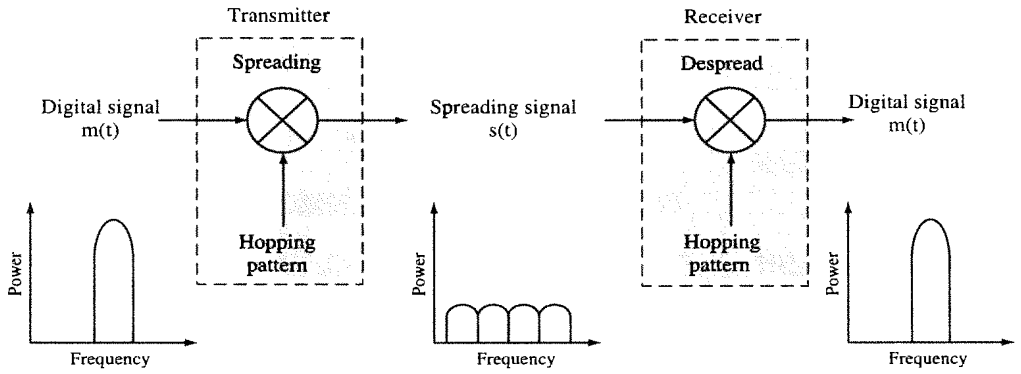


Figure 11. Concept of FH-CDMA

systems are very expensive with current technologies and are not at all common. If the channel changes at a rate less than or equal to the symbol rate, it is called *slow frequency hopping*. As demonstrated in **Figure 12b**, *slow FH* there are several data symbols during the one frequency hop duration, in other words symbol duration is smaller than the hop duration.

A frequency hopped system provides a level of security, especially when a large number of channels are used, since an unintended receiver that does not know the pseudorandom sequence of frequency slots must return rapidly to search for the signal it wishes to intercept. Multiple simultaneous transmission from several users is possible using FH, as long as each uses different frequency hopping sequences and none of them "collide" at any given instant of time.

Figure 13 shows the working principle of a DS CDMA scheme by the example of three users simultaneously transmitting three separate messages $m_1(t)$=[+1,+1, -1], $m_2(t)$,=[1, -1, +1] and $m_3(t)$=[-1, +1, -1]. Users are separated from each other by the multiplication of orthogonal codes $c_1(t)$, $c_2(t)$, and $c_3(t)$, which are equal to [+1, -1, +1, -1], [+1, +1, -1, -1], and [+1, -1, -1, +1], respectively. Messages $m_1(t)$, $m_2(t)$ and $m_3(t)$ are multiplied by the code $c_1(t)$, $c_2(t)$ and $c_3(t)$, respectively. The resulting products are added together and form the signal $s(t) = m_1(t) \times c_1(t) + m_2(t) \times c_2(t) + m_3(t) \times c_3(t)$ which is transmitted through the radio channel. At receiver side to recover the each user's data received signal $r(t)$ is first multiplied by the code sequences $c_1(t)$, $c_2(t)$ and $c_3(t)$, assigned to users 1, 2, and 3, respectively. Next, the resulting products $r(t) \times c_1(t)$, $r(t) \times c_2(t)$, *and* $r(t) \times c_3(t)$, are integrated over one symbol period. After decision (or detection) and digital-to-analog conversion procedures we get the desired stream of information. In our example we assume the ideal channel with no fading and perfect synchronization of the codes at the receiver, hence the received signal $r(t)$is equal to$s(t)$, and the recovered messages $\tilde{m}_1(t)$, $\tilde{m}_2(t)$ *and* $\tilde{m}_3(t)$ match the original messages perfectly.

Figure 14 shows waveforms for the three user messages $m_1(t)$, $m_2(t)$ and $m_3(t)$, orthogonal codes $c_1(t)$, $c_2(t)$, $c_3(t)$, and corresponding spread messages $m_1(t) \times c_1(t)$, $m_2(t) \times c_2(t)$ and $m_3(t) \times c_3(t)$. In this example the chip rate ($1/T_c$) of the

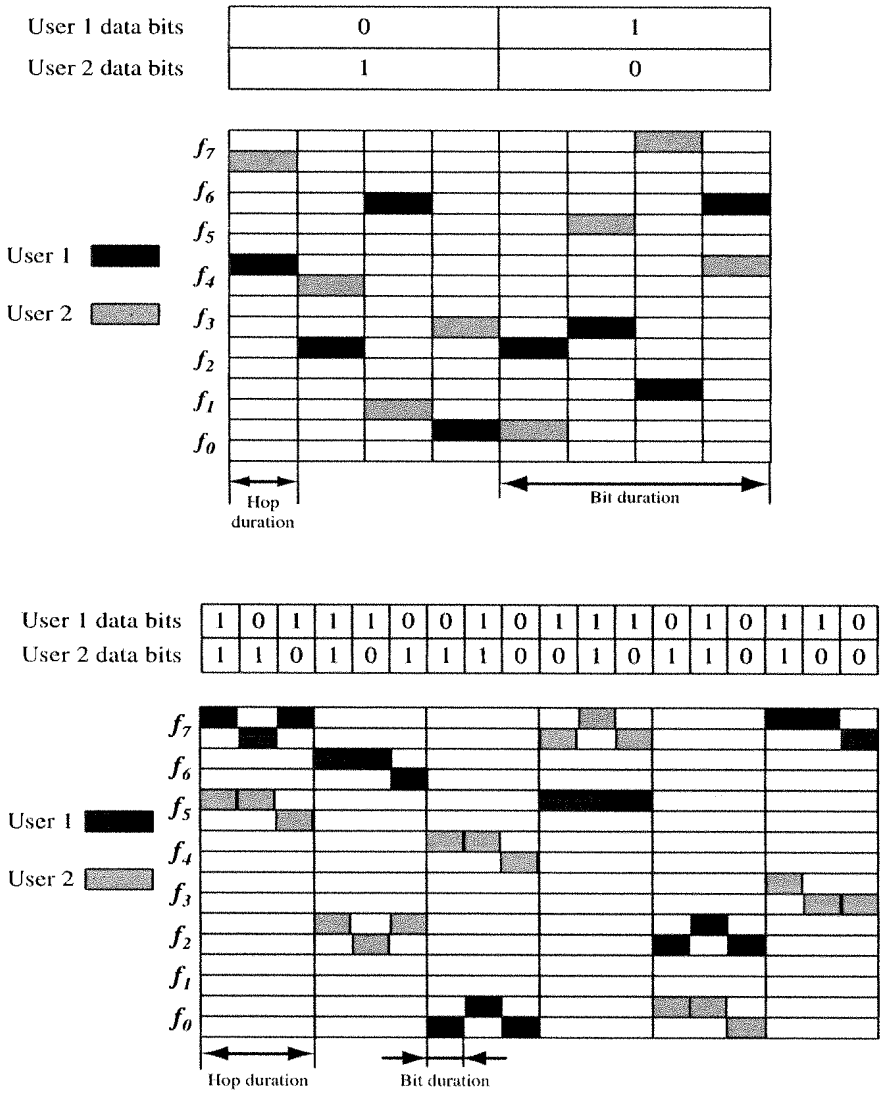


Figure 12. An example of frequency hopping patter. (a) fast frequency hopping, (b) slow frequency hopping

orthogonal code is running at four times the bit rate ($1/T_b$). Therefore, we have a processing gain or an effective bandwidth expansion factor of four.

Figure 15 shows the waveforms at the different points of the receiver. As we mentioned above the received signal $r(t)$ is equal to $s(t)$ and is the summation of the three signals, in other words

$$(1) \qquad r(t) = \sum_{n=1}^{n} m_n(t) c_n(t),$$

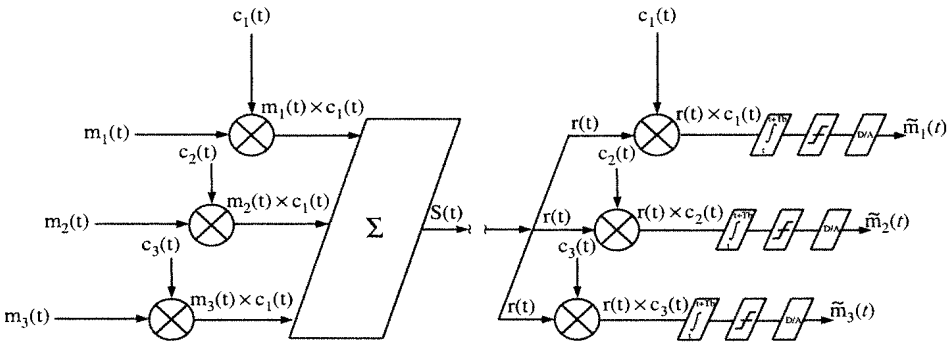


Figure 13. CDMA system example

where N is the total number of users (in this example $N = 3$). Multiplying the $r(t)$ by the three corresponding orthogonal codes $c_1(t)$, $c_2(t)$ and $c_3(t)$ we obtain waveforms represent by $r(t) \times c_1(t)$, $r(t) \times c_2(t)$, and $r(t) \times c_3(t)$, respectively.

Figure 16 shows the signals at the output of the integrators (bold line) and recovered messages (dash line). The integrator adds up the signal power over one bit interval of the baseband message, and the decision threshold decides, based on the output of the integrator, whether or not the particular bit is a +1 or -1. If the output of the integrator greater than 0, then the decision is a +1, otherwise +1. The digital-to-analog (D/A) converter transforms the decision into the recovered waveforms $\tilde{m}_1(t)$, $\tilde{m}_2(t)$ and $\tilde{m}_3(t)$. Since in our example the received signal $r(t)$ is equal to $s(t)$, the recovered messages $\tilde{m}_1(t)$, $\tilde{m}_2(t)$ and $\tilde{m}_3(t)$ match the original messages perfectly.

2.2 Spreading Codes

From previous sections we know that in CDMA system all users share the same RF band. In order to avoid mutual interference, spreading codes are used to separate single users. In the IS-95 CDMA system downlink and uplink channels use different codes to channelize individual users. The downlink uses orthogonal *Walsh codes*, whereas uplink uses *PN (pseudorandom noise) codes* for channelization. In cdma2000 new type of code, the *Quasi-orthogonal code* is introduced.

For CDMA there are three conditions that must be met by a set of spreading sequences:

1. The cross-correlation should be zero or very small.
2. Each sequence in the set has an equal number of 1s and -1s, or the number of 1s differs from the number of -1s by at most one.
3. The scaled dot product of each code should equal to 1.

Walsh codes used in IS-95 are a set of 64 binary orthogonal sequences. In the forward CDMA link, Walsh codes are used to separate users. In any given sector, each forward channel is assigned a distinct Walsh code. In the reverse CDMA link, the 64 Walsh sequences are used for waveform encoding. One Walsh function is

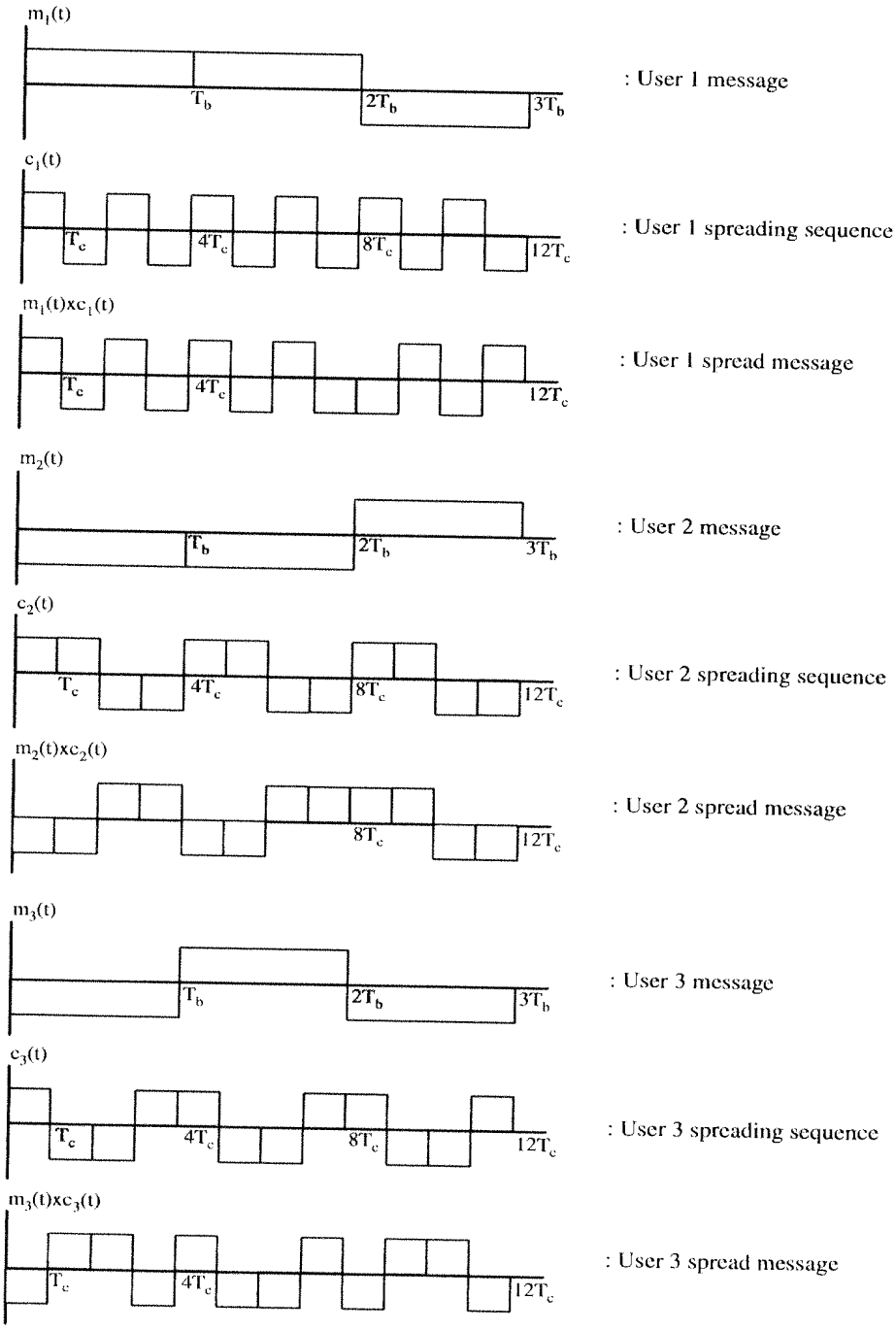


Figure 14. The waveforms for the baseband messages $m_1(t), m_2(t), and\ m_3(t)$, orthogonal codes $c_1(t), c_2(t), and c_3(t)$, and spread messages $m_1(t)c_1(t), m_2(t)c_2(t), and\ m_3(t)c_3(t)$

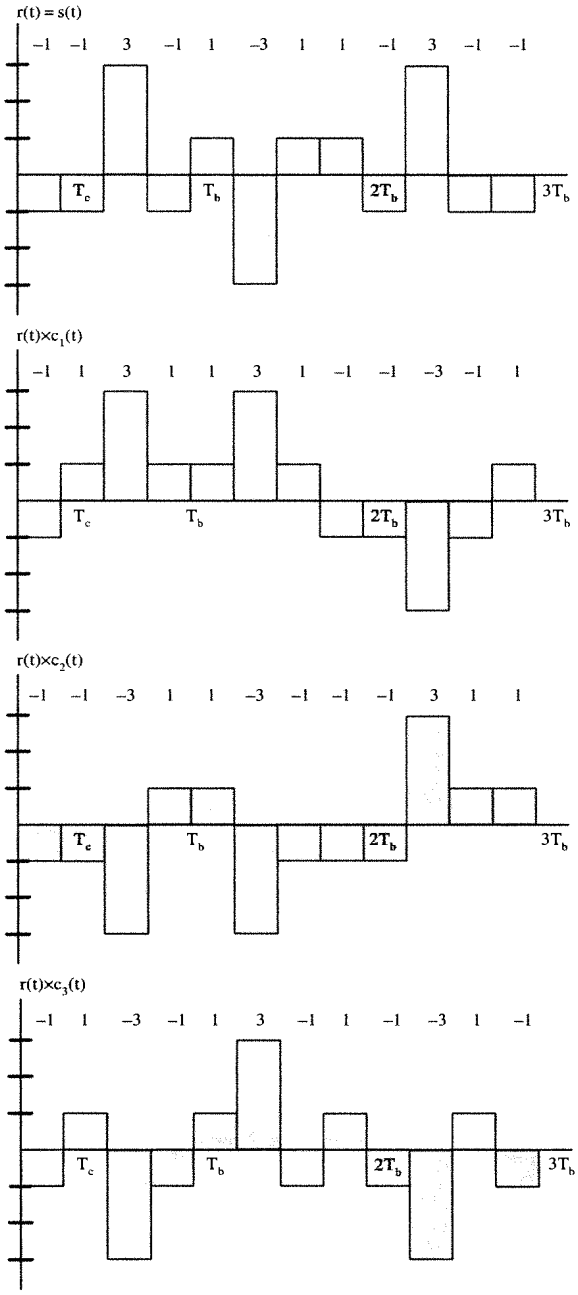


Figure 15. Time waveforms for the signals at different points of the receiver

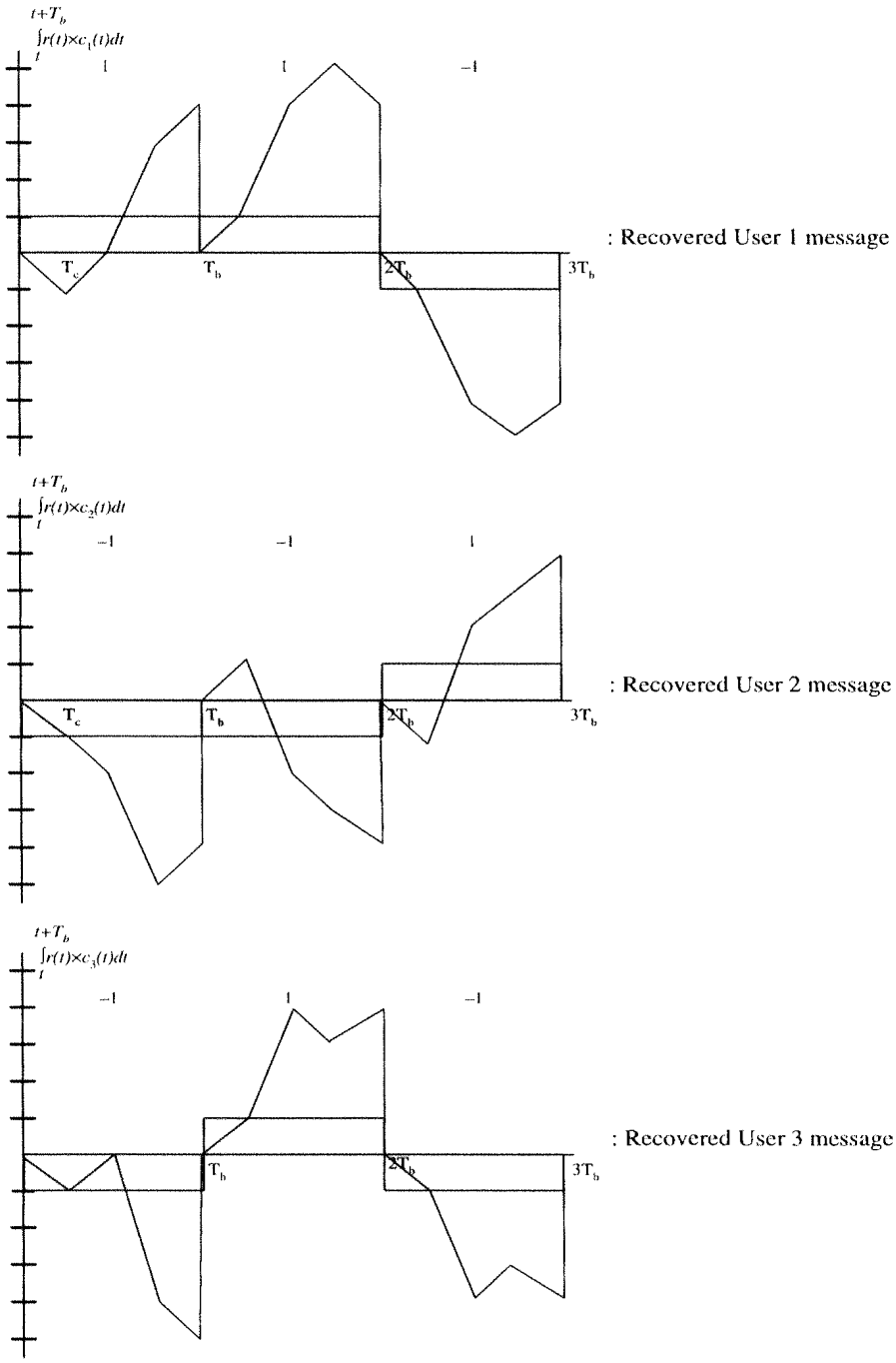


Figure 16. Time waveforms at the output of the integrators (bold line) and decision threshold (dash line)

transmitted for six coded bits. In cdma2000, the Walsh code length limit is 128 for 1x rates and, 256 for 3x rates.

Main parameter of Walsh code sequences is that they are orthogonal. Two real-valued waveforms x and y are said to be orthogonal if their cross-correlation $R_{xy}(0)$ over T is zero, where

$$(2) \qquad R_{xy}(0) = \int_0^T x(t)y(t)dt$$

In discrete time, the two sequences x and y are orthogonal if their cross-product $R_{xy}(0)$ is zero, where

$$(3) \qquad R_{xy}(0) = x^T y = \sum_{i=1}^{I} x_i y_i$$

T in (3) denotes the transpose of the column vector.

For the special case of binary sequences, the values of 0 and 1 may be viewed as having opposite polarity (-1 and 1), and when the product of two binary sequences results in an equal number of 1's and 0's, the cross-correlation is zero. For example, the following two codes, x = [1 -1 1 -1] and y = [1 1 -1 -1], are orthogonal, since their cross-product is zero:

$$R_{xy}(0) = (1)(1) + (-1)(1) + (1)(-1) + (-1)(-1) = 0$$

Walsh codes generated using an iterative process of constructing Hadamard matrix starting with H_1=[1]. The Hadamard matrix is built by using the function

$$(4) \qquad H_{2n} = \begin{bmatrix} H_n & H_n \\ H_n & \overline{H}_n \end{bmatrix}$$

where $\bar{H}_n$contains the same but inverted elements of H_n. Therefore, to obtain a set of eight orthogonal Walsh codes, we need to generate a Hadamard matrix of order 8, or

$$H_8 = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 \\ +1 & -1 & -1 & +1 & -1 & +1 & +1 & -1 \end{bmatrix}$$

where, each row of the matrix above except the first, can be used as orthogonal spreading sequence. The 1st sequence of Hadamard matrix consists of all 1s and thus cannot be used for channelization.

Earlier, in **Section 2.1**, we have illustrated orthogonal Walsh codes ability to provide channelization of different users. However, this ability heavily depends on the orthogonality of the codes during the all stages of the transmission. In practice, the IS-95 CDMA system uses a pilot channel and sync channel to synchronize the downlink and to ensure that the link is coherent. In the uplink, which does not have sync and pilot channels, another type of codes, ***PN codes*** are used for channelization, due to the noncoherent nature of the uplink

PN sequences have an important property: time-shifted versions of the same PN sequence have very little correlation with each other, in other words low *autocorrelation* property. We define the discrete-time autocorrelation of a real valued sequence $\boldsymbol{x}$ to be

$$(5) \qquad R_x(i) = \sum_{j=0}^{J-1} x_j x_{j-i}$$

In other words, for each successive shift i, we calculate the summation of the product of x_j and its shifted version x_{j-i}.

PN code sets can be generated from linear feedback shift registers, as shown in **Figure 17**. The register starts with an initial sequence of bits. In each step, the content of the register is shifted one place to the right and it is also fed back to the leftmost place, the output of the last stage and the output of the one intermediate stage are combined and fed as input to the first stage. The output bits of the last stage form the PN code.

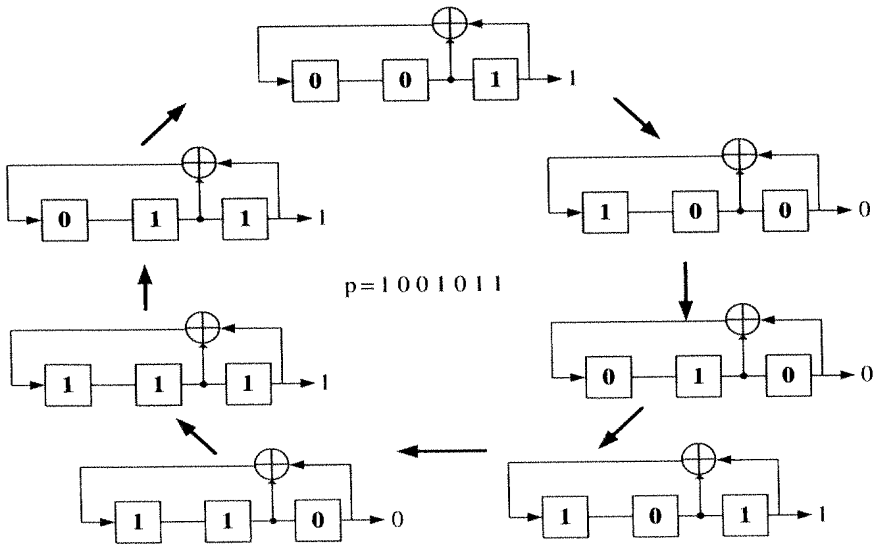


Figure 17. Example for a PN sequence generated by a linear feedback shift register of three stages

The code generated in this manner is called a maximal-length shift register code, and the length L of this code is

$$L = 2^m - 1 \tag{6}$$

where m is the number of stages of the register. In example given by **Figure 17** the linear feedback shift register with three stages is shown. An initial state of [0 0 1] is used for the register. After clocking the bits through the register, we obtain the required PN sequence, which is $p = [1\,0\,0\,1\,0\,1\,1]$.

Note that at shift $L=2^3-1=7$, the state of the register returns to that of the initial state, and further shifting of the bits yields another identical sequence of outputs. A PN code set of 7 codes can be generated by successively shifting **p**, and by changing 0s to -1s we obtain

$$p_1 = [+1\ -1\ -1\ +1\ -1\ +1\ +1]$$
$$p_2 = [+1\ +1\ -1\ -1\ +1\ -1\ +1]$$
$$p_3 = [+1\ +1\ +1\ -1\ -1\ +1\ -1]$$
$$p_4 = [-1\ +1\ +1\ +1\ -1\ -1\ +1]$$
$$p_5 = [+1\ -1\ +1\ +1\ +1\ -1\ -1]$$
$$p_6 = [-1\ +1\ -1\ +1\ +1\ +1\ -1]$$
$$p_7 = [-1\ -1\ +1\ -1\ +1\ +1\ +1]$$

We can easily verify that these codes satisfy the three conditions outlined earlier.

Figure 18 shows the *channelization using PN codes.* Suppose the same two users A, and B wish to send two separate messages:

- User A signal $m_1(t)=[+1\ -1]$, spreading code
  $p_1(t) = [+1\,-1\,-1\,+1\,-1\,+1\,+1]$
- User B signal m_2(t)=[-1 +1], spreading code
  $p_2(t) = [-1\,+1\,-1\,+1\,+1\,+1\,-1]$.
  Each message is spread by its assigned PN code:
- For message one:
  $m_1(t)p_1(t) = [+1\,-1\,-1\,+1\,-1\,+1\,+1\,-1\,+1\,+1\,-1\,+1\,-1\,-1]$;
- For message two:
  $m_2(t)p_2(t) = [+1\,-1\,+1\,-1\,-1\,-1\,+1\,-1\,+1\,-1\,+1\,+1\,+1\,-1]$;

The spread spectrum signals for two messages are combined to form a composite signal s(t):

$$s(t) = m_1 p_1(t) + m_2 p_2(t) =$$
$$= [2\ -2\ 0\ 0\ -2\ 0\ 2\ -2\ 2\ 0\ 0\ 2\ 0\ -2]$$

At the receiver of user B, the composite signal is multiplied by the PN code corresponding to the user B:

$$s(t)p_2(t) = [-2\ -2\ 0\ 0\ -2\ 0\ -2\ 2\ 2\ 0\ 0\ 2\ 0\ 2]$$

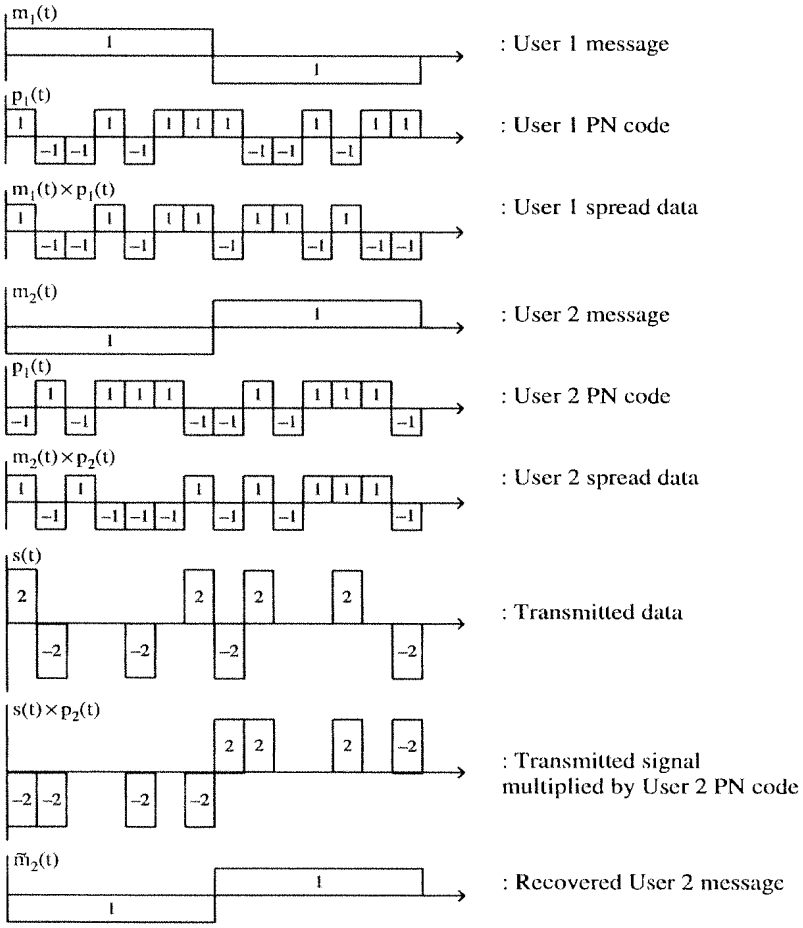


Figure 18. Example of channelization using PN code sequences

Then the receiver integrates all the values over each bit period, which results in $M_2(t) = [-8 \;\; 8]$ function for user *B*. After the decision threshold we obtain the result $\tilde{m}_2(t) = [-1 \;\; +1]$ for user *B*. may try to decode the symbols for user A in the same manner.

The two short codes of length $2^{15}-1$ and one long code length of $2^{42}-1$ used in IS-95 CDMA system. For cdma2000 Spreading Rate 3, the short code length is 3 times the short code length given above or $3x2^{15}$ in length.

All base stations and all mobiles use the same three PN sequences. In uplink direction long PN code used for channelization, by assigning different time shifted versions of the long code to different users, whereas short PN codes used for scrambling users data.

In downlink channel each base station is also assigned a unique, time shifted version of the short PN code that is superimposed on top of the Walsh code. This is done to provide isolation among the different base stations or sectors, which is

necessary because each base station uses the same 64 Walsh code set. Scrambling user data in downlink done via using of long PN code.

Table 1 summarizes the Section 2.2 and gives main parameters of spreading codes

2.3 Key Features of CDMA

As discussed earlier, CDMA offers many advantages over TDMA and FDMA. CDMA is a scheme by which multiple users are assigned radio resources using DS-SS techniques. Nowadays, the most prominent CDMA applications are mobile communication systems like IS-95, cdma2000 or WCDMA. To apply CDMA in a mobile communications systems there are specific additional methods which are required to be implemented in all these systems. Methods such as power control and soft handover have to be applied to control the inter-user interference and to be able to separate the users by their respective codes. In this section we describe some basic CDMA principles, such as frequency allocation, power control, handover, and etc.

Power control is one of the most necessary mechanisms exploited in cellular communication systems. Performance limiting factors, such as, varying path loss and fading result in the need to control the mobile's transmission power. Power control is where the transmit power from each user is controlled such that the received power of each user at the BS is equal to one other.

Especially power control is essential in CDMA based cellular networks since in CDMA all users share the same frequency separated via using of different spreading codes and each user's signals acts as random interference to other users. This issue is also known as the *near-far problem* in a spread-spectrum multiple access systems, and arises when a mobile user near a cell jams a user that is distant from the cell (assuming both are transmitting at the same power). The problem is this: consider a receiver and two transmitters (one close to the receiver; the

Table 1. Spreading codes parameters

	Length	Downlink	Uplink
Walsh codes	64 in IS-95 128 in cdma2000 Rate 1 256 in cdma2000 Rate 3	Used for channelization, except 1st sequence that consists all 1s	Used for waveform encoding (orthogonal modulation)
Long PN code	2^{42}-1	Used for scrambling	Used for channelization
Short PN code	2^{15}-1 in IS-95 and cdma2000 Rate 1 $3x2^{15}$ in cdma2000 Rate 3	Used to separate individual cells or sectors	Used for scrambling

other far away). If both transmitters transmit simultaneously and at equal powers, then the receiver will receive more power from the nearer transmitter. This makes the farther transmitter more difficult, if not impossible, to "understand." Since one transmission's signal is the other's noise the signal-to-noise ratio (SNR) for the farther transmitter is much lower. If the nearer transmitter transmits a signal that is orders of magnitude higher than the farther transmitter then the SNR for the farther transmitter may be below detectability and the farther transmitter may just as well not transmit. This effectively jams the communication channel. In CDMA systems this is commonly solved by *power control.* **Figure 19** demonstrates power control mechanism working principle. There are four MSs located at different distances from BS; if there is no power control mechanism user D signal reaches the BS with too low power since this user is located too far from BS and signals from other MSs reject the user D signal. Using power control mechanism we can achieve the equal power signals from different MSs at the receiver.

There two kinds of power control mechanisms:

- *Open-loop power control* where an original estimate is made by the mobile.
- *Closed-loop power control* where a faster correction is made to this original estimate, based on instruction provided to the mobile by the BS

In the open loop power control, the MS adjusts its own transmit power on the basis of the received downlink signal, whereas in a closed loop the BS measures the received signal strength and transmits a power control command to the MS. In consequence, the MS adjusts it's transmit power on the basis of the received uplink signal.

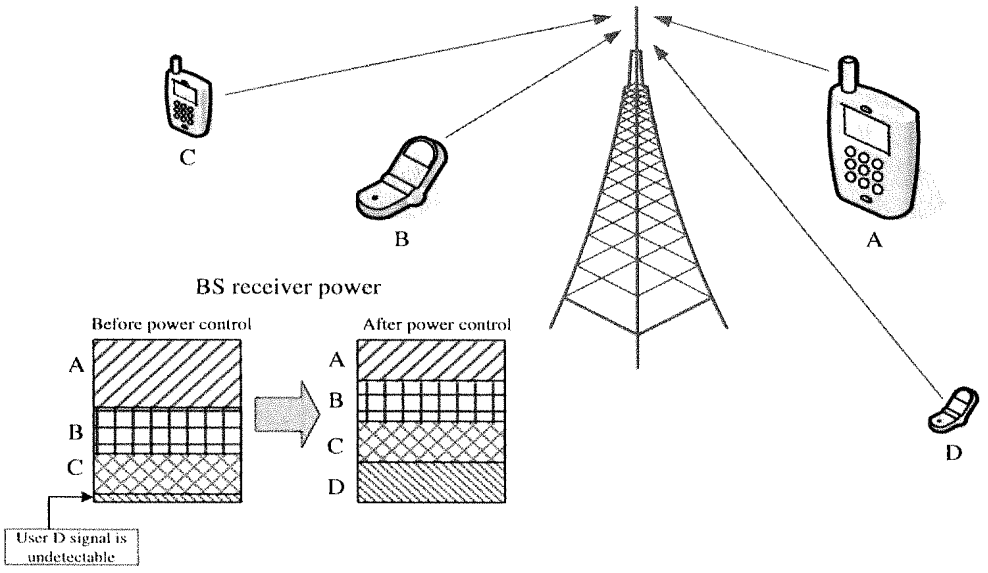


Figure 19. Near-far problem example

First CDMA standard, IS-95, utilized the both mechanisms, whereas current CDMA systems like cdma2000 and WCDMA (UMTS) exploit only closed-loop power control. Thus, in this section much attention is paid to closed-loop power control mechanism.

In ***open-loop power control*** each MS measures the received signal strength of the pilot signal, and depending on this measurement and information from the link power budget that is transmitted during initial synchronization, the downlink path loss is estimated. Assuming a similar path loss for the uplink, the MS uses this information to determine its transmitter power. Leaving out the calculation process we can say that MS power can be achieved as:

$$\begin{aligned} &Mobile\_power(dBm)=target\_SNR(dB)+BS\_power(dBm) \\ &+total\_uplink\_noise\_and\_interference(dBm)-received\_power(dBm) \\ &=constant(dB)-received\_power(dBm) \end{aligned} \tag{7}$$

In IS-95, the nominal value of the *constant* in (7) is specified to be -73 dB. This value can be attributed to the nominal values -13 dB for the target SNR, -100 dBm for the uplink noise and interference, and 40 dBm (10 W) for the BS power. The actual values of these parameters may be different and data for calibrating the *constant* in (7) are broadcast to the MSs on the sync channel.

Open loop power control is used to compensate for slow-varying and log-normal shadowing effects where there is a correlation between forward and uplinks are on different frequencies, the open loop power control is inadequate and too slow compensate for fast Rayleigh fading. To compensate for power fluctuations due to fast Rayleigh fading the ***closed loop power control*** is used.

Once mobile gets on a traffic channel and starts to communicate with the base station, the closed-loop power control process operates along with the open-loop power control. The calculation of downlink path loss through the measurement of the BS received signal strength can be used as a rough estimate of the path loss on the uplink. The true value, however, must be measured at the BS upon reception of the MS's signals. At the BS, the measured signal strength is compared with the desired strength, and a power adjustment command is generated. If the average power level is greater than the threshold, the power command generator generates a "1" to instruct the MS to decrease power. If the average power is less than the desired level, a "0" is generated to instruct the mobile to increase power. These commands instruct the MS to adjust transmitter power by a predetermined amount, usually 1 dB. Ideally, frame error rate (FER) is good indicator of link quality. But because it takes a long time for the BS to accumulate enough bits to calculate FER, E_b/N_0 is used as an indicator of uplink quality.

Figure 20 shows closed loop power control working principle on a fading channel at low speed. Closed loop power control commands the mobile station to use a transmit power proportional to the inverse of the received power (or SNR). Provided the mobile station has enough headroom to ramp the power up, only very little residual fading is left and the channel becomes an essentially non-fading channel as seen from the BS receiver. Although, this fading removal is highly desirable from

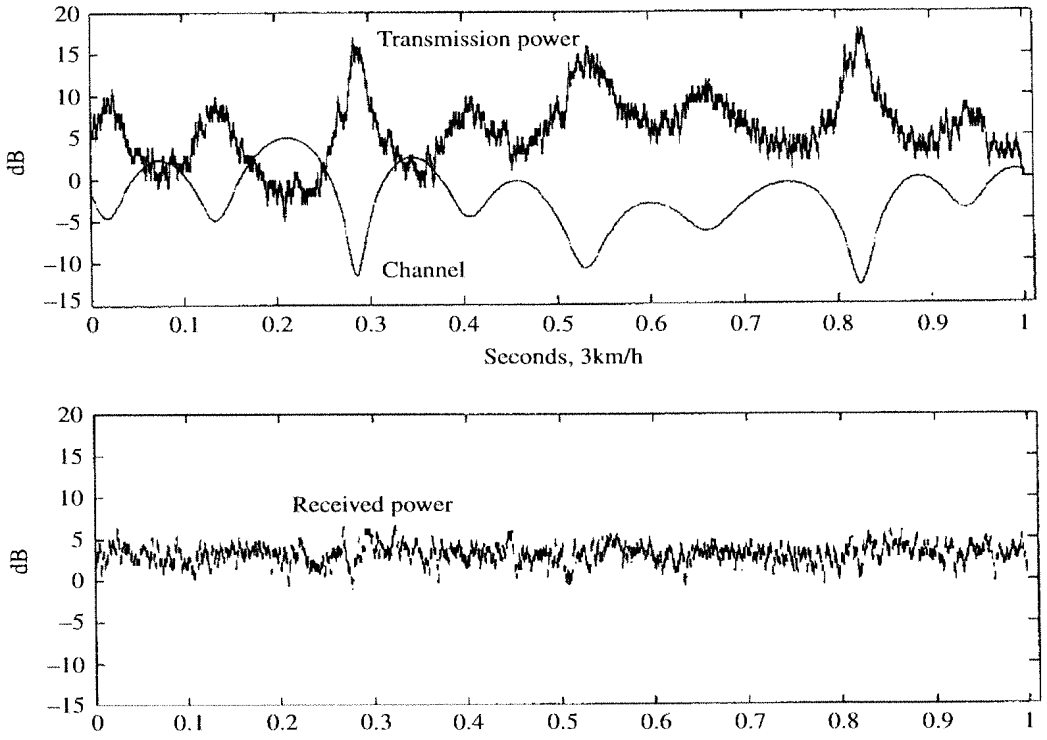


Figure 20. Fading compensation using closed loop power control

the receiver point of view, however it comes at the expense of increased average transmit power at the transmitting side. This means that a mobile station in a deep fade, i.e. using a large transmission power, will cause increased interference to other cells. **Figure 20** illustrates this point.

Closed-loop power control has an inner and an outer loop. Thus far we only have described the *inner-loop* of the closed-loop power control process. The premise of the inner loop is that there exists a predetermined SNR threshold by which power-up and power-down decisions are made. The closed-loop power control also employs what is called an *outer-loop power control.* This mechanism ensures that the power control strategy is operating correctly. The FER at the BS is measured and compared with the desired error rate, and if the difference between error rates is large, then the power command threshold is adjusted to yield the desired FER. Both, inner-loop and outer-loop power control mechanisms are illustrated in **Figure 21**.

Ideally power control is not needed in the downlink. Though in downlink direction the near-far problem does not exist and downlink power control is not necessary as uplink power control. However, in real life, one particular mobile may be nearby a significant jammer and experience a large background interference, or a mobile may suffer a large path loss such that arriving composite signal is on the order of the thermal noise. Thus, downlink power control is still needed. When downlink

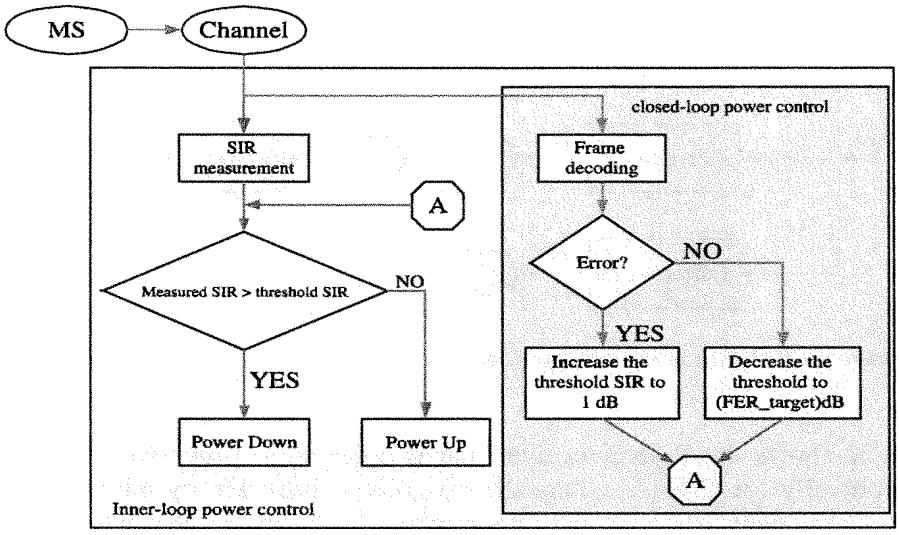


Figure 21. Inner-and outer-closed loop power control mechanism working principle

power control is enabled, the BS periodically reduces the power transmitted to an individual MS. This process continues until the MS senses an increase in the downlink FER. The MS reports the number of FER to BS, and the BS depending on this information can decide whether to increase power by a small amount, nominally 0.5 dB. Before the BS complies with the request, it must consider other requests, loading, and the current transmitted power.

The IS-95 system uses a combination of open-loop and closed-loop power control with rate of 800 Hz or 1.25 ms. Unlike IS-95 where closed loop power control was applied only to the reverse link, both CDMA2000 and WCDMA employ power control in the uplink and downlink directions. The only difference between the two technologies is the rate of the power control. CDMA2000 operates at a rate of 800 Hz, while WCDMA operates power control at a rate of 1600 Hz

Rake receiver. One of the main advantages of CDMA systems is their ability to use signals that arrive in the receivers with different time delays, due to *multipath propagation*. FDMA and TDMA, which are narrow band systems, cannot distinguish between the multipath arrivals, and resort to equalization to mitigate the negative effects of multipath. Due to its wide bandwidth and *rake receivers*, CDMA uses the multipath signals and combines them to make a more reliable signal at the receivers.

A rake receiver is a radio receiver designed to counter the effects of multipath fading. It does this by using several "sub-receivers" or "fingers" each delayed slightly in order to tune in to the individual multipath components. Each component is decoded independently, but at a later stage combined in order to make the most use of the different transmission characteristics of each transmission path. This could very well result in higher SNR ratio (or E_b/N_o) in a multipath environment than in a "clean" environment.

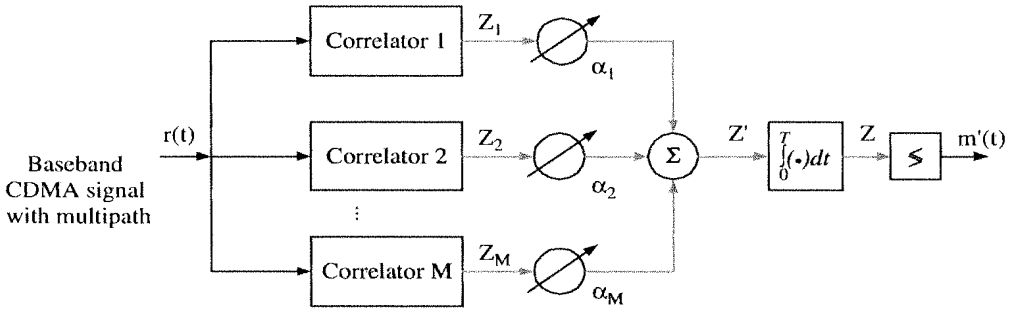


Figure 22. An M-finger RAKE-receiver implementation

In **Figure 22** shows the RAKE-receiver that is essentially a diversity receiver designed specifically for CDMA, where the diversity is provided by the fact that the multipath components are practically uncorrelated from one another when their relative propagation delay exceeds a chip period. As shown in **Figure 22**, a RAKE-receiver utilizes multiple correlators to separately detect the M strongest multipath components. The outputs of each correlator are then weighted to provide a better estimate of the transmitted signal than is provided by a single component. Demodulation and bit decision are then based on the weighted outputs of the M correlators.

To explore the performance of a RAKE-receiver, assume M correlators are used in a CDMA receiver to capture the M strongest multipath components. A weighted network is used to provide a linear combination of the correlator output for bit detection. Correlator 1 is synchronized to the strongest multipath m_1. Multipath component m_2 arrives τ_1 later than m_1 where $\tau_2 - \tau_1$ is assumed to be greater than a chip duration. The second correlator is synchronized m_2. It correlates strongly with m_2, but has low correlation with m1. The M decision statistics are weighted to form an overall decision statistics as shown in **Figure 22**. The outputs of the M correlators are denoted as $Z_1, Z_2, \ldots, Z_M$. They are weighted by $\alpha_1, \alpha_2, \ldots$ and α_M, respectively. The weighting coefficients are based on the power or the SNR from each correlator output. If the power or SNR is small out of particular correlator, it will be assigned a small weighting factor. Just as in the case of a *maximal ration combining* diversity scheme, the overall signal Z' is given by

$$Z' = \sum_{m=1}^{M} \alpha_m Z_m \tag{8}$$

The weighting coefficients α_m, are normalized to the output signal power of the correlator in such a way that the coefficients sum to unity, as shown below:

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2} \tag{9}$$

In CDMA, both the base station and mobile receivers use RAKE receiver techniques, e.g. IS-95 and WCDMA. Although there are several differences between the RAKE receiver in the MS and BS, all the basic principles presented here are the same. Each correlator in a RAKE receiver is called a RAKE-receiver finger. The base station combines the outputs of its RAKE-receiver fingers noncoherently. i.e., the outputs are added in power. The mobile receiver combines its RAKE-receiver finger outputs coherently, i.e., the outputs are added in voltage. Typically, mobile receivers have 3 RAKE-receiver fingers and base station receivers have 4 or 5 depending on the equipment manufacturer.

The reason is why it is called a "RAKE" receiver is that most block diagrams of the device resemble a garden rake, which can illustrate the RAKE receiver's operation. The manner in which a garden rake eventually picks up debris off a patch of grass resembles the way the RAKE's fingers work together to recover multiple versions of a transmitter's signal.

Handover. In a mobile communications environment, as a user moves from the coverage area of one base station to the coverage area of another BS, a handover must occur to transition the communication link from one BS to the next. Handovers in CDMA are fundamentally different from handovers in TDMA systems. While in a TDMA system handover is a short procedure, and the normal state of affairs is a non-handover situation, the situation in a CDMA system is dramatically different. A MS communicating with its serving BS can spend a large part of the connection time in a soft handover state.

Soft handover refers to the state where the mobile is in communication with multiple Base Stations at the same time. Soft handover is a *make-before-break* type of handover, whereby a mobile acquires a target code channel before breaking an existing one. Soft handover is a special attribute of CDMA that is enabled by universal frequency reuse. **Figure 23** shows the soft handover process, when MS moves from cell A to cell B.

During the soft handover process MS has to employ one of its RAKE receiver fingers for each received BS. Note that each received multipath component requires a RAKE finger of its own. Each separate link from a BS is called a soft handover branch. Since, all BSs use the same frequency in a soft handover, a MS can consider their signals as just additional multipath components. An important difference between a multipath component and a soft handover branch is that each branch is coded with a different spreading code, whereas multipath components are just time delayed versions of the same signal.

Note that during the soft handover process two power control loops per connection are active, one for each base station.

Figure 24 shows the soft handover process example when mobile MS moves from the coverage area of BS1 to the BS2 serving area. The soft handover typically uses pilot channel E_c/N_0as the handover measurement quantity. The following definitions are used to describe the handover process:

Active set: The active set contains the pilots of those sectors that are actively exchanging traffic channel information with the mobile.

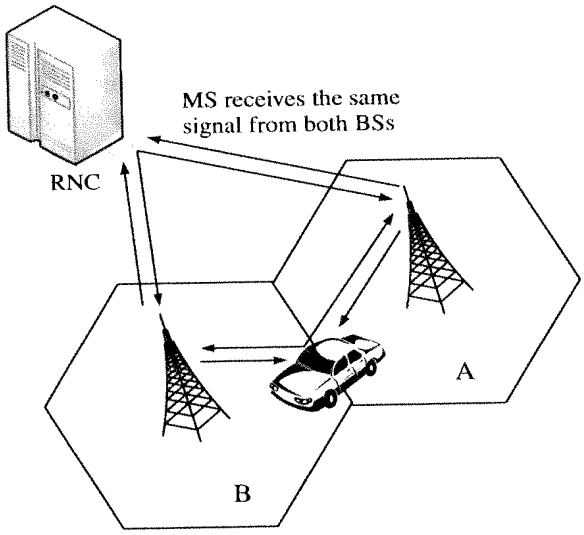


Figure 23. Soft handover

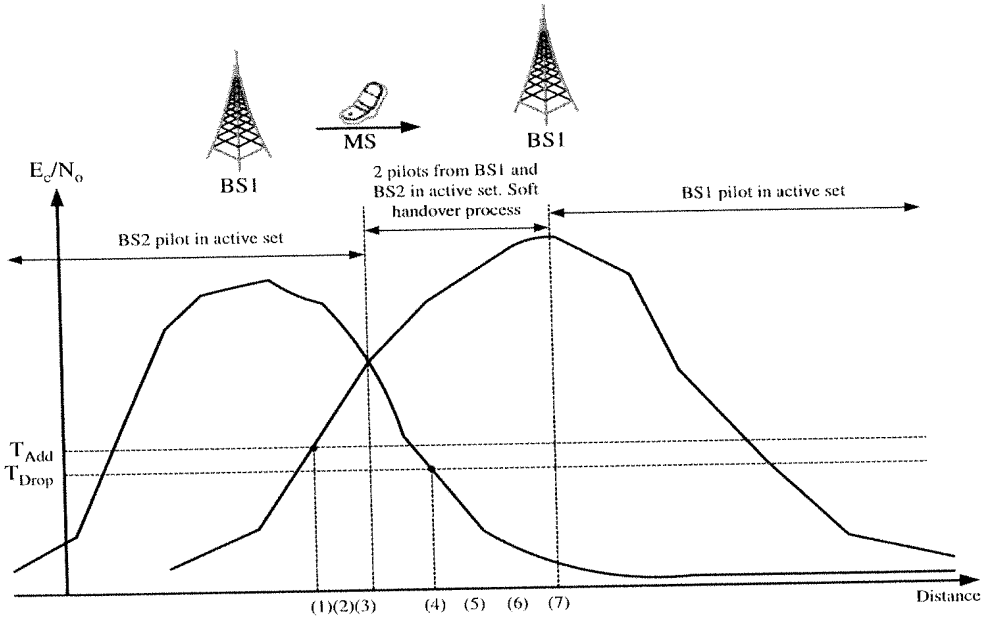


Figure 24. Soft handover process example

Neighbor set: The neighbor set or monitored set is the list of cells that MS continuously measures, but whose pilot E_c/N_0 are not strong enough to be added to the active set.

The following are the steps during the handover process:

1. MS is being served by BS1 only, and its active set contains only BS1 pilot. The MS measures the E_c/N_0 of BS2 pilot and finds it to be greater than *pilot detection threshold* T_{Add}. The MS sends a pilot measurement message and moves BS2 pilot from the neighbor set to the candidate set.
2. The MS receives a handover direction message from BS1 and starts communicating with BS2 on a new traffic channel. Handover direction message contains the PN offset of BS2 and the Walsh code of the newly assigned traffic channel.
3. The MS moves BS2 pilot from the candidate set to the active set. After acquiring the forward traffic channel specified in *the handover direction message*, the MS sends a *handover completion message*. Now active set contains two pilots.
4. The mobile detects that BS1 pilot has now dropped below the *pilot drop threshold* T_{Drop}, and starts the drop timer.
5. The drop timer reaches the *handover drop timer expiration value* T_{TDrop} and the MS sends a pilot strength measurement message.
6. The MS receives a *handover direction message* which contains only the PN offset of BS2.
7. The mobile moves BS1 pilot from the active set to the neighbor set, and it sends a *handover completion message*.

Soft handover is typically employed in cell boundary areas, where cells overlap. When MS moves from one sector to another within the same cell ***softer handover*** process is occurs. From a MS's point of view it is a just another soft handover. The difference is only meaningful to the network, since a softer handover is an internal procedure for a BS, which saves the transmission capacity between BSs and the BS controller (RNC). The uplink softer handover branches can be combined within the BS, which is a faster procedure, and uses less of the fixed infrastructure's transport resources than most other types of handover procedures in CDMA system.

Placing in soft handover any additional BSs that can be detected by the mobile station, as soon as possible, results in reduced call dropping probabilities, increased capacity and coverage, and improved voice quality in cell boundaries, which usually has poor coverage coupled with increased interference from other cells.

In this section main attention is paid to soft handover. However, note that hard handover process is also important in CDMA systems, e.g. in WCDMA hard handover procedure can be used to change the radio frequency band of the connection between MS and BS or to change the cell on the same frequency when no network support of macro diversity exist. It can be also used to change the mode between FDD and TDD.

Capacity. The capacity of a CDMA system is proportional to the *processing gain* of the system, which is the ratio of the spread bandwidth to the data rate. A general

expression for the signal-to-noise (SNR) power ratio for a particular mobile user at the base station given by

$$(10) \qquad \frac{S}{N} = \frac{R \cdot E_b}{B \cdot N_0} = \frac{E_b/N_0}{B/R}$$

where, $S = E_b/T_b = RE_b$ is the carrier power and $N = BN_0$ is the interference power at the base station receiver. The quantity E_b/N_0 is the bit energy to noise power spectral density ratio, and B/R is the processing gain of the system. Let K denote the number of mobile users. If power control is used to ensure that every mobile has the same received power, the SNR of one user can be written as

$$(11) \qquad \frac{S}{N} = \frac{1}{K-1}$$

This is so because the total interference power in the band is equal to the sum of powers from individual users. Substituting S/N from (7) into (8), the capacity for a CDMA system is found to be

$$(12) \qquad K \approx K - 1 = \frac{B/R}{E_b/N_0}$$

The capacity of a CDMA system is limited by the interference caused by other users simultaneously occupying the same bandwidth; this interference is reduced by the processing gain of the system.

The IS-95 CDMA standard specifies that each user conveys baseband information at 9.6 kbps, which is the rate of the vocoder output. The rate of the spread signal is 1.2288 Mcps, resulting in processing gain equal to

$$(13) \qquad P_G = \frac{B}{R} = \frac{1.2288 \cdot 10^6}{9.6 \cdot 10^3} = 128$$

Assuming the required E_b/N_0=6dB=4 we can derive the single cell CDMA system capacity using (8)

$$(14) \qquad K \approx \frac{B/R}{E_b/N_0} = \frac{128}{4} = 32 \ users$$

Equation (12) is effectively a model that describes the number of users a single CDMA cell can support. In reality particular cell is bordered by other CDMA cells that are serving other users. **Figure 25** shows an example when the signal powers from users located in different cells constitute interference each other. This effect calls ***effect of loading***, cell A in example given above is said to be loaded by users from other cells.

Equation to account for the effect of loading given as:

$$(15) \qquad \frac{E_b}{N_0} = \frac{1}{K-1}\frac{B}{R}\left(\frac{1}{1+\eta}\right)$$

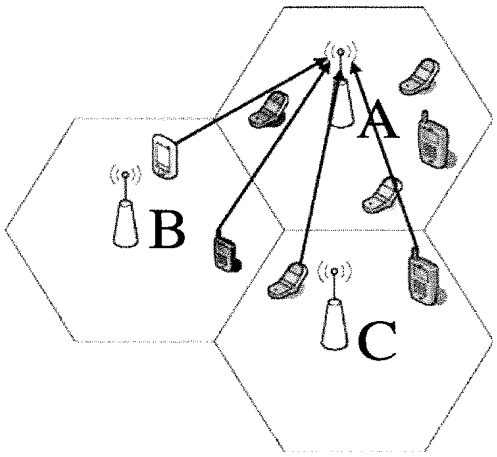


Figure 25. Interference introduced by users in the neighboring cell

where η is the loading factor, between 0% and 100%. The inverse of the factor $(1+\eta)$ is sometimes known as the ***frequency reuse factor*** F; that is

$$F = \frac{1}{1+\eta} \tag{16}$$

In the single cell case the frequency reuse factor is ideally 1, however in real environment with multicell case, as the loading η increases, the frequency reuse factor correspondingly decreases.

Instead of an omnidirectional antenna, which has an antenna pattern over 360 degrees, cells can be sectorized to several sectors, e.g. in example above cell A can be sectorized to six sectors so that each sector is only receiving signals over 60 degrees (**Figure 26**). In effect, a sectorized antenna rejects interference from users that are now within its antenna pattern. This arrangement decreases the effect of loading by a factor of approximately 6. This factor is called ***sectorization gain*** G_s. In reality, G_s is typically around 2.5 and 5 for three- and six-sector configured systems, respectively.

Equation (15) is thus modified to account for the effect of sectorization:

$$\frac{E_b}{N_0} = \frac{1}{K-1}\frac{B}{R} \cdot F \cdot G_s \tag{17}$$

Equation (15) assumes that all users are transmitting 100% of the time. In practice CDMA systems uses variable rate vocoders, which means that the output rate of the vocoder is adjusted according to a user's actual speech pattern. The effect of this variable-rate vocoding is the reduction of overall transmitted power and hence interference. By employing variable-rate vocoding, the system reduces the total interference power by this ***voice activity power.***

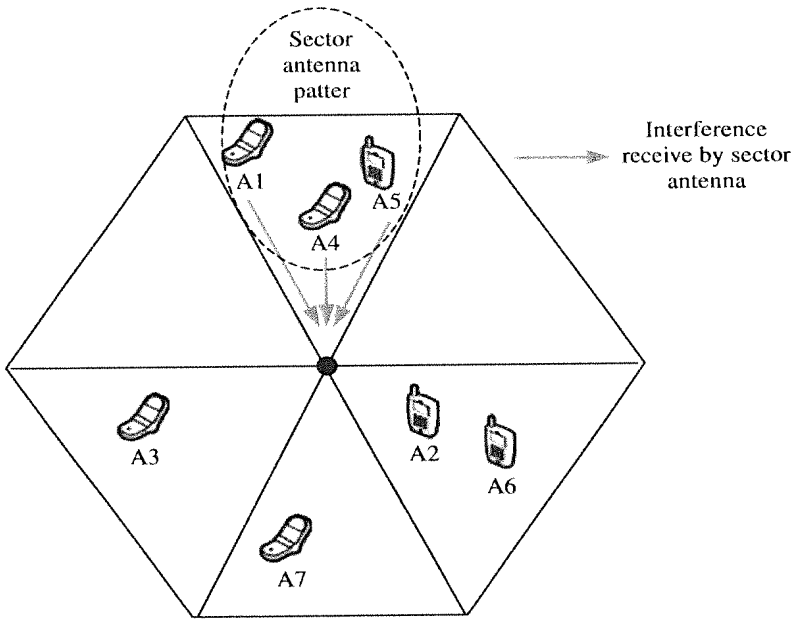


Figure 26. Cell sectorization using 60° directional antenna (6 sectors per cell)

Thus, (17) is again modified to account for the effect of voice activity:

$$\frac{E_b}{N_0} = \frac{1}{K-1}\frac{B}{R}\frac{1}{D_v}\cdot F\cdot G_s \tag{18}$$

where D_v is the voice activity factor. Solving (18) for M gives:

$$K = 1 + \frac{(B/R)}{(E_b/N_0)}\frac{1}{D_v}\cdot F\cdot G_s \tag{19}$$

If M is large, then

$$K \approx \frac{(B/R)}{(E_b/N_0)}\frac{1}{D_v}\cdot F\cdot G_s \tag{20}$$

In real systems voice activity power D_v is typically around $0.35 \sim 5$.

Taking into account the all parameters above, we can update the equation (14) for multicell environment. Assuming the voice activity power $D_v = 0.4$, sectorization gain $G_s = 2.5$ (3 sectors per cell) and frequency reuse factor $F = 0.6$ we get

$$K \approx \frac{(B/R)}{(E_b/N_0)}\frac{1}{D_v}\cdot F\cdot G_s = \frac{128}{4}\cdot\frac{1}{0.4}\cdot 0.6\cdot 2.5 = 120 \tag{21}$$

$K = 120$ channels per cell or 40 channels per sector.

Resulting from statements above, we can draw several conclusions regarding CDMA capacity:

1. Capacity is directly proportional to the processing gain of the system.
2. Capacity is inversely proportional to the required E_b/N_0 of the link. The lower the required threshold E_b/N_0, the higher the system capacity.
3. Capacity can be increased if one can decrease the amount of loading from users in adjacent cells.
4. Spatial filtering, such as sectorization, increases system capacity. For example, a six-sector cell would have more capacity than a three sector cell.

3. MULTI-CARRIER TRANSMISSION

The principle of multi-carrier transmission is to convert a serial high-rate data stream onto multiple parallel low rate sub-streams. Each sub-stream is modulated on another sub-carrier. Since the symbol rate on each sub-carrier is much less than the initial serial data symbol rate, the effects of delay spread, i.e., ISI, significantly decrease, reducing the complexity of the equalizer. **Figure 27** illustrates an example of multi-carrier modulation with 4 sub-carriers.

One of the efficient multi-carrier modulation techniques is an Orthogonal frequency-division multiplexing (OFDM). In OFDM the frequencies and modulation of frequency-division multiplexing are arranged to be orthogonal with each other which almost eliminates the interference between channels. Although the principles and some of the benefits have been known for 40 years, it is made popular today by the lower cost and availability of digital signal processing components.

3.1 Orthogonal Frequency Division Multiplexing.

OFDM can be simply defined as a form of multicarrier modulation where its carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. As is well known, orthogonal signals can be separated at the receiver

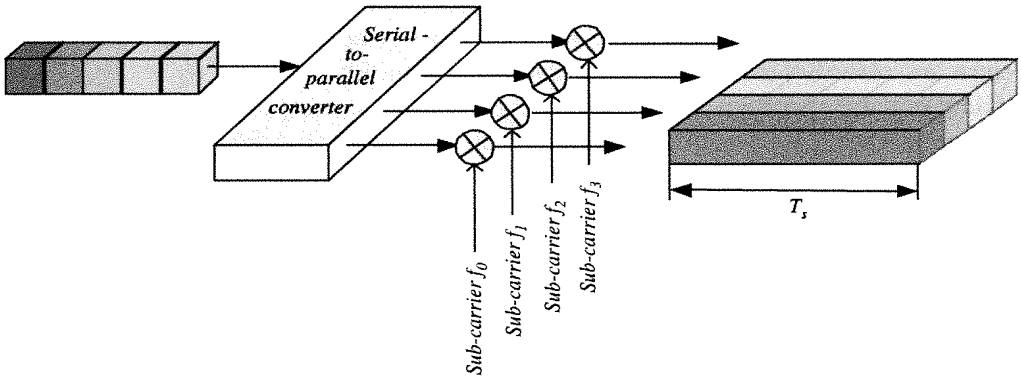


Figure 27. Multi-carrier modulation with 4 sub-carriers

by correlation techniques; hence, intersymbol interference among channels can be eliminated. Orthogonality can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing be equal to the reciprocal of the useful symbol period. In order to occupy sufficient bandwidth to gain advantages of the OFDM system, it would be good to group a number of users together to form a wideband system, in order to interleave data in time and frequency (depends how broad one user signal is).

A communication system with multi-carrier modulation transmits N_c complex valued source symbols S_n, $n=0,\ldots,N_c-1$, in parallel on N_c sub-carriers. The source symbol duration T_d of the serial data symbols results after serial-to-parallel conversion in the OFDM symbol duration

$$T_S = N_c T_d \tag{22}$$

In order to achieve orthogonality each of N_c sub-streams modulated on sub-carriers with a spacing of

$$F_S = \frac{1}{T_S} \tag{23}$$

presuming a rectangular pulse shaping. The N_c parallel modulated source symbols S_n are referred to as an OFDM symbol.

The $N_c$sub-carrier frequencies are located at

$$f_n = \frac{n}{T_S}, \quad n = 0, \ldots, N_c-1 \tag{24}$$

As an example, **Figure 28** shows four subcarriers from one OFDM signal. In this example, all subcarriers have the same phase and amplitude, but in practice the amplitudes and phases may be modulated differently for each subcarrier. Note that each subcarrier has exactly an integer number of cycles in the interval T, and the number of cycles between adjacent subcarriers differs by exactly one. This property accounts for the orthogonality between the subcarriers. As it is shown from **Figure 29** at the maximum of each sub-carrier spectrum, all other subcarrier spectra are zero. Because an OFDM receiver essentially.

calculates the spectrum values at those points that correspond to the maxima of individual subcarriers, it can demodulate each subcarrier free from any interference from other subcarriers

A key advantage of using OFDM is that multi-carrier modulation can be implemented in the discrete domain by using and IDFT, or a more computationally efficient IFFT. The block diagram of a multi-carrier modulator employing OFDM based on IDFT and a multicarrier demodulator employing inverse OFDM based on a DFT is illustrated in **Figure 30**

When the number of sub-carriers increases, the OFDM symbol duration T_s becomes large compared to the duration of the impulse response τ_{max} of the channel,

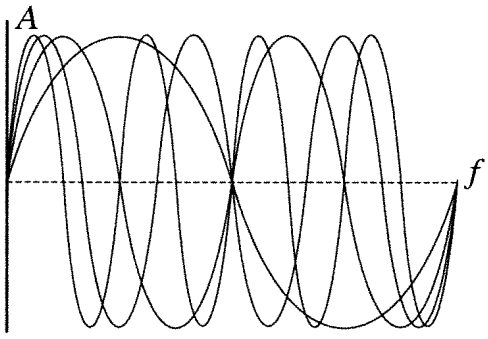


Figure 28. Example of four subcarriers within one OFDM symbol

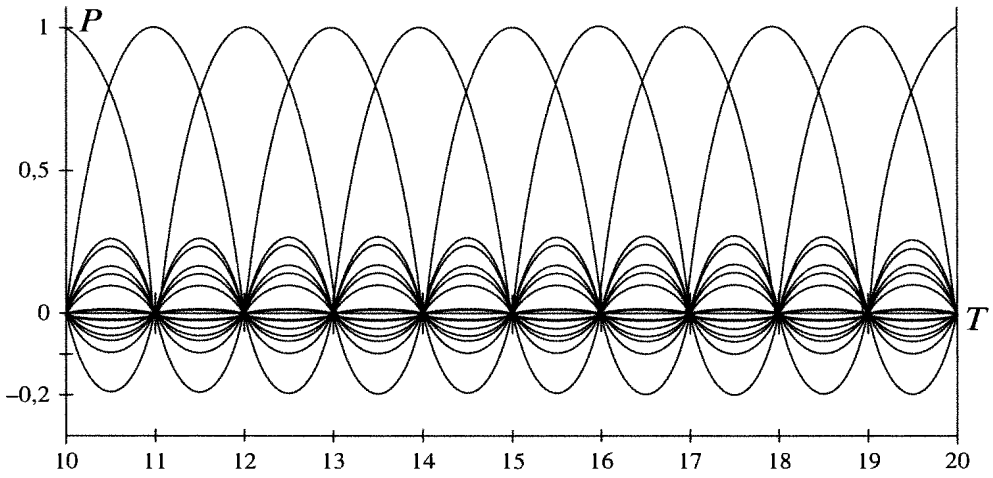


Figure 29. Spectra of individual sub-carriers

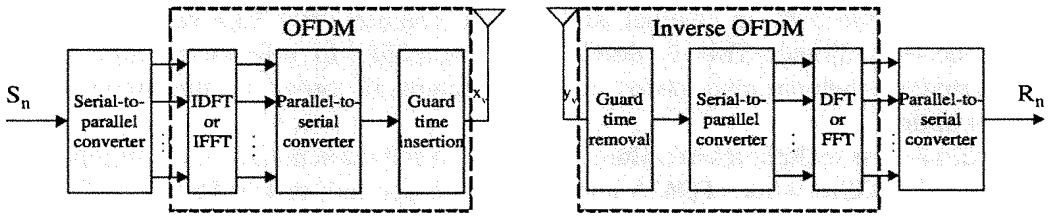


Figure 30. Digital multi-carrier transmission system applying OFDM

and the amount of ISI reduces. However, to completely avoid the effects of ISI and, thus, maintain the orthogonality between the signals on the on the sub-carriers, i.e., to also avoid ICI, a guard interval duration

$$T_g \geq \tau_{\max} \tag{25}$$

has to be inserted between adjacent OFDM symbols. The guard interval is a cyclic extension of each OFDM symbol which is obtained by extending the duration of an OFDM symbol to

$$T_s' = T_g + T_s \tag{26}$$

A block of subsequent OFDM symbols, where the information transmitted within these OFDM symbols belongs together, e.g., due to coding and/or spreading in time and frequency direction, is referred to as an OFDM frame.

The benefits of using OFDM are many, including high spectrum efficiency, resistance against multipath interference (particularly in wireless communications), simple digital realization by using FFT operation, flexible spectrum allocation and low complex receivers due to the avoidance of ISI and ICI with sufficiently long guard interval.

An extremely important benefit from using multiple sub-carriers is that because each carrier operates at a relatively low symbol rate, the duration of each symbol is relatively long. If one sends, say, a million bits per second over a single baseband channel, then the duration of each bit must be under a microsecond. This imposes severe constraints on synchronization and removal of multipath interference. If the same million bits per second are spread among N_c subcarriers, the duration of each bit can be longer by a factor of N_c, and the constraints of timing and multipath sensitivity are greatly relaxed. For moving vehicles, the Doppler Effect on signal timing is another constraint that causes difficulties for some other modulation schemes.

However, OFDM suffers from time-variations in the channel, or presence of a carrier frequency offset. This is due to the fact that the OFDM subcarriers are spaced closely in frequency. Imperfect frequency synchronization causes a loss in subcarrier orthogonality which severely degrades performance.

Because the signal is the sum of a large number of subcarriers, it tends to have a high peak-to-average power ratio (PAPR). Also, it is necessary to minimize intermodulation between the subcarriers, which would effectively raise the noise floor both in-channel and out of channel. For this reason circuitry must be very linear. This is demanding, especially in relation to high power RF circuitry, which also needs to be efficient in order to minimize power consumption.

Radio access techniques are often combined to hybrid schemes in communication systems like GSM where TDMA and FDMA are applied, or UMTS where CDMA, TDMA and FDMA are used. These hybrid combinations additionally increase the user capacity and flexibility of the system. Nowadays much attention paid

to the systems combined with OFDM. For example the combination of OFDM with DS-CDMA or FDMA offers the possibility to overload an otherwise limited systems. Next in this section we describe the different hybrid multiple radio access schemes.

3.2 Multi-carrier FDMA (OFDMA)

OFDMA is a combination of modulation scheme that resembles OFDM and a multiple access scheme that combines TDMA and FDMA. OFDMA typically uses a FFT size much higher than OFDM, and divides the available sub-carriers into logical groups called sub-channels. Unlike OFDM that transmits single user information on all subcarriers at any given time, OFDMA allows multiple users to transmit simultaneously on the different subcarriers per OFDM symbol. Therefore, an OFDMA system with, e.g., $N_c = 1024$ sub-carriers and adaptive sub-carrier allocation is able to handle thousand of users. Another approach is that OFDMA may transmit different amounts of energy in each sub-channel (**Figure 31**).

Figure 32 illustrates the simplest OFDMA scheme with one sub-carrier per user. At the base station the received signal, being the sum of K users' signals, acts as an OFDM signal due to its multipoint to point nature. Unlike conventional FDMA, which requires K demodulators to handle simultaneous K users, OFDMA requires only a single demodulator, followed by an N_c-point DFT.

The basic components of an OFDMA transmitter at the terminal station are FEC channel coding, mapping, sub-carrier assignment, and single carrier modulator (multi-carrier modulator in the case that several sub-carriers assigned per user).

A very accurate clock and carrier synchronization is essential for an OFDMA system, to ensure orthogonality between the Kmodulated signals originating from different terminal stations.

Nowadays, OFDMA is being considered as a modulation and multiple access method for 4th generation wireless networks, and currently the modulation of choice for high speed data access systems such as IEEE 802.11a/g wireless LAN (Wi-Fi) and IEEE 802.16a/d/e wireless broadband access systems (WiBro, WiMAX).

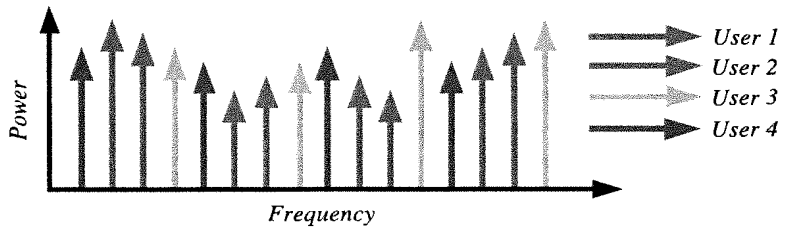


Figure 31. Example of four users sharing the same OFDM symbol

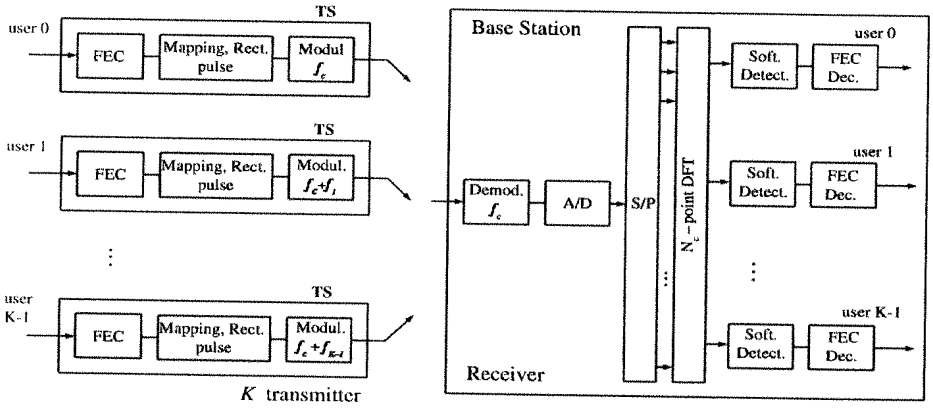


Figure 32. Basic principle of OFDMA

3.3 Multi-carrier Spread Spectrum

There are various combinations of multi-carrier modulation with the spread spectrum technique as multiple access schemes have been introduced. It has been shown that multi-carrier spread spectrum (MC-SS) offers high spectral efficiency, robustness and flexibility.

There are two general schemes of multi-carrier spread spectrum, namely MC-CDMA (OFDM-CDMA) and MC DS-CDMA.

In both schemes, the different users share the same bandwidth at the same time and separate the data by applying different user specific spreading codes, i.e., the separation of users signals is carried out in the code domain. Moreover, both schemes apply multi-carrier modulation to reduce the symbol rate and, thus, the amount of ISI per sub-channel. This ISI reduction is significant in spread spectrum systems where high chip rates occur.

The MC-CDMA transmitter spreads the original signal using a given spreading code in the frequency domain. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. Multi-carrier modulation is realized by using low-complex OFDM operation. **Figure 33** demonstrates the general principle of MC-CDMA. Each symbols of the serial data stream is copied on the sub-streams before multiplying it with a chip of the spreading code assigned to the specific user. Mapping of the chips in the frequency domain allows for simple methods of signal detection.

This concept was proposed with OFDM for optimum use of the available bandwidth. For multi-carrier transmission, it is essential to have frequency nonselective fading over each subcarrier, hence in MC-CDMA the number of subcarriers N_c has to be chosen sufficiently large to guarantee frequency nonselective fading on each subchannel.

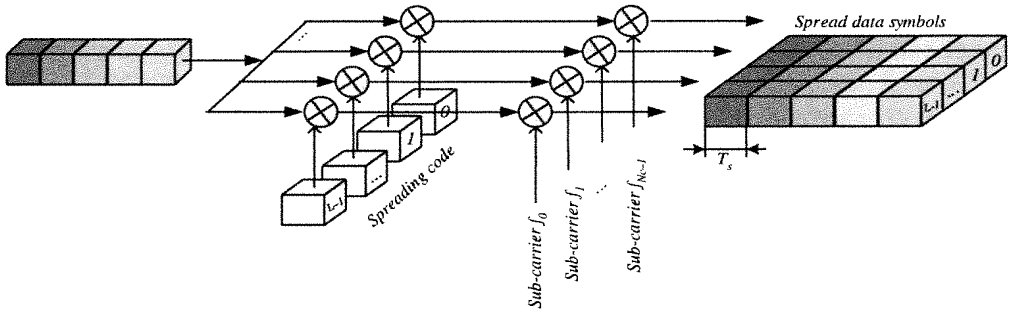


Figure 33. MC-CDMA signal generation for one user

Note that one of the IMT-2000 family of protocols is based on MC-CDMA technology. The IMT-MC (multicarrier) protocol (cdma2000) uses MC-CDMA spreading in the downlink, although in the uplink direction, the IMT-MC uses DS-CDMA.

Another success combination of multi-carrier modulation technique with spread spectrum is MC DS-CDMA. Unlike MC-CDMA, that maps the chips of a spread data symbol in frequency direction over a several parallel sub-channels, MC DS-CDMA maps the chips of spread data symbol in the time direction over several multi-carrier symbols. The principle of MC DS-CDMA is illustrated in **Figure 34**. MC DS-CDMA serial-to-parallel converts the high-rate data symbols into parallel low-rate sub-streams before spreading the data symbols on each sub-channel with a user-specific spreading code in time direction, which corresponds to direct sequence spreading on each sub-channel. The same spreading codes can be applied on the different sub-channels.

MC DS-CDMA systems have been proposed with different multi-carrier modulation schemes, also without OFDM, such that within the description of MC DS-CDMA the general term multi-carrier symbol instead of OFDM symbol is used. The MC DS-CDMA schemes can be subdivided in schemes with broadband sub-channels and schemes with narrowband sub-channels. Systems with broadband

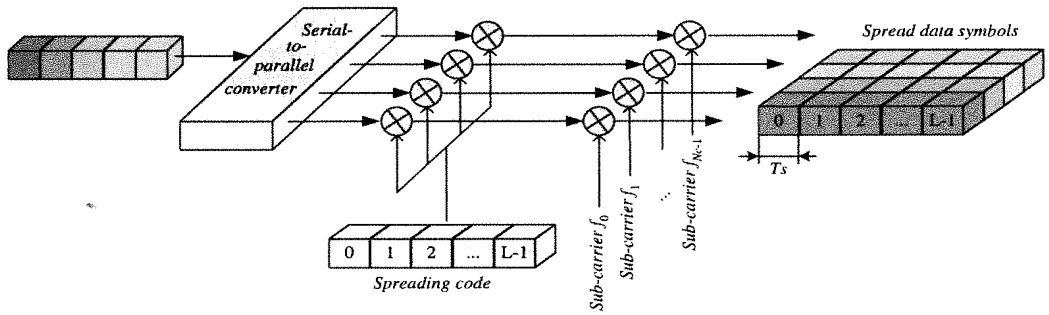


Figure 34. MC DS-CDMA signal generation for one user

sub-channels typically apply only few numbers of sub-channels, where each sub-channel can be considered as a classical DS-CDMA system with reduced data rate and ISI, depending in the number of parallel DS-CDMA systems. MC DS-CDMA systems with narrowband sub-channels typically use high numbers of sub-carriers and can be efficiently realized using the OFDM operation. Since each sub-channel is narrowband and spreading is performed in time direction, these schemes can only achieve a time diversity gain if no additional measures as coding or interleaving are applied.

It can be noted that both schemes have a generic architecture. In the case where the number of sub-carriers $N_c = 1$, the classical DS-CDMA transmission scheme is obtained, whereas without spreading (spreading gain $P_G = 1$) it results in a pure OFDM system.

Table 2 below gives the main characteristics of different MC-SS concepts and summarize the main advantages and drawbacks of different schemes.

3.4 Multi-carrier Code-select CDMA

As we mentioned above a main disadvantage of multi-carrier systems is the high PAPR of the output signal, which may take values within a range that is the proportional to the number of carriers in the system. High peak power in transmitted signal will occasionally reach the amplifier saturation region and cause signal distortion, which results in performance degradation. To reduce PAPR in OFDM

Table 2. Comparison table between MC-CDMA and MC DS-CDMA

Parameter	MC-CDMA	MC DS-CDMA
Spreading	Frequency direction	Time direction
Subcarrier spacing	$F_s = \frac{P_G}{N_c T_d}$	$F_s \geq \frac{P_G}{N_c T_d}$
Detection algorithm	MRC, EGC, ZF, MLD, equalization IC.	Correlation detector (coherent RAKE)
Specific characteristics	Very efficient for the synchronous downlink via using orthogonal codes	Designed especially for an asynchronous uplink
Applications	Synchronous uplink and downlink	Asynchronous uplink and downlink
Advantages	– Simple implementation – Low complex receivers – High spectral efficiency – High frequency diversity	– Low PAPR in the uplink – High time diversity
Disadvantages	– High PAPR especially in the uplink – Synchronous transmission	– ISI and/or ICI can occur – More complex receivers – Less spectral efficient if other multi-carrier modulation than OFDM is used.

based systems several proposals have been suggested and studied. Although, most of the PAPR reduction schemes are at the expense of BER performance, there are several interesting schemes to avoid the large amplitude fluctuations in Multi-carrier CDMA systems. One of such schemes is the Multi-carrier Code-select CDMA, namely MC CS-CDMA.

Main difference between conventional MC DS-CDMA and MC CS-CDMA is the so called code selection process added at transmitter side. **Figure 35** shows the simple single carrier code selection scheme with M=3 code selecting (CS) bits. As illustrated in **Figure 35**, stream of serial bits are first parallelized into $M+1$ substreams, where M code selecting bits are going into *Spreading Code Block (SCB)*. Depending on the CS bits combination SCB chooses one of the $L=2^M$ spreading codes and $(M+1)^{th}$ bit is spread by this spreading sequence. At the receiver side we have the L parallel fingers, one per each spreading code, and by simple correlation process we determine the spreading code and depending on this code Decision Block recovers the bits were transmitted.

Combining the CS CDMA scheme with conventional MC DS-CDMA we achieve the following advantages:

- Decreased number of subcarriers
- Low PAPR
- Bandwidth efficiency

All of this advantages only at the cost of receiver complexity and does not affect on the data rate and performance of the system. On the contrary due to the decreased number of subcarriers we can use the remain bandwidth for the purpose of performance improvement (*e.g. frequency repetition*).

Figure 36 shows transmitter schematic for MC CS-CDMA system. At the transmitter side, the binary bit stream is first serial-to-parallel converted into U parallel substream. Next, M bits of each group select a spreading code of SCB (spreading code block). The spreading code which is selected is then spreads the each $M+1$ bit of parallel substreams. Each SCB in MC CS-CDMA consists of code sequence sets with $L=2^M$ code sequences.

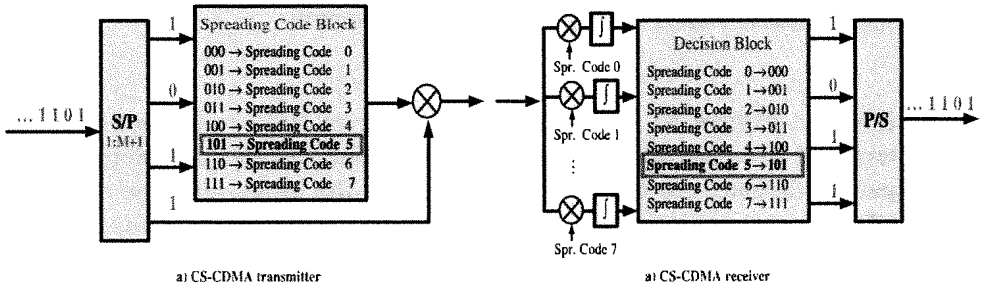


Figure 35. CS-CDMA concept

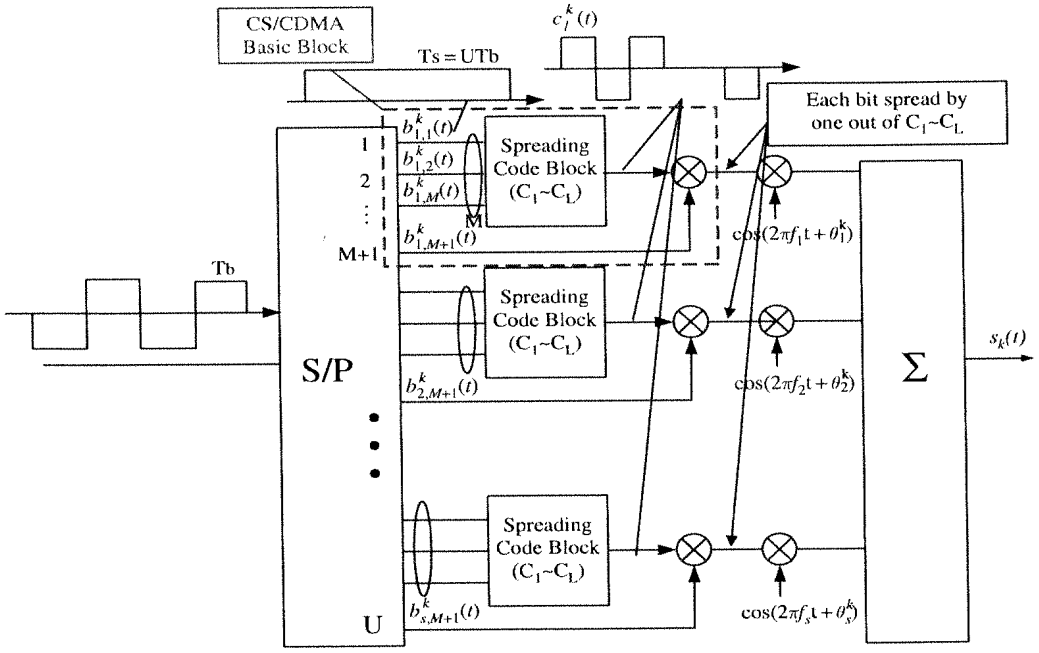


Figure 36. MC CS-CDMA system transmitter scheme

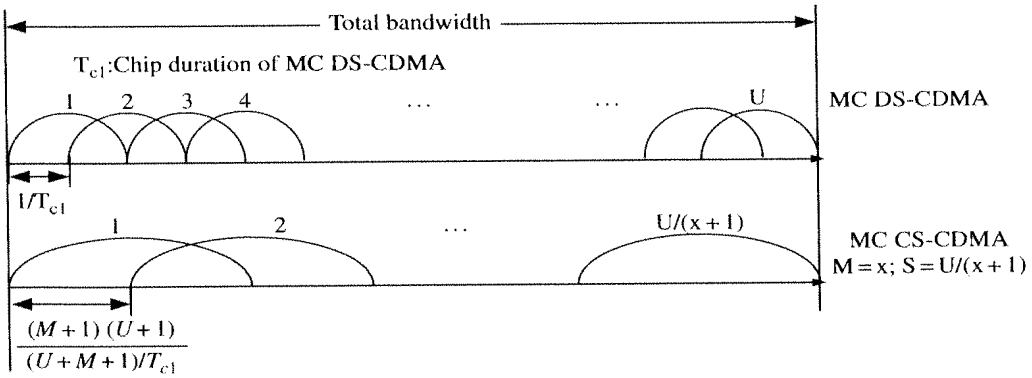


Figure 37. Frequency domain view of MC DS-CDMA and MC CS-CDMA

As it is shown in **Figure 37** increasing the number of code select bits MC CS-CDMA system can decrease the number of parallel subcarriers, but increases the subcarrier spacing distance for each carrier, achieving the improved time diversity.

MC CS-CDMA system is robust with respect to multipath interference and multiuser interference due to increasing spreading gain and diversity gain. Also note that MC CS-CDMA achieves lower PAPR than conventional MC DS-CDMA due to the reduced number of subcarriers. However, the advantages of MC CS-CDMA

is at the expense of higher system complexity of receiver when increasing of various parallel input bits M of SCB and the number of fingers of Rake receiver in each subcarrier.

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CHAPTER 3

FUNDAMENTALS OF SINGLE-CARRIER CDMA TECHNOLOGIES

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Abstract: A broad range of wireless services of e.g., 100Mbps-to-1Gbps are demanded for the beyond 3rd generation (3G) wireless mobile communications systems. Wireless channels for such high-speed data transmissions are characterized by severely frequency-selective channel, which is caused by many interfering paths with different time delays. Promising wireless access technique that can overcome the channel frequency-selectivity and even improve the transmission performance is code division multiple access (CDMA). There are two approaches in CDMA: multi-carrier (MC)-CDMA and single-carrier (SC)-CDMA (direct-sequence CDMA or DS-CDMA is another popular terminology, but in this Chapter, the terminology "SC-CDMA" is used). Both MC- and SC-CDMA techniques have flexibility for providing variable rate transmissions, yet retaining multiple access capability. Their special case is orthogonal frequency division multiplexing (OFDM) and non-spread single carrier (SC) transmission, respectively. A lot of attention has been paid to MC-CDMA. However, it was recently shown that SC-CDMA can achieve a good performance comparable to MC-CDMA if proper frequency-domain equalization (FDE) is adopted. In this chapter, various techniques for improving SC-CDMA transmission performance are presented

Keywords: CDMA, frequency-domain equalization, space-time block coded transmit diversity, MIMO, space division multiplexing, hybrid ARQ

1. INTRODUCTION

During the last 25 years, wireless technologies have enhanced our communications networks by providing an important capability, i.e., mobility. Before the introduction of wireless mobile networks, communication was possible only from/to fixed places (i.e., houses, offices and public phones). In fixed and wireless networks, voice conversation was a long-time dominant service, but the introduction of Internet communications services in the fixed networks has been changing our society at a very rapid pace. In line with the recent explosive expansion of Internet traffic in the fixed networks, demands for broad ranges of services are becoming stronger even in wireless networks. People

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want to be connected anytime, anywhere with the networks for not only making voice conversations with people but also data conversation (i.e., downloading/uploading their information). A variety of services are now available over the 2nd and 3rd generation (2G and 3G) wireless networks, including e-mailing, Web access, and on-line services ranging from bank transactions to entertainment.

The 3G wireless networks based on single-carrier code division multiple access (SC-CDMA) technique, with much higher data rates of up to 384kbps (around 14Mbps in the later stage) and better representation than the present 2G wireless networks, were put into services in some countries and their deployment speed has since accelerated. However, the capabilities of 3G wireless networks will sooner or later be insufficient to cope with the increasing demands for broadband services, which is now in full force in fixed networks. Demands for downloading of ever increasing volume of information will become higher and higher even in mobile communications networks. Most of the services may contain high resolution and short delay streaming video combined with high fidelity audio. 3G wireless networks will be continuously evolving with high speed downlink packet access (HSDPA) technique, multiple-input/multiple-output (MIMO) antenna technique, etc, for providing packet data services of around 14Mbps as the mid-term evolution and of 30~100Mbps as the long-term evolution. The evolution of 3G wireless networks will be followed by the development of next generation wireless networks, called 4th generation (4G) wireless networks, that support extremely higher-speed packet data services, of e.g., 100M~1Gbps, than 3G wireless networks. Most of the wireless techniques to be developed for the 3.9G wireless networks will be used for the 4G wireless networks.

The broadband SC-CDMA technologies for the 4G wireless networks will be introduced in this chapter. Another promising access technology is multi-carrier CDMA (MC-CDMA), which has recently been attracting much attention. Before briefly compare SC- and MC-CDMA techniques in **Section 3**, the broadband propagation channel is discussed in **Section 2**. Frequency-domain equalization is a key technique for improving the transmission performance of SC-CDMA in a broadband channel. This will be introduced in **Section 4**. MIMO antenna techniques can be used for achieving better transmission performance and higher transmission rate with a limited bandwidth. First, space-time block coding for achieving better transmission performance is presented in **Section 5** and then space-division multiplexing (SDM) for increasing the transmission rate in **Section 6**. Multi-access interference (MAI) limits the transmission performance. Block spreading can be used to avoid MAI. This will be discussed in **Section 7**. Since a major transmission mode in beyond 3G systems will be packet based, also introduced in **Section 8** is the hybrid automatic repeat request (HARQ).

2. BROADBAND CHANNEL

A simplified propagation model is illustrated in **Figure 1**. There are several large obstacles between a base station (BS) and a mobile station (MS) and also many local scatterers in the vicinity of the MS. The reflection of the transmitted signal

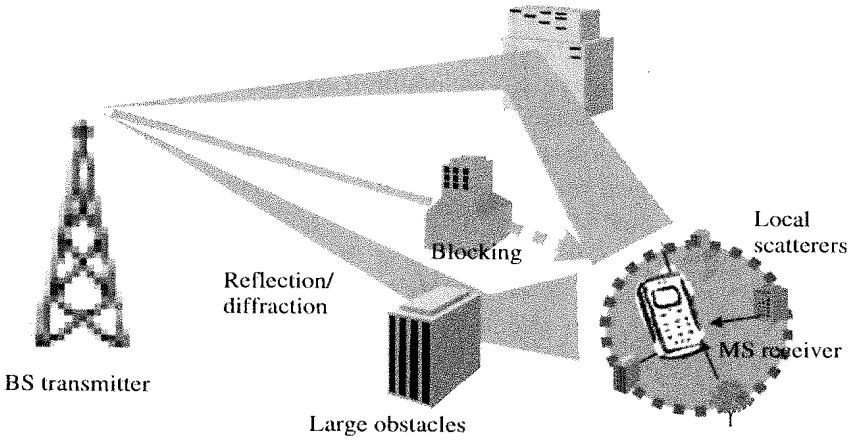


Figure 1. Propagation model

by large obstacles creates the propagation paths with different time delays, where time delay difference is more than the inverse of signal bandwidth W. Each path is a cluster of irresolvable multipaths, having a time delay difference of shorter than $1/W$, created by reflection or diffraction of the transmitted signal reaching the surroundings of a MS by local scatterers (such as neighboring buildings). They interfere with each other and the received signal power changes rapidly in a random manner with a period of about half carrier wavelength as the MS moves.

When multiple paths with different time delays are present, many impulses with different time delays are received after the transmission of an impulse from a transmitter, as shown in **Figure 2**. Such a multipath channel can be viewed as a time varying linear filter having an impulse response $h(\tau, t)$ observed at time t, which can be expressed as

$$(1) \qquad h(\tau, t) = \sum_{l=0}^{L-1} h_l(t)\delta(\tau - \tau_l),$$

where L is the number of resolvable paths, $h_l(t)$ and τ_l are respectively the path gain and time delay of the l-th path and $\delta(t)$ is the delta function. In urban areas,

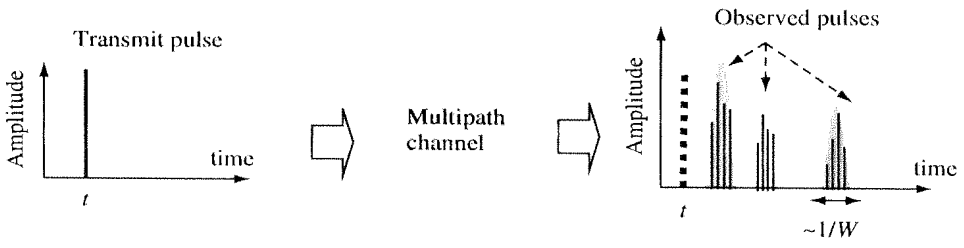


Figure 2. Channel impulse response

since $h_l(t)$ is the contribution from many irresolvable paths, it is known to be characterized as the complex Gaussian process (resulting in the Rayleigh fading). $\Omega(\tau) = E[|h_l(t)|^2]\delta(\tau - \tau_l)$ is the so-called power delay profile. Often used model is an exponentially decaying power delay profile. Power delay profile with decay

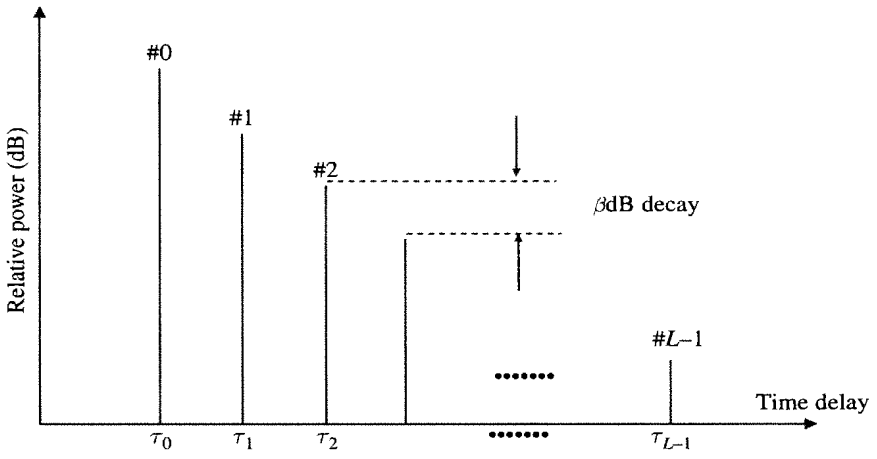


Figure 3. Power delay profile of multipath channel

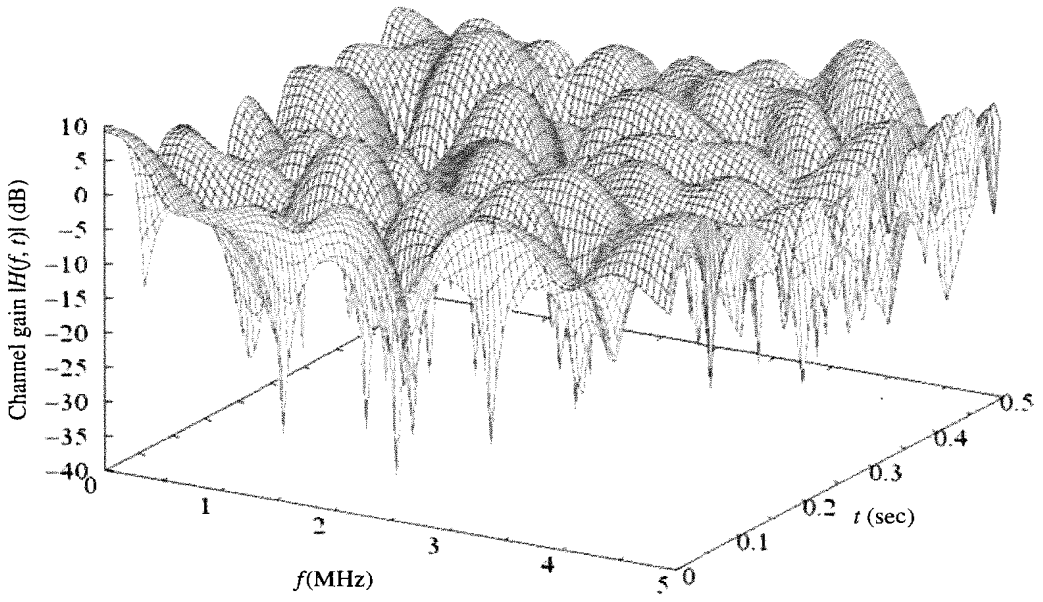


Figure 4. Transfer function of multipath channel

factor β is illustrated in **Figure 3**. The transfer function $H(f, t)$ of such a multipath channel at time t is expressed as

$$H(f,t) = \sum_{l=0}^{L-1} h_l(t) \exp(-j2\pi f \tau_l), \tag{2}$$

which is not anymore constant over the signal bandwidth and results in the so-called frequency-selective channel. Furthermore, the channel transfer function varies rapidly in a random manner over a short distance. When a transmitter or/and receiver travels, doubly (frequency-time) selective fading channel is produced. **Figure 4** shows how the channel transfer function varies in the frequency- and time-domain for an $L = 16$-path channel with uniform power delay profile ($\beta = 0$dB) and a time delay separation of 100ns between adjacent paths. A carrier frequency of 2GHz and a terminal speed of 4km/h are assumed.

3. MULTI-CARRIER CDMA AND SINGLE-CARRIER CDMA

Promising multiple access techniques under a severe frequency- and time-selective fading environment are SC-CDMA and MC-CDMA. The former uses the time-domain spreading technique, while the latter uses the frequency-domain spreading technique. First, we start with the overview of SC-CDMA with rake combining and then, MC-CDMA.

Figure 5 illustrates the transmitter/receiver structure for SC-CDMA. At the transmitter, after the binary information data is channel-encoded and interleaved, the encoded information data sequence is transformed into data-modulated symbol sequence. The resulting symbol sequence is spread (time-domain spreading) by a spreading chip sequence, $c(t)$, with SF times higher rate $1/T_c$ than symbol rate $1/T$. The spreading factor SF is defined as $SF = T/T_c$. The bandwidth of spread signal is $(1+\alpha)/T_c$, where α is the roll-off factor (typically $\alpha = 0.5$) of the chip shaping filter. At the receiver, the SC-CDMA signal is received via an L-path channel. The receiver matched filter (MF) consists of L correlators; each correlator multiplies the received signal with the locally generated chip sequence, which is time-synchronized to the time delay of each propagation path, and integrates over one symbol period. The MF outputs are coherently summed up based on maximal ratio combining (MRC), which is called as coherent rake combining, followed by despreading. Finally, the coherent rake combiner output sequence is demodulated, de-interleaved and passed to the channel decoder to obtain the decoded binary information sequence.

In MC-CDMA, a number of narrowband orthogonal subcarriers are used for parallel transmission and simple one-tap frequency-domain equalization (FDE) is used. **Figure 6** shows the transmitter/receiver structure for MC-CDMA with N_c subcarriers. A difference from SC-CDMA transmitter is the introduction of N_c-point inverse fast Fourier transform (IFFT) after time-domain spreading and the guard interval (GI) insertion. The use of serial-to-parallel (S/P) conversion followed by the IFFT transforms the time-domain spread signal into a frequency-domain

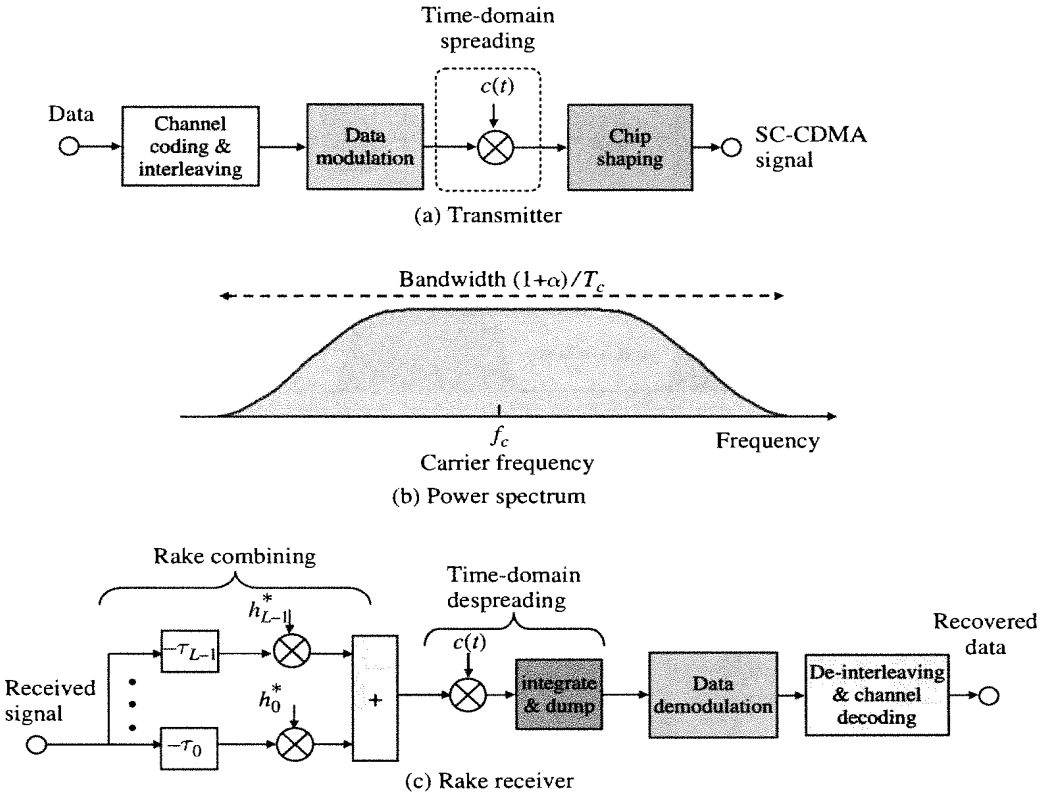


Figure 5. Transmitter/receiver structure for SC-CDMA with rake combining

spread signal, resulting in the MC-CDMA signal. MC-CDMA with $SF = 1$ is OFDM. The GI insertion is necessary to avoid the orthogonality destruction among N_c subcarriers due to the presence of multipaths with different time delays. The GI length needs to be larger than the maximum time delay difference among multipaths. At the receiver, after removing the GI, the received signal is decomposed by N_c-point FFT into N_c subcarrier components. The distortion of the signal spectrum due to frequency-selective fading is compensated by using one-tap FDE. The equalized subcarrier components are parallel-to-serial (P/S) converted into the time-domain spread signal, followed by despreading as in SC-CDMA receiver. FDE can be jointly used with antenna diversity reception for further performance improvement in MC-CDMA. Among various FDE weights, it was shown that the use of minimum mean square error (MMSE) weight provides the best bit error rate (BER) performance. This is because the MMSE weight can provide the best compromise between the noise enhancement and suppression of frequency-selectivity. MC-CDMA with MMSE-FDE provides much better BER performance than SC-CDMA with coherent rake combining. Because of this, until recently, research attention was shifted from SC techniques to MC techniques such as MC-CDMA and OFDM ($SF = 1$). But, as will be shown in this chapter, FDE can

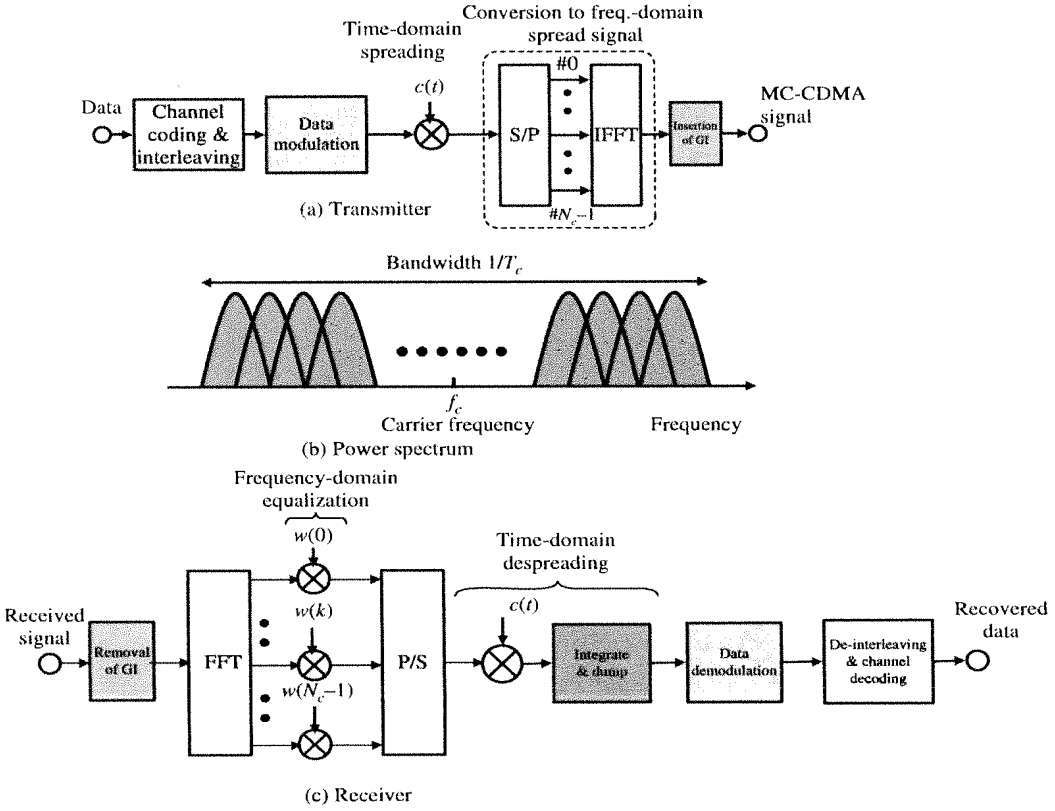


Figure 6. Transmitter/receiver structure for MC-CDMA

also be applied to SC-CDMA with much improved performance compared to rake combining. SC-CDMA is considered again as a promising access technique similar to MC-CDMA.

4. FREQUENCY-DOMAIN EQUALIZATION

The application of MMSE-FDE to SC-CDMA can replace the coherent rake combining with much improved BER performance. First, FDE for SC-CDMA is shown. However, the residual inter-chip interference (ICI) is present after MMSE-FDE and this will limit the BER performance improvement. The ICI cancellation can be used to reduce the residual ICI and hence improve the BER performance. These are presented here.

4.1 MMSE Equalization

Transmitter/receiver structure of multicode SC-CDMA with FDE is illustrated in **Figure 7**. We assume that C data streams are simultaneously transmitted. At the

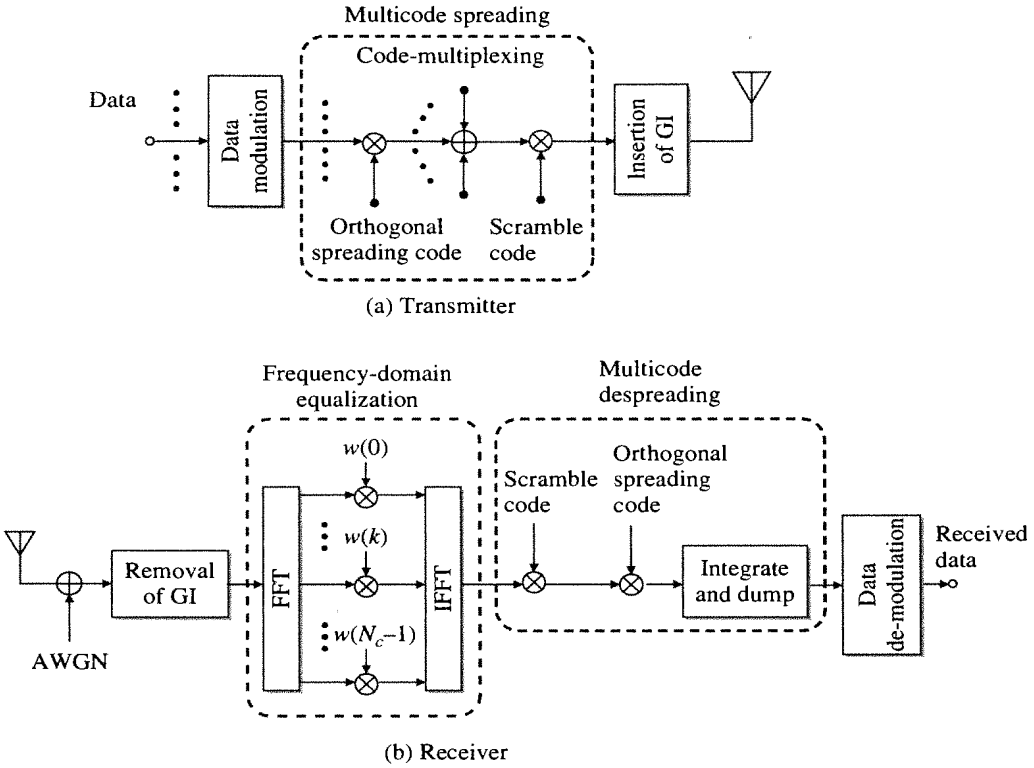


Figure 7. Multicode SC-CDMA transmitter/receiver structure

transmitter, the uth binary data sequence is transformed into a data modulated symbol sequence $\{d_u(n);\ n = 0 \sim N_c/SF - 1\}$, $u = 0 \sim C - 1$, and then spread by multiplying an orthogonal spreading sequence $c_u(t)$ with spreading factor SF. The resulting C chip sequences are added and further multiplied by a common scramble sequence $c_{scr}(t)$ to make the resulting multicode SC-CDMA chip sequence white-noise like. C is called code-multiplexing order. This is called multicode spreading. Then, the orthogonal multicode SC-CDMA chip sequence is divided into a sequence of blocks of N_c chips each and then the last N_g chips of each block are copied as a cyclic prefix and inserted into the GI placed at the beginning of each block as shown in **Figure 8**. The GI-inserted multicode SC-CDMA chip sequence

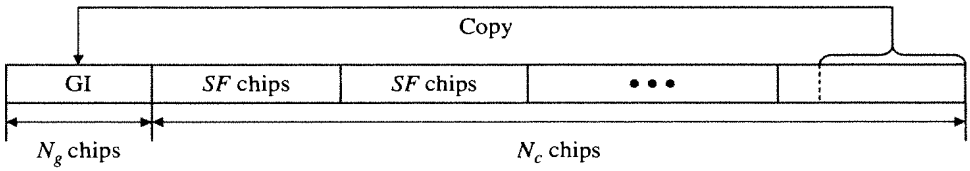


Figure 8. Block structure

$\{\hat{s}(t);\ t = -N_g \sim N_c - 1\}$ in a block can be expressed, using the equivalent lowpass representation, as

$$\hat{s}(t) = \sqrt{\frac{2E_c}{T_c}} s(t \bmod N_c), \tag{3}$$

where E_c and T_c denote the chip energy and the chip duration, respectively, and $s(t)$ is given by

$$s(t) = \left[\sum_{u=0}^{C-1} d_u (\lfloor t/SF \rfloor)\, c_u(t \bmod SF) \right] c_{scr}(t) \tag{4}$$

for $t = 0 \sim N_c - 1$, where $|c_u(t)| = |c_{scr}(t)| = 1$ and $\lfloor x \rfloor$ represents the largest integer smaller than or equal to x.

The chip block $\{\hat{s}(t);\ t = -N_g \sim N_c - 1\}$ is transmitted over a frequency-selective fading channel and received by a receiver. After the removal of the GI, the received chip sequence $\{r(t); t = 0 \sim N_c - 1\}$ in a block is decomposed by N_c-point FFT into N_c subcarrier components $\{R(k);\ k = 0 \sim N_c - 1\}$ (the terminology "subcarrier" is used for explanation purpose although subcarrier modulation is not used). The kth subcarrier component $R(k)$ can be written as

$$\begin{aligned} R(k) &= \sum_{t=0}^{N_c-1} r(t) \exp\left(-j2\pi k \frac{t}{N_c}\right) \\ &= \sqrt{\frac{2E_c}{T_c}} H(k)S(k) + \Pi(k) \end{aligned}, \tag{5}$$

where $S(k)$, $H(k)$ and $\Pi(k)$ are the kth subcarrier components of $s(t)$, the channel gain and the noise component due to the additive white Gaussian noise (AWGN), respectively. $H(k)$ corresponds to $H(f, t)$ defined by Eq. (2), but with $f = k/(N_c T_c)$; time dependency of the channel gain is dropped since we are assuming very slow fading channel for simplicity.

FDE is carried out similar to MC-CDMA. $R(k)$ is multiplied by the FDE weight $w(k)$ as

$$\begin{aligned} \hat{R}(k) &= w(k)R(k) \\ &= \sqrt{\frac{2E_c}{T_c}} S(k)\hat{H}(k) + \hat{\Pi}(k) \end{aligned}, \tag{6}$$

where $\hat{H}(k) = w(k)H(k)$ and $\hat{\Pi}(k) = w(k)\Pi(k)$ are the equivalent channel gain and the noise component after performing FDE, respectively. As the FDE weight,

maximal ratio combining (MRC), zero forcing (ZF), equal gain combining (EGC) and minimum mean square error (MMSE) weights are considered. They are given by

$$w(k) = \begin{cases} H^*(k) & \text{for MRC} \\ H^*(k)\Big/|H(k)|^2 & \text{for ZF} \\ H^*(k)\Big/|H(k)| & \text{for EGC,} \\ H^*(k)\Big/\left(|H(k)|^2 + \left(\frac{C}{SF}\frac{E_s}{N_0}\right)^{-1}\right) & \text{for MMSE} \end{cases} \tag{7}$$

where E_s/N_0 ($=E_cSF/N_0$) is the average received signal energy per data symbol-to-AWGN power spectrum density ratio and * denotes the complex conjugate operation.

One-shot observation of the equivalent channel gain $\hat{H}(k)$ and the noise $\hat{\Pi}(k)$ for MMSE, ZF and MRC weights are illustrated in **Figure 9**. An $L = 16$-path fading channel is assumed. Also plotted in the figure is the original channel gain $H(k)$. The MRC weight enhances the frequency-selectivity of the channel after equalization. Using the ZF weight, the frequency-nonselective channel can be perfectly restored after equalization (of course, only if the channel estimation is ideal), but the noise enhancement is produced at the subcarrier where the channel gain drops. However, the MMSE weight can avoid the noise enhancement by giving up the perfect restoration of the frequency-nonselective channel (the MMSE weight minimizes the mean square error between $S(k)$ and $\hat{R}(k)$). Among these FDE weights, the MMSE weight can provide the best compromise between the noise enhancement and suppression of frequency-selectivity and therefore, gives the best BER performance.

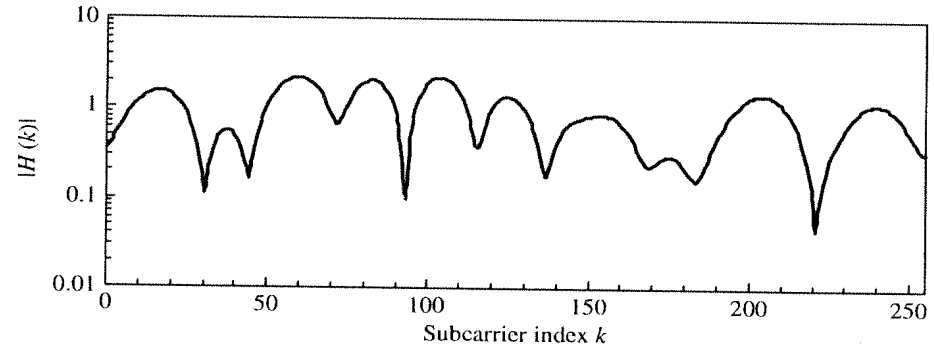
After MMSE-FDE, N_c-point IFFT is applied to obtain the time-domain multicode SC-CDMA chip sequence as

$$\begin{aligned} \hat{r}(t) &= \frac{1}{N_c}\sum_{k=0}^{N_c-1}\hat{R}(k)\exp\left(j2\pi t\frac{k}{N_c}\right) \\ &= \sqrt{\frac{2E_c}{T_c}}\left(\frac{1}{N_c}\sum_{k=0}^{N_c-1}\hat{H}(k)\right)s(t) + \hat{\mu}(t) + \hat{\eta}(t) \end{aligned}, \tag{8}$$

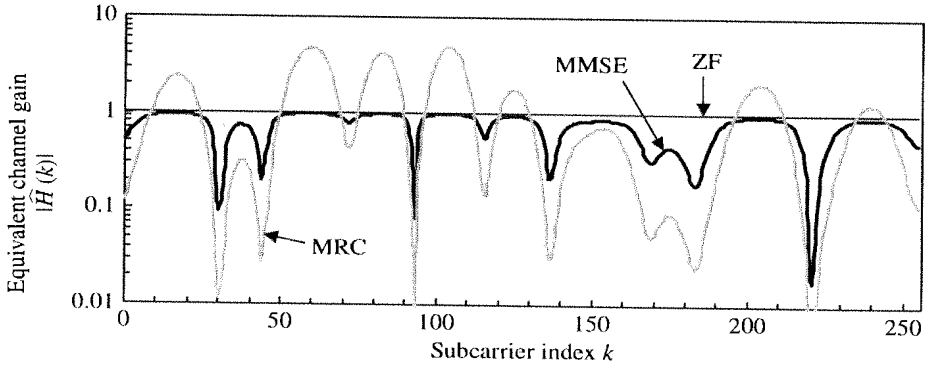
where $s(t)$ in the first term represents the transmitted chip sequence, $\hat{\mu}(t)$ is the residual inter-chip interference (ICI) component and $\hat{\eta}(t)$ is the noise component. $\hat{\mu}(t)$ can be expressed as

$$\hat{\mu}(t) = \sqrt{\frac{2E_c}{T_c}}\frac{1}{N_c}\sum_{k=0}^{N_c-1}\hat{H}(k)\left[\sum_{\substack{\tau=0 \\ \neq t}}^{N_c-1} s(\tau)\exp\left(j2\pi k\frac{t-\tau}{N_c}\right)\right]. \tag{9}$$

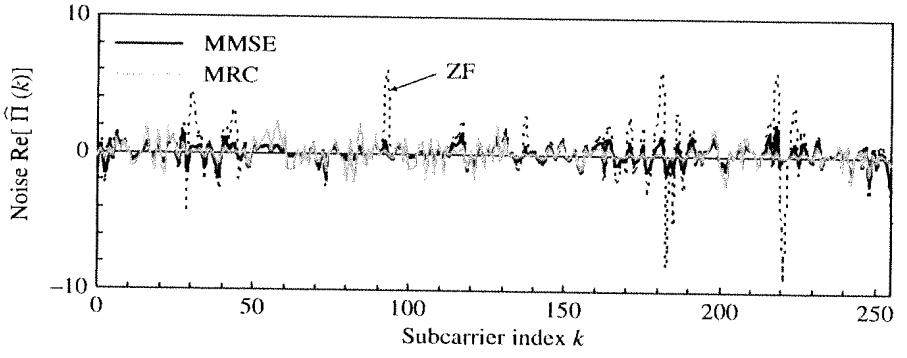
Note that if $\hat{H}(k) = \text{constant}$, $\hat{\mu}(t) = 0$ (i.e., this is the case of ZF-FDE and no ICI is produced). The residual ICI degrades the achievable BER performance (this is



(a) Original channel gain



(b) Equivalent channel gain



(c) Noise

Figure 9. One-shot observation of equivalent channel gain and noice after FDE

explained later). Multicode despreading is carried out on $\hat{r}(t)$ to obtain the decision variable for the data modulated symbol sequence $\{d_u(n);\ n = 0 \sim N_c/SF - 1\}$, $u = 0 \sim C - 1$, as

$$\hat{d}_u(n) = \frac{1}{SF} \sum_{t=nSF}^{(n+1)SF-1} \hat{r}(t) c_u^*(t \bmod SF) c_{scr}^*(t), \tag{10}$$

based on which data demodulation is done.

An arbitrary spreading factor SF can be used for the given value of FFT window size N_c. This property allows variable rate transmission even when FDE is used in SC-CDMA systems.

Figure 10 plots the BER performance of multicode SC-CDMA using MMSE-FDE for $SF = 16$, obtained by computer simulation, as a function of the average received bit energy-to-AWGN noise power spectrum density ratio E_b/N_0. QPSK data modulation and an $L = 16$-path frequency-selective Rayleigh fading channel having a uniform power delay profile ($E[|h_l|^2] = 1/L$) are assumed. For comparison,

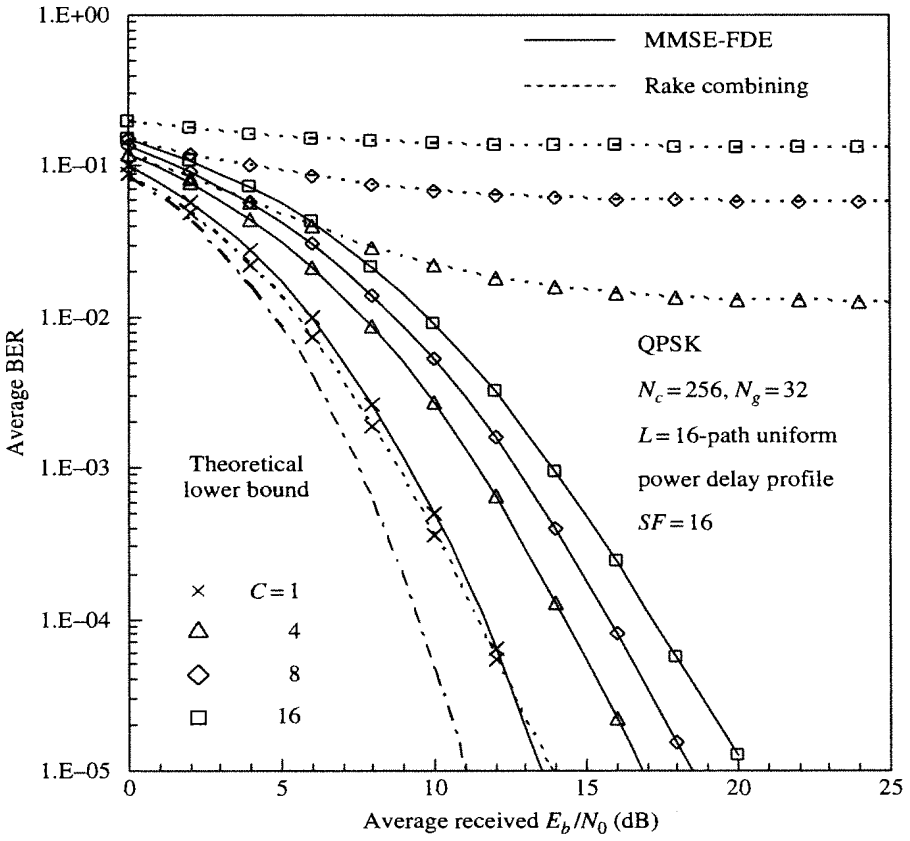


Figure 10. BER performance of multicode SC-CDMA with MMSE-FDE

the BER performance of coherent rake combining and theoretical lower-bound are also plotted. When $C = 1$, MMSE-FDE and rake combining can achieve almost the same BER performance. However, when $C \geq 4$, the BER performance using rake combining significantly degrades due to strong ICI and exhibits large BER floors. MMSE-FDE can always achieve better BER performance than rake combining and no BER floors are seen. However, although MMSE-FDE provides much better BER performance, the BER performance degrades as the code-multiplexing order C increases since the orthogonality distortion among codes is produced due to the residual ICI $\hat{\mu}(t)$. As the frequency-selectivity becomes stronger (or L increases), the complexity of the rake receiver increases since more correlators are required for collecting enough signal power for data demodulation. However, unlike rake receiver, the complexity of MMSE-FDE receiver is independent of the channel frequency-selectivity. The use of FDE can alleviate the complexity problem of the rake receiver arising from too many paths in a severe frequency-selective channel. These suggest that SC-CDMA with MMSE-FDE is a promising broadband access as MC-CDMA for 4G wireless networks.

4.2 Inter-chip Interference (ICI) Cancellation

Although MMSE-FDE can significantly improve the BER performance of orthogonal multicode SC-CDMA, there is still a big performance gap to the theoretical lower-bound as shown in **Figure 10**. This is due to the residual ICI after MMSE-FDE, given by Eq. (9). An ICI cancellation technique can be introduced into MMSE-FDE to improve the BER performance. The ICI in SC-CDMA with $SF = 1$ is equivalent to the inter-symbol interference (ISI) in the non-spread (i.e., $SF = 1$) SC transmissions; the ISI cancellation techniques can be found in the literature. Similar to ISI cancellation for MC-CDMA, ICI cancellation for SC-CDMA can be carried out either in the time-domain or in the frequency-domain after performing MMSE-FDE.

For the frequency-domain ICI cancellation, the replicas of frequency components $\{M(k);\ k = 0 \sim N_c - 1\}$ of the residual ICI $\hat{\mu}(t)$ in Eq. (9) are subtracted from $\{\hat{R}(k) : k = 0 \sim N_c - 1\}$ after MMSE-FDE. $M(k)$ is given by

$$\begin{aligned} M(k) &= \sum_{t=0}^{N_c-1} \hat{\mu}(t) \exp\left(-j2\pi k \frac{t}{N_c}\right) \\ &= \sqrt{\frac{2E_c}{T_c}} \left\{ \hat{H}(k) - \frac{1}{N_c} \sum_{k'=0}^{N_c-1} \hat{H}(k') \right\} S(k) \end{aligned} \tag{11}$$

A joint MMSE-FDE and ICI cancellation is repeated in an iterative fashion so as to improve the accuracy of the ICI replica generation. **Figure 11** shows the structure of joint MMSE-FDE and ICI cancellation.

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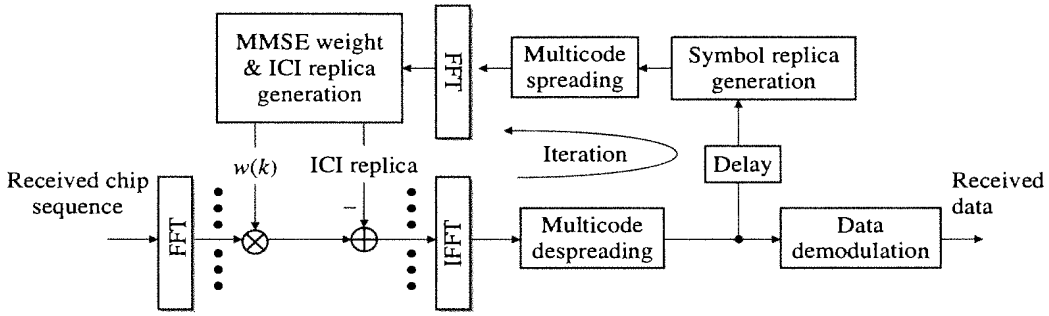


Figure 11. Joint MMSE-FDE and ICI cancellation

The ith iteration is described below. After performing MMSE-FDE with the MMSE weight $w^{(i)}(k)$, ICI cancellation is performed in the frequency-domain as

$$\tilde{R}^{(i)}(k) = \hat{H}^{(i)}(k) - \tilde{M}^{(i)}(k), \tag{12}$$

where $\hat{H}^{(i)}(k)\left(= w^{(i)}(k)H(k)\right)$ is the equivalent channel gain and $\tilde{M}^{(i)}(k)$ is the replica of $M(k)$ which is given, from Eq. (11), as

$$\tilde{M}^{(i)}(k) = \begin{cases} 0 & \text{for } i = 0 \\ \sqrt{\dfrac{2E_c}{T_c}} \left\{ \hat{H}^{(i)}(k) - A^{(i)} \right\} \tilde{S}^{(i-1)}(k) & \text{for } i > 0, \end{cases} \tag{13}$$

where $\tilde{S}^{(i-1)}(k)$ is the kth frequency component of the soft decision transmitted chip block replica $\tilde{s}^{(i-1)}(t)$ (which is generated by feeding back the $(i-1)$th ICI cancellation result) and $A^{(i)}$ is given by

$$A^{(i)} = \frac{1}{N_c} \sum_{k=0}^{N_c-1} \hat{H}^{(i)}(k). \tag{14}$$

N_c-point IFFT is performed on $\{\tilde{R}^{(i)}(k); k = 0 \sim N_c - 1\}$to obtain the time-domain chip sequence for multicode despreading.

A series of joint MMSE-FDE and ICI cancellation, N_c-point IFFT, multicode despreading, data symbol replica generation, and multicode spreading is repeated a sufficient number of times. Finally, data-demodulation is carried out to obtain the received data.

The MMSE weight $w^{(i)}(k)$ minimizes the mean square error (MSE) $E[|e(k)|^2]$ for the given $H(k)$, i.e., $\partial E[|e(k)|^2]/\partial w^{(i)}(k) = 0$, where $e(k)$ is the equalization error between $\tilde{R}^{(i)}(k)$ after the ICI cancellation and $S(k)$ of the transmitted signal $s(t)$ and is defined as

$$e(k) = \tilde{R}^{(i)}(k) - A^{(i)}S(k). \tag{15}$$

The MMSE weight is given as

$$w^{(i)}(k) = \frac{H^*(k)}{\rho^{(i-1)}\,|H(k)|^2 + \left(\frac{E_c}{N_0}\right)^{-1}}, \tag{16}$$

where $\rho^{(i-1)}$ is an interference factor determined by feeding back the $(i-1)$th iteration result and given by

$$\rho^{(i-1)} \approx \sum_{t=0}^{N_c-1} \left\{ \left|\tilde{s}^{(i-1)}(t)\right|^2 - \left|\tilde{s}^{(i-1)}(t)\right|^2 \right\}, \tag{17}$$

where $\tilde{s}^{(i-1)}(t)$ is the hard decision replica of transmitted chip block.

The BER performance for the case of $SF = 16$ is plotted in **Figure 12** with the code-multiplexing order C as a parameter. When $C = 1$, the BER performance approaches the theoretical lower-bound by about 0.5 dB. As C increases, the BER

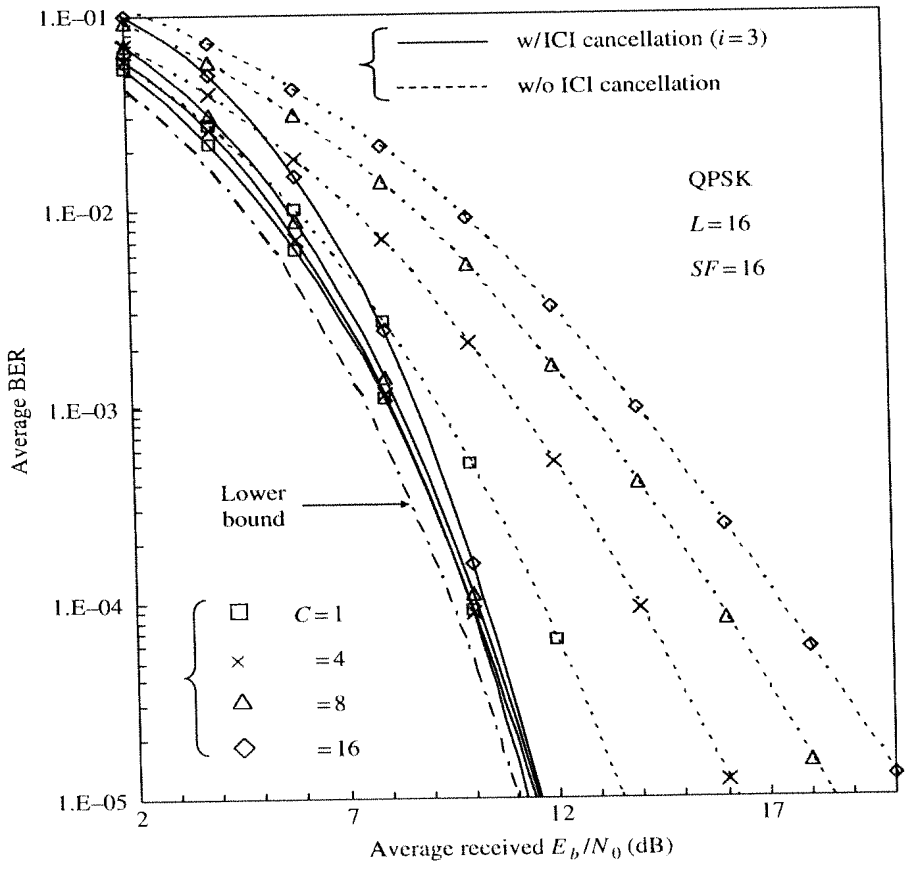


Figure 12. Simulated BER performance with joint MMSE-FDE and ICI cancellation

performance without ICI cancellation degrades. This is because a severe orthogonality distortion is produced by the residual ICI. The use of ICI cancellation can improve the BER performance. When $C = 16$, the E_b/N_0 reduction from the no ICI cancellation case is as much as 6.9 dB for BER $= 10^{-4}$.

5. SPACE-TIME BLOCK CODING

The antenna diversity technique can be used to increase the received signal-to-noise power ratio (SNR) and hence improve the transmission performance. There are two types of antenna diversity: receive diversity and transmit diversity (they can be jointly used). Receive antenna diversity has been successfully used in practical systems. Recently, transmit antenna diversity has been gaining much attention since the use of transmit diversity at a base station can alleviate the complexity problem of mobile receivers.

Space-time block coded transmit diversity (STTD) can achieve the space diversity gain without requiring channel information at the transmitter. In MC-CDMA, each subcarrier component is STTD encoded and then decoded in conjunction with MMSE equalization. This STTD can be applied to SC-CDMA with MMSE-FDE. Here, this is called frequency-domain STTD. In frequency-domain STTD, consecutive chip blocks are encoded in the frequency-domain.

(a) $N_t = 2$

STTD encoding for $N_t = 2$ is shown in **Table 1**. Two consecutive chip blocks, $\{s_e(t);\ t = 0 \sim N_c - 1\}$ and $\{s_o(t);\ t = 0 \sim N_c - 1\}$, at even and odd time intervals are decomposed by N_c-point FFT into N_c subcarrier components, $\{S_e(k);\ k = 0 \sim N_c - 1\}$ and $\{S_o(k);\ k = 0 \sim N_c - 1\}$, respectively, for STTD encoding. Then, N_c-point IFFT is used to obtain the time-domain coded chip blocks. This encoding requires FFT and IFFT operations. An equivalent time-domain STTD encoding that requires no FFT and IFFT operations is shown in. Since

$$(18) \qquad \begin{cases} \frac{1}{N_c}\sum_{k=0}^{N_c-1} S_e^*(k)\exp\left(j2\pi t\frac{k}{N_c}\right) = s_e^*\left((N_c - t) \bmod N_c\right) \\ \frac{1}{N_c}\sum_{k=0}^{N_c-1} S_o^*(k)\exp\left(j2\pi t\frac{k}{N_c}\right) = s_o^*\left((N_c - t) \bmod N_c\right) \end{cases},$$

STTD encoding of **Table 1** can be replaced by equivalent time-domain STTD encoding of **Table 2**. Equivalent time-domain STTD encoding is illustrated in

Table 1. Frequency-domain STTD encoding for $N_t = 2$

Time (in chip block)	Antenna #0	Antenna #1
Even	$\frac{1}{\sqrt{2}}S_e(k)$	$\frac{1}{\sqrt{2}}S_o(k)$
Odd	$-\frac{1}{\sqrt{2}}S_o^*(k)$	$\frac{1}{\sqrt{2}}S_e^*(k)$

Table 2. Equivalent time-domain STTD encoding $N_t = 2$

Time (in chip block)	Antenna #0	Antenna #1
Even	$\frac{1}{\sqrt{2}} s_e(t)$	$\frac{1}{\sqrt{2}} s_o(t)$
Odd	$-\frac{1}{\sqrt{2}} s_o^*((N_c - t) \bmod N_c)$	$\frac{1}{\sqrt{2}} s_e^*((N_c - t) \bmod N_c)$

Figure 13 (note that transmit power from each antenna is halved to keep the same total transmit power).

At a receiver, after the removal of the GI, the even and odd chip blocks received by the n_rth ($n_r = 0 \sim N_r - 1$) receive antenna are decomposed by N_c-point FFT into N_c subcarrier components $\{R_{e,n_r}(k); k = 0 \sim N_c - 1\}$ and $\{R_{o,n_r}(k); k = 0 \sim N_c - 1\}$, respectively. $R_{e,n_r}(k)$ and $R_{o,n_r}(k)$ can be written as

$$(19) \qquad \begin{cases} R_{e,n_r}(k) = \frac{1}{\sqrt{2}} S_e(k) H_{n_r,0}(k) + \frac{1}{\sqrt{2}} S_o(k) H_{n_r,1}(k) + \Pi_{e,n_r}(k) \\ R_{o,n_r}(k) = -\frac{1}{\sqrt{2}} S_o^*(k) H_{n_r,0}(k) + \frac{1}{\sqrt{2}} S_e^*(k) H_{n_r,1}(k) + \Pi_{o,n_r}(k) \end{cases},$$

where $H_{n_r,0}(k)$ (or $H_{n_r,1}(k)$) represents the N_c-point Fourier transform of the channel gain between the n_rth receive antenna and the 0th (or 1st) transmit antenna and $\Pi_{e,n_r}(k)$ and $\Pi_{o,n_r}(k)$ represent the k-th subcarrier components of the noise in the received even and odd chip blocks, respectively. STTD decoding for $N_t = 2$ is carried out jointly with receive antenna diversity combining, in the frequency-domain, jointly with MMSE-FDE as

$$(20) \qquad \begin{cases} \tilde{S}_e(k) = \sum_{n_r=0}^{N_r-1} \left\{ w_{n_r,0}^*(k) R_{e,n_r}(k) + w_{n_r,1}(k) R_{o,n_r}^*(k) \right\} \\ \tilde{S}_o(k) = \sum_{n_r=0}^{N_r-1} \left\{ w_{n_r,1}^*(k) R_{e,n_r}(k) - w_{n_r,0}(k) R_{o,n_r}^*(k) \right\}. \end{cases}$$

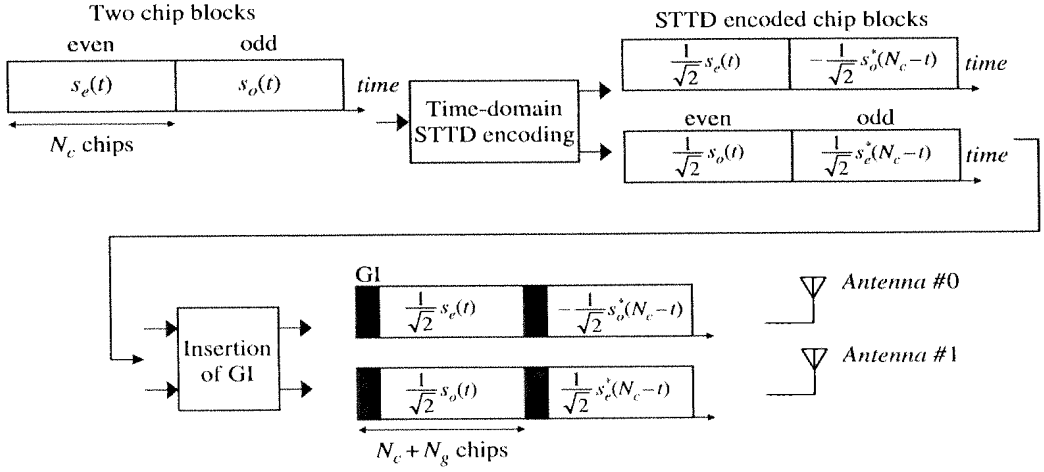


Figure 13. Equivalent time-domain STTD encoding for SC-CDMA

In the above, $w_{0,n_r}(k)$ and $w_{1,n_r}(k)$ are the MMSE weights, given by

$$(21)\qquad \begin{cases} w_{n_r,0}(k) = \dfrac{H_{n_t,0}(k)}{\sum_{n_r=0}^{N_r}\sum_{n_t=0}^{1}|H_{n_r,n_t}(k)|^2+\left(\frac{1}{2}\frac{C}{SF}\frac{E_s}{N_0}\right)^{-1}} \\ w_{n_r,1}(k) = \dfrac{H_{n_r,1}(k)}{\sum_{n_r=0}^{N_r}\sum_{n_t=0}^{1}|H_{n_r,n_t}(k)|^2+\left(\frac{1}{2}\frac{C}{SF}\frac{E_s}{N_0}\right)^{-1}}. \end{cases}$$

where C denotes the code multiplexing order. Finally, N_c-point IFFT is applied to $\{\tilde{S}_e(k)\}$ and $\{\tilde{S}_o(k)\}$ to obtain the time-domain chip blocks for despreading and data demodulation.

(b) $N_t = 3$ and 4

When $N_t = 3$ and 4, four consecutive chip blocks $\{s_q(t);\ t = 0 \sim N_c - 1\}$, $q = 0 \sim 3$, are encoded. STTD encoding for $N_t = 3$ and 4 can be expressed, using the matrix representation, as

$$(22)\qquad \begin{pmatrix} s_{0,0}(t) & s_{1,0}(t) & s_{2,0}(t) & s_{3,0}(t) \\ s_{0,1}(t) & s_{1,1}(t) & s_{2,1}(t) & s_{3,1}(t) \\ s_{0,2}(t) & s_{1,2}(t) & s_{2,2}(t) & s_{3,2}(t) \end{pmatrix}$$
$$= \frac{1}{\sqrt{3}} \begin{pmatrix} s_0(t) & -s_1^*((N_c-t) \bmod N_c) & -s_2^*((N_c-t) \bmod N_c) & 0 \\ s_1(t) & s_0^*((N_c-t) \bmod N_c) & 0 & -s_2^*((N_c-t) \bmod N_c) \\ s_2(t) & 0 & s_0^*((N_c-t) \bmod N_c) & s_1^*((N_c-t) \bmod N_c) \end{pmatrix} \text{ for } N_t = 3$$

and

$$(23)\qquad \begin{pmatrix} s_{0,0}(t) & s_{1,0}(t) & s_{2,0}(t) & s_{3,0}(t) \\ s_{0,1}(t) & s_{1,1}(t) & s_{2,1}(t) & s_{3,1}(t) \\ s_{0,2}(t) & s_{1,2}(t) & s_{2,2}(t) & s_{3,2}(t) \\ s_{0,3}(t) & s_{1,3}(t) & s_{2,3}(t) & s_{3,3}(t) \end{pmatrix}$$
$$= \frac{1}{2} \begin{pmatrix} s_0(t) & -s_1^*((N_c-t) \bmod N_c) & -s_2^*((N_c-t) \bmod N_c) & 0 \\ s_1(t) & s_0^*((N_c-t) \bmod N_c) & 0 & -s_2^*((N_c-t) \bmod N_c) \\ s_2(t) & 0 & s_0^*((N_c-t) \bmod N_c) & s_1^*((N_c-t) \bmod N_c) \\ 0 & s_2(t) & -s_1(t) & s_0(t) \end{pmatrix} \text{ for } N_t = 4,$$

where $\{s_{q,n_t}(t);\ t = 0 \sim N_c - 1\}$ is the coded chip block to be transmitted from the n_tth transmit antenna in the qth time interval.

STTD decoding are carried out, in the frequency-domain, jointly with MMSE-FDE as

$$(24)\qquad \begin{pmatrix} \tilde{S}_0(k) \\ \tilde{S}_1(k) \\ \tilde{S}_2(k) \end{pmatrix} = \begin{pmatrix} \sum_{n_r=0}^{N_r-1}\{R_{0,n_r}(k)w_{n_r,0}^*(k) + R_{1,n_r}^*(k)w_{n_r,1}(k) + R_{2,n_r}^*(k)w_{n_r,2}(k)\} \\ \sum_{n_r=0}^{N_r-1}\{R_{0,n_r}(k)w_{n_r,1}^*(k) - R_{1,n_r}^*(k)w_{n_r,0}(k) + R_{3,n_r}^*(k)w_{n_r,2}(k)\} \\ \sum_{n_r=0}^{N_r-1}\{R_{0,n_r}(k)w_{n_r,2}^*(k) - R_{2,n_r}^*(k)w_{n_r,0}(k) - R_{3,n_r}^*(k)w_{n_r,1}(k)\} \end{pmatrix} \text{ for } N_t = 3$$

and

$$(25)\quad \begin{pmatrix} \tilde{S}_0(k) \\ \tilde{S}_1(k) \\ \tilde{S}_2(k) \end{pmatrix} = \begin{pmatrix} \sum_{n_r=0}^{N_r-1} \left\{ \begin{array}{l} R_{0,n_r}(k)w^*_{n_r,0}(k) + R^*_{1,n_r}(k)w_{n_r,1}(k) \\ +R^*_{2,n_r}(k)w_{n_r,2}(k) + R_{3,n_r}(k)w^*_{n_r,3}(k) \end{array} \right\} \\ \sum_{n_r=0}^{N_r-1} \left\{ \begin{array}{l} R_{0,n_r}(k)w^*_{n_r,1}(k) - R^*_{1,n_r}(k)w_{n_r,0}(k) \\ -R_{2,n_r}(k)w^*_{n_r,3}(k) + R^*_{3,n_r}(k)w_{n_r,2}(k) \end{array} \right\} \\ \sum_{n_r=0}^{N_r-1} \left\{ \begin{array}{l} R_{0,n_r}(k)w^*_{n_r,2}(k) + R_{1,n_r}(k)w^*_{n_r,3}(k) \\ -R^*_{2,n_r}(k)w_{n_r,0}(k) - R^*_{3,n_r}(k)w_{n_r,1}(k) \end{array} \right\} \end{pmatrix} \text{ for } N_t = 4,$$

where $R_{q,n_r}(k)$ is the kth frequency component of the chip block received by the n_rth receive antenna in the qth time interval, and $w_{n_r,n_t}(k)$ is the MMSE weight given as

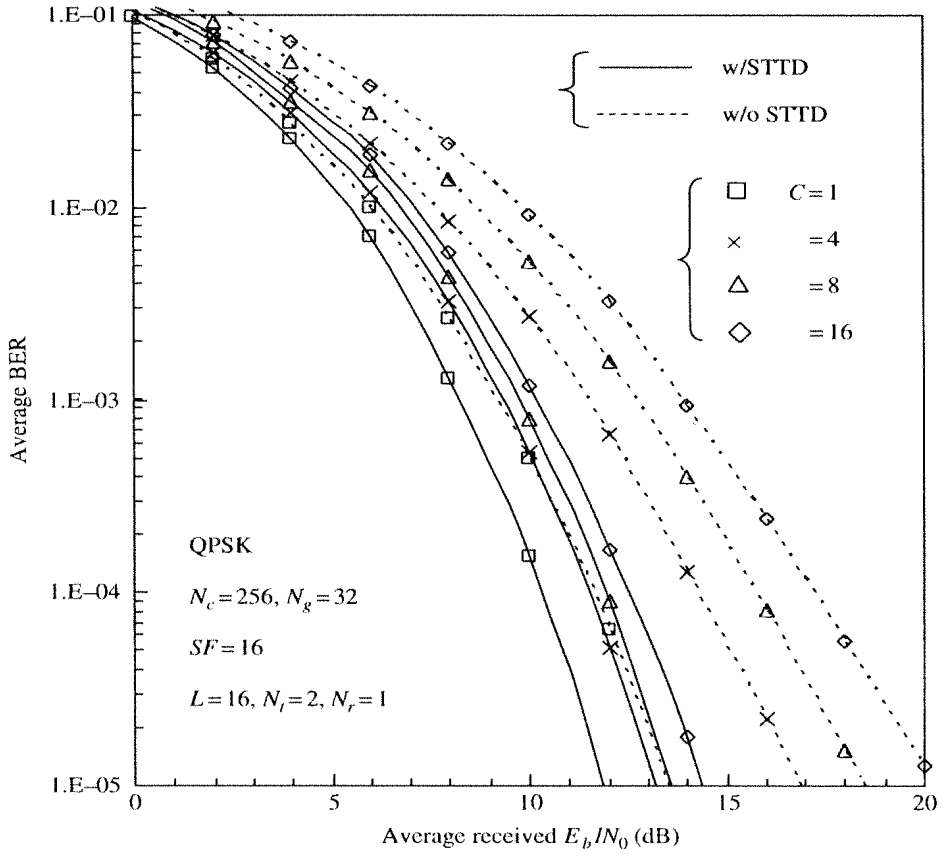


Figure 14. BER performance of SC-CDMA using STTD with $N_t = 2$ and $N_r = 1$

$$(26) \qquad w_{n_r,n_t}(k) = \frac{H_{n_r,n_t}(k)}{\frac{1}{N_t}\sum_{n_t=0}^{N_t-1}\sum_{n_r=0}^{N_r-1}|H_{n_r,n_t}(k)|^2 + \left(\frac{C}{SF}\frac{E_s}{N_0}\right)^{-1}}.$$

Frequency-domain STTD with $N_t = 2$ and $N_r = 1$ is evaluated by the computer simulation. We assume $N_c = 256$, $N_g = 32$, coherent QPSK data-modulation, and a chip-spaced $L = 16$-path frequency-selective block Rayleigh fading channel with uniform power delay profile ($\beta = 0$ dB), and ideal channel estimation. The BER performance using frequency-domain STTD is plotted in **Figure 14** for $SF=16$. For comparison, the single transmit antenna case ($N_t = 1$) is also plotted. The transmit diversity gain similar to that of two-antenna receive diversity ($N_r = 2$) using MRC is obtained, but with a 3dB power penalty (this is because the transmit power from each antenna is halved to keep the same total transmit power).

6. MIMO SPACE DIVISION MULTIPLEXING

High-speed data services of 100M~1Gbps are demanded in the next generation wireless systems. However, the available bandwidth is limited. Space division multiplexing (SDM) is a promising technique to achieve highly spectrum-efficient transmission. In SDM, different data sequences are transmitted in parallel from different transmit antennas using the same carrier frequency. At a receiver, a superposition of different data sequences transmitted from different antennas is received. A lot of research attention has been paid to the signal separation/detection schemes, e.g., maximum likelihood detection (MLD), ZF detection, MMSE detection and vertical-Bell Laboratories layered space-time architecture (V-BLAST). For high-speed data transmissions, the channels become severely frequency-selective and the BER performance of SC-CDMA using SDM degrades due to the inter-chip interference (ICI) and interference from other antennas. Therefore, the receiver must have two tasks: signal separation/detection and channel equalization.

6.1 Transmit/Receive Signal Representation

Orthogonal multicode SC-CDMA is considered. **Figure 15** illustrates the transmitter/receiver structure of (N_t, N_r)SDM, where N_t and N_r denote the number of

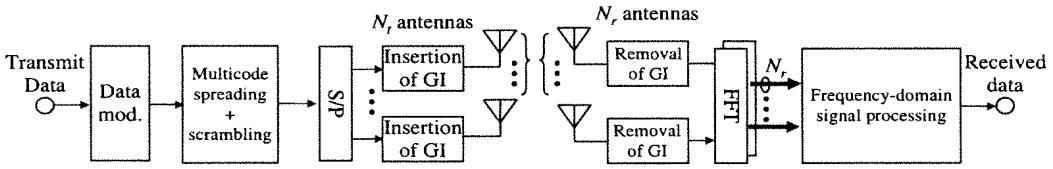


Figure 15. Transmitter/receiver structure for (N_t, N_r) SDM

transmit antennas and that of receive antennas, respectively. At the transmitter, a binary information sequence is data-modulated and converted to C parallel streams by serial/parallel (S/P) conversion. Then, each stream is spread by using a different orthogonal spreading code with the spreading factor SF. The resulting C parallel chip streams are added and multiplied by a scramble sequence for making the resulting orthogonal multicode SC-CDMA signal noise-like. The full code-multiplexed SC-CDMA (i.e., $C=SF$) has the same data rate as the non-spread SC transmission. The code-multiplexed SC-CDMA signal is converted by S/P converter to N_t parallel streams $\{s_{n_t}(t)\}$, $n_t=0\sim N_t-1$. Each stream is divided into a sequence of blocks of N_c chips each. After inserting the GI, N_t chip blocks are transmitted simultaneously from N_t transmit antennas.

A superposition of N_t transmitted chip blocks is received by N_r receive antennas. After the removal of GI, the chip block $\{r_{n_r}(t);\ t=0\sim N_c-1\}$ received on the n_rth receive antenna is decomposed byN_c-point FFT into N_c frequency components $\{R_{n_r}(k);\ k=0\sim N_c-1\}$ as

$$\begin{aligned} R_{n_r}(k) &= \sum_{t=0}^{N_c-1} r_{n_r}(t)\exp\left(-j2\pi k\frac{t}{N_c}\right), \\ &= \sqrt{\frac{2E_c}{T_c}}\sum_{n_t=0}^{N_t-1} H_{n_r,n_t}(k)S_{n_t}(k)+\Pi_{n_r}(k) \end{aligned} \tag{27}$$

where E_c is the chip energy, T_c is the chip length, $H_{n_r,n_t}(k)$ is the complex channel gain between the n_tth transmit antenna and the n_rth receive antenna, $S_{n_t}(k)$ is the kth frequency component of $s_{n_t}(t)$, and $\Pi_{n_r}(k)$ is the noise.

6.2 Signal Separation/Detection

Since the channel is frequency-selective, signal separation/detection and frequency-domain equalization need to be jointly performed. Below, frequency-domain MLD (FD-MLD), two dimensional (2D)-ZF FDE detection, 2D-MMSE FDE detection, FD V-BLAST and iterative joint MMSE-FDE/FD-parallel interference cancellation (PIC) are introduced.

(a) FD-MLD

MLD computes the log-likelihood metric as

$$\lambda=\sum_{k=0}^{N_c-1}\sum_{n_r=0}^{N_r-1}\left|R_{n_r}(k)-\sqrt{\frac{2E_c}{T_c}}\sum_{n_t=0}^{N_t-1}H_{n_r,n_t}(k)\tilde{S}_{n_t}(k)\right|^2, \tag{28}$$

where $\tilde{S}_{n_t}(k)$ is the kth frequency component of the candidate chip block $\{\tilde{s}_{n_t}(t);\ t=0\sim N_c-1\}$. MLD finds the best combination of N_t transmitted chip blocks which

provides the smallest log-likelihood metric, i.e., $\{\hat{s}_0(t), .., \hat{s}_{n_t}(t), ..., \hat{s}_{N_t-1}(t)\} = \min_{\{\hat{s}_{n_t}(t)\}} \lambda$. After de-spreading and de-scrambling, the most reliable symbol sequence is obtained. MLD provides the best transmission performance; however, it has a drawback of quite large computational complexity since the number of metric computations is as much as $2^{N_t \cdot N_c \cdot B}$, where B is the number of bits per symbol.

(b) 2D-ZF FDE detection and 2D-MMSE FDE detection

In 2D-ZF FDE detection and 2D-MMSE FDE detection, the kth frequency component $\hat{R}_{n_t}(k)$ of the n_tth transmitted chip block is obtained as

$$\hat{R}_{n_t}(k) = \mathbf{w}_{n_t}(k)\mathbf{R}(k), \tag{29}$$

where $\mathbf{R}(k) = [R_0(k), \cdots, R_{N_r-1}(k)]^T$ is the N_r-by-1 received signal vector and $\mathbf{w}_{n_t}(k) = [w_{0,n_t}(k), \cdots, w_{N_r-1,n_t}(k)]$ is the 1-by-N_r weight vector. 2D-ZF FDE weight can be derived by Moore-Penrose generalized inversed matrix. The MMSE weight minimizes the MSE $E[|e(k)|^2]$ between the signal transmitted from the n_tth antenna and the received signal after performing FDE, where $e(k)$ is defined as

$$e(k) = \sqrt{\frac{2E_c}{T_c}} S_{n_t}(k) - \mathbf{w}_{n_t}(k)\mathbf{R}(k). \tag{30}$$

$\mathbf{w}_{n_t}(k)$ can be derived from as

$$\mathbf{w}_{n_t}(k) = \begin{cases} \left[\mathbf{H}^H(k)\mathbf{H}(k)\right]^{-1}_{n_t} \mathbf{H}^H(k) & \text{for 2D-ZF} \\ \mathbf{H}^H_{n_t}(k)\left[\mathbf{H}(k)\mathbf{H}^H(k) + \left(\dfrac{C \cdot E_c}{N_0}\right)^{-1} \mathbf{I}_{N_r}\right]^{-1} & \text{for 2D-MMSE} \end{cases}, \tag{31}$$

where $\mathbf{H}(k) = [\mathbf{H}_0(k), \cdots, \mathbf{H}_{N_t-1}(k)]$ is the N_r-by-N_t complex channel gain matrix whose element of the n_rth row and the n_tth column is $H_{n_r,n_t}(k)$, $[\mathbf{H}^H(k)\mathbf{H}(k)]^{-1}_{n_t}$ is the n_tth row vector of the inverse matrix of $\mathbf{H}^H(k)\mathbf{H}(k)$ and $\mathbf{I}_{N_r}$ is the N_r-by-N_r identity matrix. N_c-point IFFT is performed on $\{\hat{R}_{n_t}(k);\ k = 0 \sim N_c - 1\}$ to obtain the time-domain chip block. After performing despreading and de-scrambling, the received symbol sequence is recovered.

2D-ZF FDE weight gives the perfect separation of transmitted chip blocks since a frequency-nonselective channel is restored (if the channel estimation is ideal). However, the BER performance using 2D-ZF FDE detection degrades due to the noise enhancement. The 2D-MMSE FDE weight can reduce simultaneously the ICI and the interference from other antennas while suppressing the noise enhancement. Therefore, 2D-MMSE FFDE gives much better transmission performance.

(c) FD V-BLAST

In FD V-BLAST, the signal detection and interference cancellation are repeated until all the transmitted signals are detected according to the descending order of the received signal reliability. Without loss of generality, the transmit antenna having

the highest reliability is assumed to be the 0th transmit antenna, followed by the 1st, 2nd, ..., and (N_t-1)th antennas. The n_tth signal component $\hat{R}_{n_t}(k)$ is obtained, by performing 2D-MMSE FDE detection (or 2D-ZF FDE detection), as

$$\hat{R}_{n_t}(k) = \mathbf{w}'_{n_t}(k)\mathbf{R}'(k), \tag{32}$$

where $\mathbf{R}'(k) = [R'_0(k), \cdots, R'_{N_r-1}(k)]^T$ is the received signal vector after interference cancellation of the signals transmitted from the $0 \sim (n_t-1)$th antennas and $\mathbf{w}'_{n_t}(k) = [w'_{0,n_t}(k), \cdots, w'_{N_r-1,n_t}(k)]$ is the 1-by-N_r MMSE FDE or ZF FDE weight vector given by

$$\mathbf{w}'_{n_t}(k) = \begin{cases} \left[\mathbf{H}'^H(k)\mathbf{H}'(k)\right]^{-1}_{n_t}\mathbf{H}'^H(k) \text{ for 2D-ZF} \\ \mathbf{H}'^H_{n_t}(k)\left[\mathbf{H}'(k)\mathbf{H}'^H(k) + \left(\frac{C \cdot E_c}{N_0}\right)^{-1}\mathbf{I}_{N_r}\right]^{-1} \text{ for 2D-MMSE} \end{cases}, \tag{33}$$

where $\mathbf{H}'(k) = [\mathbf{H}'_{n_t}(k), \cdots, \mathbf{H}'_{N_t-1}(k)]$ is the N_r-by-(N_t-n_t) channel gain matrix obtained by deleting the $0 \sim (n_t-1)$th channel gain column vector from the N_r-by-N_t channel gain matrix $\mathbf{H}(k)$. The n_tth time-domain received chip block is obtained by carrying out N_c-point IFFT on $\{\hat{R}_{n_t}(k);\ k = 0 \sim N_c-1\}$. After performing despreading and descrambling, the received symbol sequence is recovered.

For the detection of the signal transmitted from the (n_t+1)th antenna, the interference replicas $\tilde{S}_{n'_t}(k)$, $n'_t = 0 \sim n_t$, are generated and subtracted from $R_{n_r}(k)$ as

$$R'_{n_r}(k) = R_{n_r}(k) - \sqrt{\frac{2E_c}{T_c}}\sum_{n'_t=0}^{n_t} H_{n_r,n'_t}(k)\tilde{S}_{n'_t}(k) \tag{34}$$

for the detection of the chip block transmitted from the (n_t+1)th antenna. The above operation is repeated, until all the transmitted signals are detected.

(d) Iterative joint MMSE-FDE/FD-PIC

The interference from other transmit antennas are suppressed by joint MMSE-FDE and FD-PIC. However, since the interference suppression is not sufficient, joint MMSE-FDE and FD-PIC is repeated. At the initial stage $(i=0)$, 2D-MMSE FDE is used. The interfering signal replicas $\{\tilde{S}^{(i-1)}_{n'_t}(k);\ k = 0 \sim N_c-1\}$, $n'_t = 0 \sim N_t-1, \neq n_t$, at the $(i-1)$th iteration are generated and are subtracted from the received signal $R_{n_r}(k)$ as

$$R'^{(i)}_{n_r,n_t}(k) = R_{n_r}(k) - \sqrt{\frac{2E_c}{T_c}}\sum_{n'_t=0\neq n_t}^{N_t-1} H_{n_r,n'_t}(k)\tilde{S}^{(i-1)}_{n'_t}(k). \tag{35}$$

Since the resulting signal is close to that for the single antenna transmission case, 1D-MMSE FDE is used instead of 2D-MMSE FDE for $i \geq 1$. Joint 1D-MMSE FDE is performed as

$$\hat{R}^{(i)}_{n_t}(k) = \mathbf{w}'^{(i)}_{n_t}(k)\mathbf{R}'^{(i)}_{n_t}(k), \tag{36}$$

where $\mathbf{R}'^{(i)}_{n_t}(k) = [R'^{(i)}_{0,n_t}(k), \cdots, R'^{(i)}_{N_r-1,n_t}(k)]^T$ and $\mathbf{w}'^{(i)}_{n_t}(k) = [w'^{(i)}_{0,n_t}(k), \cdots, w'^{(i)}_{N_r-1,n_t}(k)]$ is the 1D-MMSE FDE weight vector, given by

$$\mathbf{w}'^{(i)}_{n_t}(k) = \mathbf{H}^H_{n_t}(k)\left[\mathbf{H}^H_{n_t}(k)\mathbf{H}_{n_t}(k) + \left(\frac{C \cdot E_c}{N_0}\right)^{-1}\right]^{-1}. \quad (37)$$

6.3 BER Performance

The BER performance of full code-multiplexed SC-CDMA using (4,4)SDM is plotted in **Figure 16** as a function of the average received E_b/N_0 per receive antenna. $N_t \times N_r$ channels are independent Rayleigh fading channels having an $L = 16$-path uniform power delay profile ($\beta = 0$dB). Iterative joint MMSE-FDE/FD-PIC is superior to 2D-ZF FDE detection, 2D-MMSE FDE detection, and FD V-BLAST. For comparison, the BER performance of the perfect PIC (i.e., the interference from

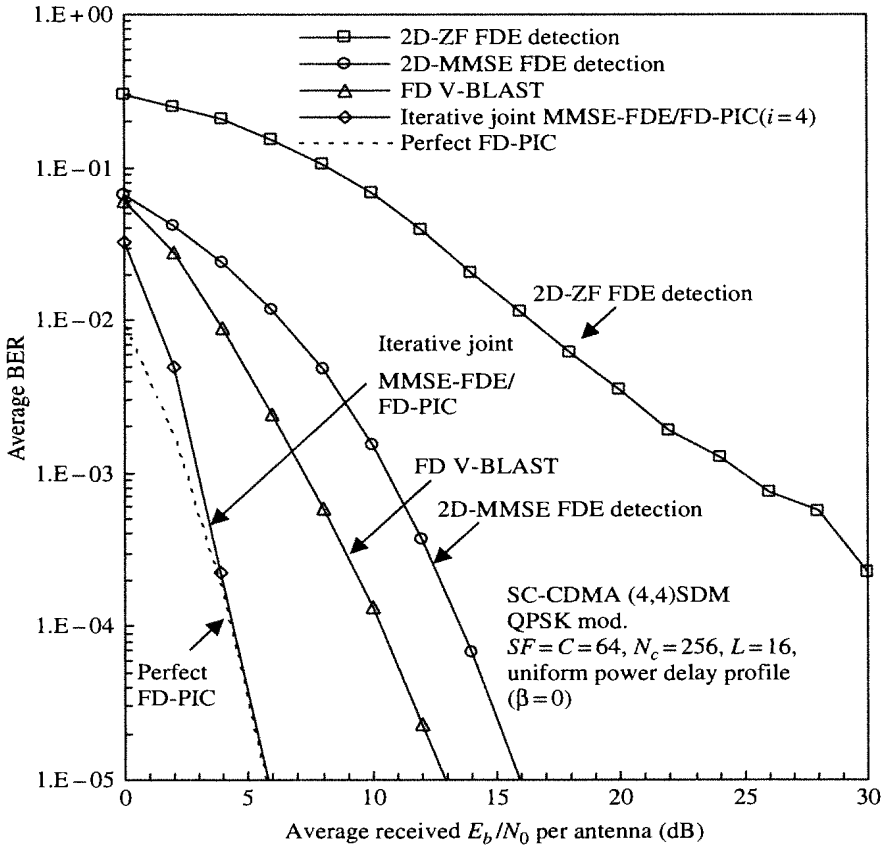


Figure 16. BER performance of full code-multiplexed SC-CDMA using (4,4) SDM

other antennas is perfectly cancelled) is also plotted. The E_b/N_0 degradation, for BER $= 10^{-4}$, of iterative joint MMSE-FDE/FD-PIC from the perfect PIC is only about 0.1dB. A reason for this superiority of iterative FD-PIC is discussed below.

Only an $(N_r - N_t + 1)$-order antenna diversity gain can be obtained by 2D-ZF FDE detection and 2D-MMSE FDE detection. The BER performance with 2D-ZF FDE detection degrades due to the noise enhancement. In FD V-BLAST, the transmitted signals are detected according to the descending order of signals' reliability. After performing signal detection, the detected signal is subtracted from the received signal by using its replica and then the corresponding channel gain vector is deleted from the N_r-by-N_t channel gain matrix. For the detection of the signal transmitted from the n_t'th antenna ($n_t' = 0 \sim N_t - 1$), the N_r-by-$(N_t - n_t')$ channel gain matrix is used. As a consequence, a diversity order of between $(N_r - N_t + 1)$ and N_r is obtained by FD V-BLAST. On the other hand, iterative joint MMSE-FDE/FD-PIC can always obtain the N_rth-order diversity gain.

7. BLOCK SPREAD CDMA

Relying on orthogonal spreading codes, SC-CDMA allows simultaneous transmissions from multiple users. However, as the chip rate increases, multipath channels become time-dispersive and frequency-selective fading is produced. The frequency-selective fading causes ICI. In the downlink (base-to-mobile) transmission, different users' data sequences are spread by orthogonal spread codes and are code-multiplexed. The ICI destroys the code orthogonality at an MS receiver and gives rise to the downlink multi-access interference (MAI). The downlink MAI severely limits the performance of single-user rake receivers. The use of MMSE-FDE can exploit the channel frequency-selectivity as well as suppressing the downlink MAI and therefore improve the downlink BER performance as discussed in **Section 4**. However, in the uplink (mobile-to-base) transmission, different users' signals go through different channels and are asynchronously received, thereby producing the uplink MAI. Unfortunately, the uplink MAI cannot be sufficiently suppressed by single-user MMSE-FDE. Multiuser detection (MUD), can suppress the uplink MAI. However, its computational complexity grows exponentially with the number of users. Block spreading can be used to convert the MUD problem into a set of equivalent single-user equalization problems.

7.1 One-dimensional Block Spreading

One-dimensional (1D) block spreading technique proposed in is shown in **Figure 17**. The uth user's data block consisting of N_c symbols, $\mathbf{d}_u = [d_u(0),\ldots,d_u(N_c - 1)]^T$, is block spread by using a spreading code $\mathbf{c}_u = [c_u(0),\ldots,c_u(SF_u - 1)]^T$. The result can be expressed as an $SF_u \times N_c$ matrix $\mathbf{S}_u$ as

$$\mathbf{S}_u = \mathbf{c}_u \mathbf{d}_u^T. \quad (38)$$

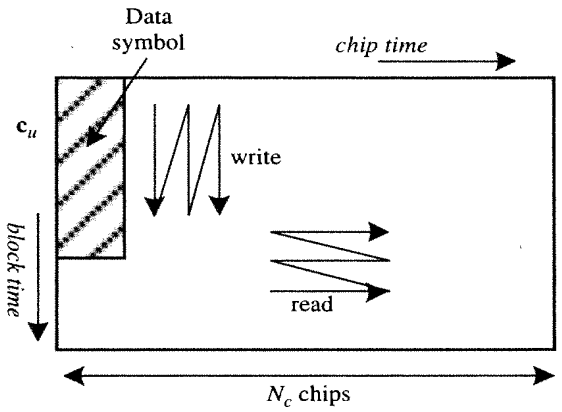


Figure 17. 1D block spreading

Chips from matrix $\mathbf{S}_u$ are transmitted row-by-row over SF_u block periods, which means that N_c chips are transmitted in each block. The mth chip block is represented by the $N_c \times 1$ vector as

$$\mathbf{x}_u(m) = c_m(m)\,[d_u(0), \cdots, d_u(N_c - 1)]^T. \tag{39}$$

The signal to be transmitted can be expressed, using equivalent lowpass representation, as

$$\mathbf{s}_u = \sqrt{\frac{2E_c}{T_c}}\,[\mathbf{x}_u^T(0), \cdots, \mathbf{x}_u^T(SF_u - 1)]^T, \tag{40}$$

where E_c is the chip energy, T_c is the chip duration. After the insertion of N_g-chip GI, the uth user's signal is transmitted.

A superposition of U users' faded signals is received, via L-path fading channels, by the BS's receiver. The sum of the maximum time delay of the channel and the timing offsets among different users is assumed to be within the GI. After the GI removal, the received signal vector $\mathbf{r} = [r(0), \ldots, r(SF_uN_c - 1)]^T$ with length SF_uN_c chips is given by

$$\mathbf{r} = \sqrt{\frac{2E_c}{T_c}} \sum_{u=0}^{U-1} \tilde{\mathbf{H}}_u \mathbf{s}_u + \boldsymbol{\eta}, \tag{41}$$

where $\tilde{\mathbf{H}}_u = diag\,\{\mathbf{H}_u(0), \ldots, \mathbf{H}_u(SF_u - 1)\}$ is the uth user's channel matrix with $\mathbf{H}_u(m)$ being the $N_c \times N_c$ channel matrix at the mth block time and $\boldsymbol{\eta} = [\eta(0), \ldots, \eta(SF_uN_c - 1)]^T$ is the noise vector with zero-mean and variance $2N_0/T_c$ (N_0 is the AWGN one-sided power spectrum density). Because of the GI insertion, $\mathbf{H}_u(m)$ is a circulant Toeplitz matrix with the first column given as $[h_{u,0}(m),\ldots,h_{u,L-1}(m),0,\ldots,0]^T$, where $h_{u,l}(m)$ is the lth path gain of the uth user's

channel at the mth block time. $\mathbf{r}$ is written into an $SF_u \times N_c$ matrix row-by-row as $\mathbf{R}_u$ and then despread by using $\mathbf{c}_u$ as

$$\begin{aligned}\hat{\mathbf{r}}_u &= \frac{1}{SF_u}\left(\mathbf{c}_u^H \mathbf{R}_u\right)^T \\ &= \sqrt{2E_c/T_c}\,\overline{\mathbf{H}}_u \mathbf{d}_u + \sum_{\substack{u'=0 \\ u' \neq u}}^{U-1} \sqrt{2E_c/T_c}\,\overline{\mathbf{H}}_{u'} \mathbf{d}_{u'} + \overline{\boldsymbol{\eta}},\end{aligned} \tag{42}$$

where the 1st and 2nd terms are respectively the desired signal and the MAI with

$$\begin{cases} \overline{\mathbf{H}}_{u'} = \dfrac{1}{SF_u} \displaystyle\sum_{m=0}^{SF_u-1} c_u^*(m) c_{u'}(m) \mathbf{H}_{u'}(m) \\ \overline{\boldsymbol{\eta}} = \dfrac{1}{SF_u}\left(\mathbf{c}_u^H \Pi\right)^T \end{cases} \tag{43}$$

Here, Π is the $SF_u \times N_c$ noise matrix, whose xth row and yth column element is $\eta(x \cdot SF_u + y)$, and $\overline{\boldsymbol{\eta}}$ is an $N_c \times 1$ vector whose elements are independent zero-mean complex Gaussian variables with variance $2N_0/T_c/SF_u$. If the channel is time-invariant (i.e., $\mathbf{H}_u(m) = \mathbf{H}_u(0)$ for $m = 0 \sim SF_u - 1$), the MAI is removed since $\mathbf{c}_u^H \mathbf{c}_{u'} = SF_u \delta(u - u')$, where $\delta(\cdot)$ is the delta function.

7.2 Two-dimensional Block Spreading

1D block spread SC-CDMA is a single-rate transmission. In the next generation mobile communications, a flexible support of low-to-high multi-rate services is required. The suppression of MAI to increase the link capacity in a mutli-rate environment is a challenging task. Two-dimensional (2D) block spreading using orthogonal variable spreading factor (OVSF) codes can remove the MAI while allowing multi-rate transmissions. 2D block spreading also achieves the time- and frequency-domain diversity gains.

A transmitter/receiver structure of 2D block spread SC-CDMA is illustrated in **Figure 18**. The data symbol to be transmitted is spread in two dimensions, as shown in **Figure 19**. The overall spreading factor is $SF_u = SF_u^t \times SF_u^f$, where SF_u^f is the spreading factor of chip-time spreading and SF_u^t is that of block-time spreading. 2D block spread SC-CDMA includes the conventional SC-CDMA and 1D block spread SC-CDMA as its special cases; 2D block spread SC-CDMA becomes the conventional SC-CDMA when $SF_u^t = 1$, while it becomes 1D block spread SC-CDMA when $SF_u^f = 1$.

Let's consider a block transmission of N_c/SF_u^f data symbols. The data symbol vector $\mathbf{d}_u = [d_u(0), \ldots, d_u(N_c/SF_u^f - 1)]^T$ is spread by a 2D block spreading code $\mathbf{C}_u$ with the overall spreading factor SF_u as

$$\mathbf{S}_u = \mathbf{C}_u \otimes \mathbf{d}_u^T, \tag{44}$$

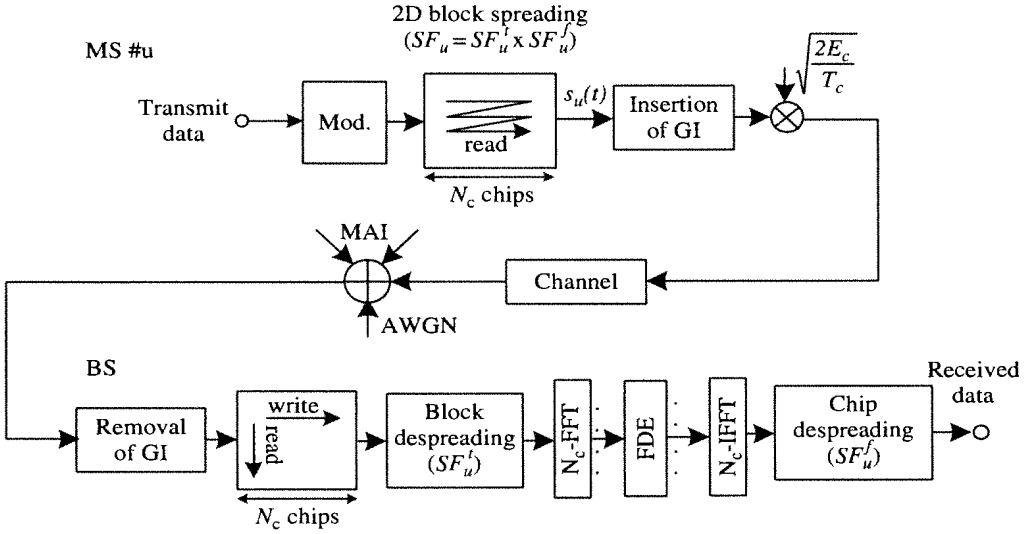


Figure 18. 2D block spread SC-CDMA transmitter/receiver

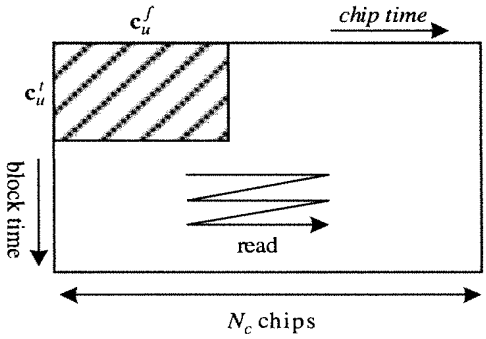


Figure 19. 2D block spreading

where $\otimes$ denotes the Kronecker product and $\mathbf{C}_u$ is an $SF_u^t \times SF_u^f$ matrix and can be written as

$$\mathbf{C}_u = \mathbf{c}_u^t \left(\mathbf{c}_u^f\right)^T \tag{45}$$

with $\mathbf{c}_u^t$ and $\mathbf{c}_u^f$ being respectively the column and row spreading codes, given by

$$\begin{cases} \mathbf{c}_u^t = [c_u^t(0), \ldots, c_u^t(SF_u^t - 1)]^T \\ \mathbf{c}_u^f = [c_u^f(0), \ldots, c_u^f(SF_u^f - 1)]^T \end{cases} . \tag{46}$$

$\mathbf{c}_u^f$ is used for multi-rate transmissions and SF_u^f can be arbitrarily set according to the requested data rate independently of the FFT block size N_c, but $SF_u^f \leq N_c$. $\mathbf{c}_u^t$

is used for orthogonal multi-user multiplexing without MAI. In order to maintain the orthogonality among different users, SF_u^t should be as small as possible.

7.3 Code Assignment

$\mathbf{c}_u^t$ and $\mathbf{c}_u^f$ can be selected from OVSF codes. OVSF codes are generated by the code tree, as shown in **Figure 20**. The data rates may be different for different users. $\mathbf{c}_u^t$ should be orthogonal for different users while $\mathbf{c}_u^f$ is not necessary orthogonal. If the number U of users is $U=2^k$ $(k=0, 1, \ldots)$, all users can be assigned $SF_u^t = 2^k$. If $2^{k-1} < U < 2^k$, $(2^k - U)$ users among U users can be assigned $SF_u^t = 2^{k-1}$ and the other $(2U-2^k)$ users can be assigned $SF_u^t = 2^k$. After setting the value of SF_u^t, SF_u^f can be set equal to $SF_u^f = SF_u/SF_u^t$ for the given overall spreading factor SF_u. By doing so, all U users' signals can be orthogonal.

For simplicity, we assume that the data rate is the same for all users and the overall spreading factor is $SF_u = SF$. Hence, we use $(SF_u^t, SF_u^f) = (U, SF/U)$. Consider $SF = 16$. If $U=8$, $\mathbf{c}_u^t$ is selected from $\{\mathbf{c}_m^8;\ m = 0 \sim 7\}$, e.g., $\mathbf{c}_u^t = \mathbf{c}_5^8 = [1, -1, 1, -1, -1, 1, -1, 1]^T$ in **Figure 20**, and $\mathbf{c}_u^f$ can be selected from $\{\mathbf{c}_m^2;\ m = 0 \sim 1\}$. If $U=4$, $\mathbf{c}_u^t$ is selected from $\{\mathbf{c}_m^4;\ m = 0 \sim 3\}$, e.g., $\mathbf{c}_u^t = \mathbf{c}_2^4 = [1, -1, 1, -1]^T$, and $\mathbf{c}_u^f$ can also be selected from $\{\mathbf{c}_m^4;\ m = 0 \sim 3\}$. If $U=2$, then $\mathbf{c}_u^t$ is selected from $\{\mathbf{c}_m^2;\ m = 0 \sim 1\}$, e.g., $\mathbf{c}_u^t = \mathbf{c}_1^2 = [1, -1]^T$, and $\mathbf{c}_u^f$ can be selected from $\{\mathbf{c}_m^8;\ m = 0 \sim 7\}$. When $U = 1$, 2D block spreading reduces to the conventional 1D spreading.

7.4 BER Performance

The BER performance of 2D block spread SC-CDMA using single-user MMSE-FDE is compared, in **Figure 21**, with conventional SC-CDMA using MMSE-MUD

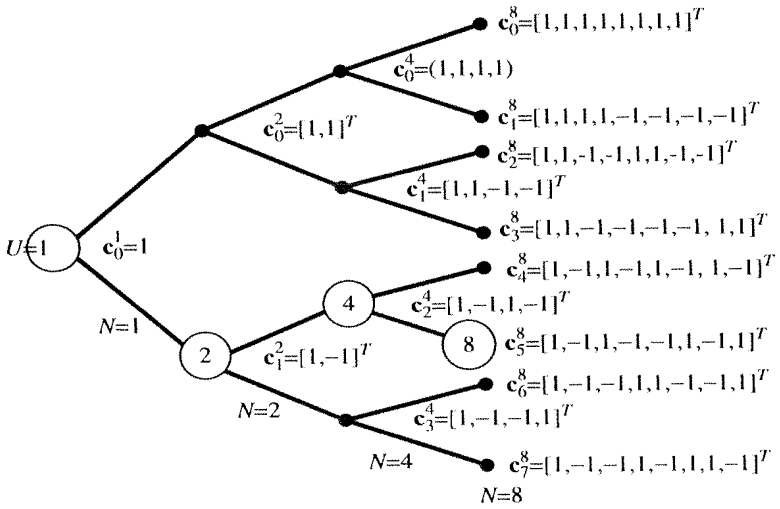


Figure 20. OVSF code tree

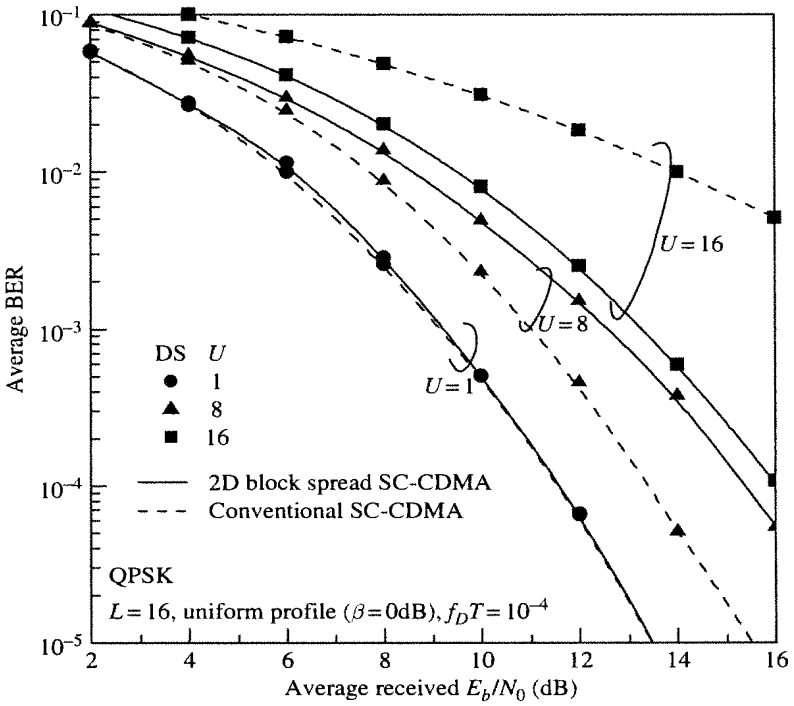


Figure 21. BER performance comparison of 2D block spread and conventional SC-CDMA when $SF = 16$

when $SF = 16$. For block spread SC-CDMA, $(SF_u^t, SF_u^f) = (U, 16/U)$ is assumed for all users. When the system is lightly loaded (i.e., $U = 8$), conventional SC-CDMA using MUD exhibits better BER performance since the MAI is less severe. However, when the system is heavily loaded (i.e., $U \approx SF$), the BER performance of conventional SC-CDMA with MUD severely degrades. Even when $U = 16$, 2D block spread SC-CDMA provides better BER performance than conventional SC-CDMA.

The block spreading technique can also be applied to MC-CDMA. The chip-time spreading in 2D block spread SC-CDMA corresponds to the frequency-domain spreading in the case of 2D block spread MC-CDMA. **Figure 22** compares the BER performances of 2D block spread SC- and MC-CDMA when $SF = 16$. In 2D block spread SC-CDMA, the data symbol is always spread over all subcarriers, yielding large frequency-diversity gain irrespective of SF_u^f. However, SC-CDMA suffers from ICI. On the other hand, in the case of MC-CDMA, the data symbol is spread over only SF_u^f subcarriers. When $U = 1$, 2D block spread MC-CDMA performs slightly better than SC-CDMA since no ICI is present in MC-CDMA. As U increases, the value of SF_u^f must be decreased and therefore, frequency-diversity gain becomes smaller in MC-CDMA and the ICI suppression become weaker in SC-CDMA. When $U = 16$

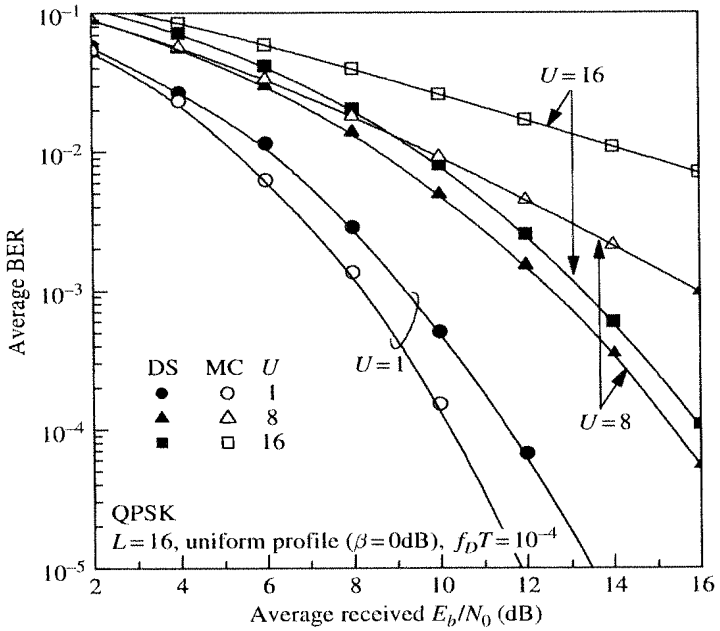


Figure 22. BER performance comparison of 2D block spread SC- and MC-CDMA when $SF = 16$

(i.e., $SF_{ii}^{f} = 1$), the frequency-diversity gain cannot be obtained in MC-CDMA, but larger frequency-diversity gain can still be obtained in SC-CDMA. Therefore, 2D block spread SC-CDMA provides much better BER performance than MC-CDMA.

8. HYBRID AUTOMATIC REPEAT REQUEST

For packet transmission, some form of error control mechanism is necessary to satisfy the quality requirement. There are two techniques for controlling transmission errors: the forward error correction (FEC) scheme that adds redundancy to the information to be transmitted and errors are corrected at the receiver, and the backward error correction or the automatic repeat request (ARQ) scheme in which error control is accomplished using error detection and retransmission. ARQ is simple and provides high system reliability. However, ARQ systems have a severe drawback - their throughput falls rapidly with increasing channel error rate. Systems using FEC maintain constant throughput regardless of the channel error rate. However, FEC systems cannot achieve high system reliability without using long powerful codes. This makes the decoding hard to implement and the throughput is considerably low in case of low error channels. Drawbacks in both ARQ and FEC could be overcome if two error control schemes are properly combined. Such a combination of two error control schemes is referred to as hybrid ARQ (HARQ).

8.1 Hybrid ARQ

An HARQ system consists of an FEC subsystem contained in an ARQ system. Popular HARQ strategies are Chase combing (CC) and incremental redundancy (IR). In HARQ using CC strategy, the previously transmitted packet is retransmitted following a negative acknowledgement (NAK); the retransmitted packets are combined to increase the received signal power. In CC, a fixed number of parity bits for error correction are transmitted even if all of them are not needed under good channel conditions. However, in IR, the parity bits are transmitted only when requested. In IR the coding rate decreases and the error correction power becomes stronger as the redundancy increases with each retransmission. A conceptual diagram for CC and IR is shown in **Figure 23**. Cyclic redundancy code (CRC) is the most commonly used error detection code in ARQ. At the receiver, the processing is shown for the case when a retransmitted packet is received following an NAK.

HARQ with turbo coding has gained importance as a promising error control scheme. Since the invention of turbo codes, they have been widely accepted and incorporated in many communications systems. Turbo encoder consists of recursive systematic convolutional (RSC) encoders connected in parallel with interleavers between them. The simplest and the most widely studied and used turbo encoder/decoder consist of two RSC component encoders and decoders resulting in a rate 1/3 code. The turbo encoder with a constraint length 4 and (13, 15) RSC component encoders followed by a puncturer (to adjust the coding rate) is illustrated in **Figure 24 (a)**. The turbo decoder is an iterative decoder with component decoders associated with the constituent RSC encoders in the turbo encoder. At the receiver, each component decoder computes the reliability (soft value) for each information bit from the coherently detected received signal and the extrinsic information generated by the other component decoder, except for the first decoder in the first iteration which uses only the coherently detected received signal. The iterative turbo decoder is illustrated in **Figure 24 (b)**. Several algorithms are available to generate the extrinsic estimation: soft-output Viterbi algorithm (SOVA), maximum-a-posteriori (MAP) algorithm, log-MAP algorithm, and max-log-MAP algorithm. The performance improvement is known to be minimal after about 8 decoding iterations. Turbo codes with coding rates higher than 1/3 are generated by puncturing the parity sequences at the transmitter and replacing the unsent bits at the receiver by a zero channel value.

8.2 Combination of HARQ and Frequency-domain Equalization

The data rate can be increased in a SC-CDMA system by assigning C orthogonal spreading codes to the same user, resulting in what is commonly referred to as multicode SC-CDMA. The data-modulated symbol sequence is converted into C parallel streams and spread using C different orthogonal codes. The spread signals are multiplexed and divided into a sequence of chip blocks of N_c chips each. After

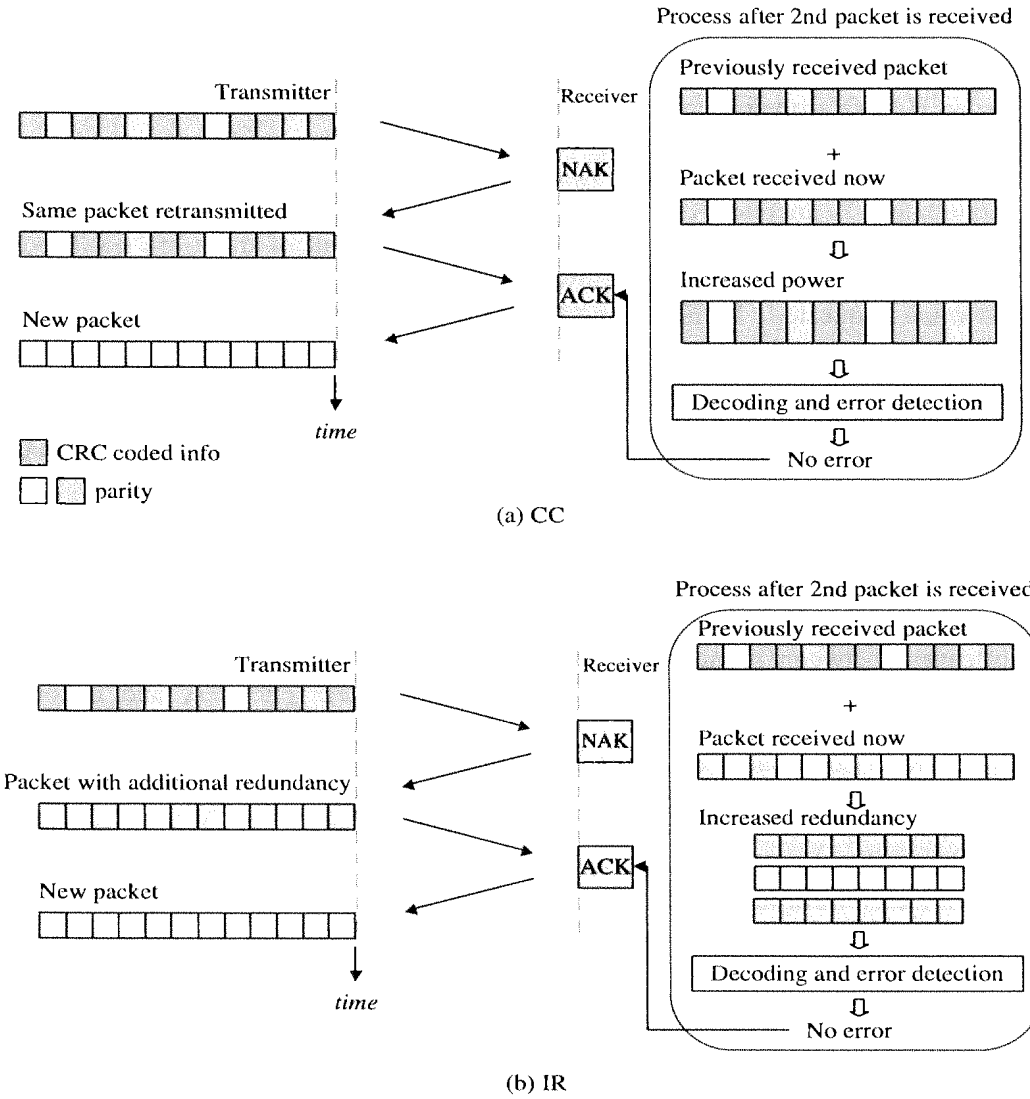
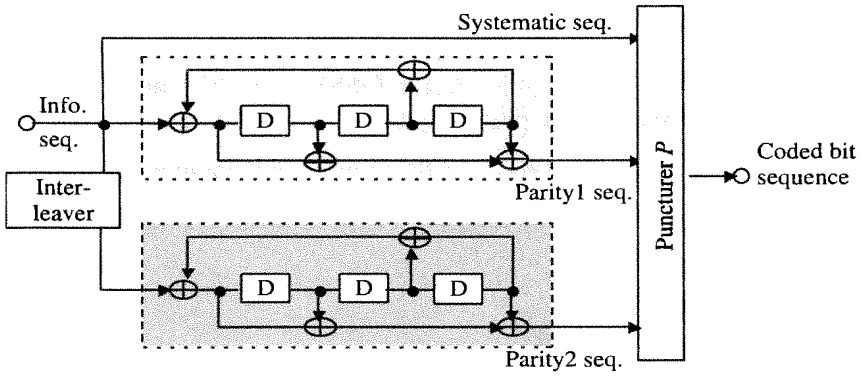


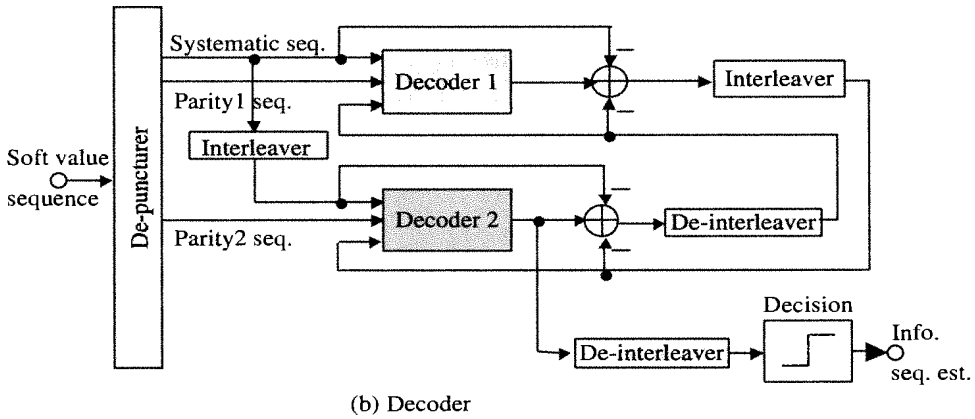
Figure 23. Conceptual diagram for Chase combining (CC) and incremental redundancy (IR)

the insertion of N_g-sample GI in each block, a sequence of GI-inserted chip blocks is transmitted. At the receiver, after GI removal, each block is first decomposed by applying N_c-point FFT into N_c frequency components for MMSE-FDE. The time-domain signal is obtained by applying N_c-point IFFT. Then, the time-domain signal is despread using the C different orthogonal codes. When the number C of codes multiplexed is taken to be the same as the spreading factor SF, the transmission rate is the same as that of a non-spread system.

The component decoders of the turbo decoder requires soft values as input. The soft value for turbo decoding can be generated using the log-likelihood ratio (LLR)



(a) Encoder



(b) Decoder

Figure 24. Turbo encoder and decoder

for each bit. It is necessary to know the statistics of the received symbol to properly calculate the LLR. Hence it is important to know the statistics of the despread signal that is input to the turbo decoder when turbo coding is used in the SC-CDMA system using FDE.

The LLR values should be computed for each bit taking into account its equivalent channel gain and the residual ICI after FDE. The residual ICI can be approximated as a complex Gaussian noise and therefore the sum of residual ICI and noise can be treated as a new complex Gaussian noise process with variance $2\sigma^2$. The LLR is given by

$$L(b) = \ln\left[\frac{\sum_{\{\hat{s}:b=1\}} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2}\left|\hat{d}_c(n) - \sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}\right|^2\right)}{\sum_{\{\hat{s}:b=0\}} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2}\left|\hat{d}_c(n) - \sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}\right|^2\right)}\right], \tag{47}$$

where $\hat{d}_c(n)$ is the despreader output corresponding to the nth symbol for the cth parallel stream ($c = 0 \sim C-1$), $\hat{s}$ is the candidate symbol with the bth bit as 0 or 1 ($b = 0 \sim B-1$ with $B = 2$, 4 or 6 for QPSK, 16QAM and 64QAM, respectively), E_c is the chip energy per parallel stream, T_c is the chip period, and $\tilde{H} = \frac{1}{N_c}\sum_{k=0}^{N_c-1}\hat{H}(k)$, where $\hat{H}(k) = w(k)H(k)$ is the equivalent channel gain introduced in Eq. (6). The variance $2\sigma^2$ of the Gaussian approximated residual ICI plus noise is given by

$$2\sigma^2 = 2\frac{N_0}{T_c}\left[\frac{1}{N_c}\sum_{k=0}^{N_c-1}|w(k)|^2 + \left(\frac{C}{SF}\frac{E_s}{N_0}\right)\left\{\frac{1}{N_c}\sum_{k=0}^{N_c-1}|\hat{H}(k)|^2 - \left|\frac{1}{N_c}\sum_{k=0}^{N_c-1}\hat{H}(k)\right|^2\right\}\right], \tag{48}$$

where N_0 is the one-sided noise power spectrum density, SF is the spreading factor, and $E_s = SF \cdot E_c$ is the symbol energy. The denominator and numerator inside the brackets of Eq. (47) can be approximated as

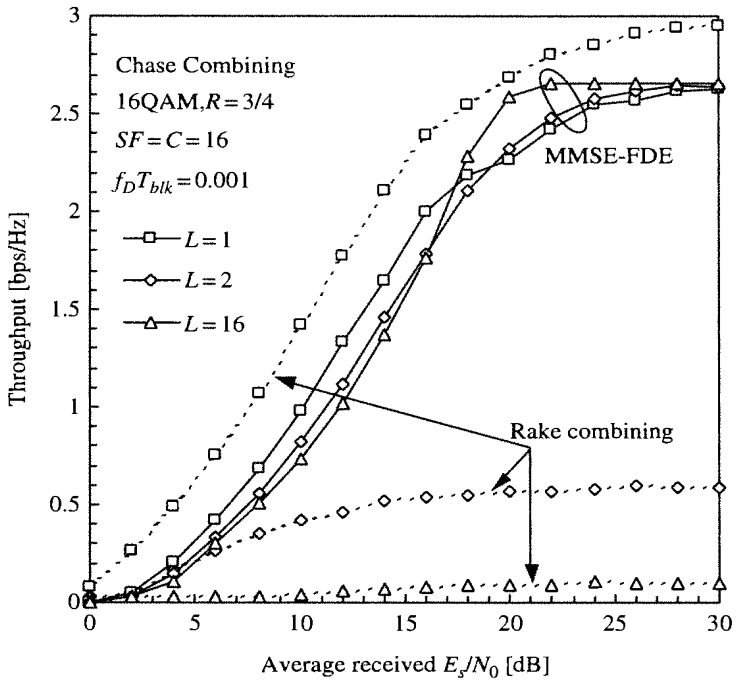
$$\begin{aligned}&\sum_{\{\hat{s}:b=1 \text{ or } 0\}}\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{1}{2\sigma^2}\left|\hat{d}_c(n)-\sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}\right|^2\right)\\ &\approx \max_{\{\hat{s}:b=1 \text{ or } 0\}}\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{1}{2\sigma^2}\left|\hat{d}_c(n)-\sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}\right|^2\right)\end{aligned}. \tag{49}$$

Hence, the LLR can be written as

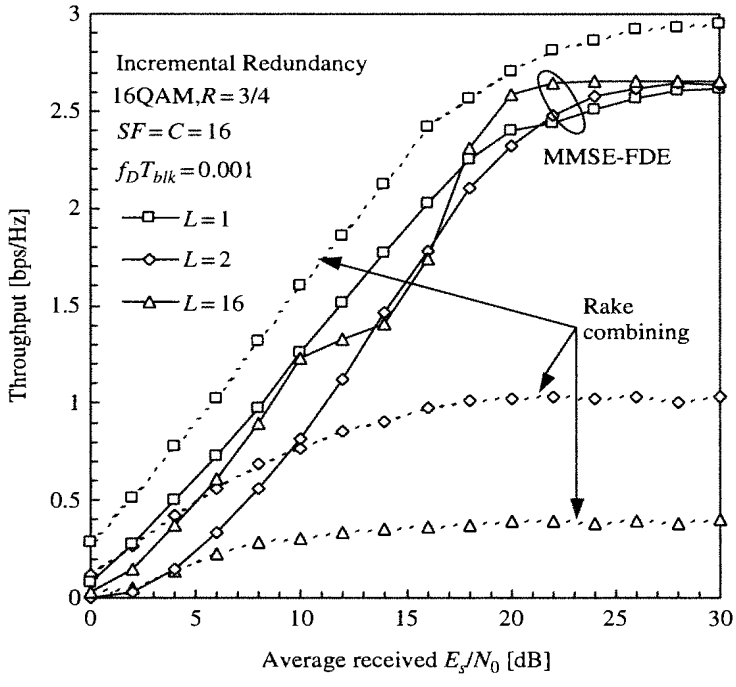
$$L(b) = \frac{1}{2\sigma^2}\left(\left|\hat{d}_c(n)-\sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}_{0,\min}\right|^2 - \left|\hat{d}_c(n)-\sqrt{\frac{2E_c}{T_c}}\tilde{H}\hat{s}_{1,\min}\right|^2\right) \tag{50}$$

for the bth bit in the nth symbol, where $\hat{s}_{0,\min}$ (or $\hat{s}_{1,\min}$) is the symbol that has the minimum Euclidean distance from $\hat{d}_c(n)$ among all candidate symbols with the bth bit as 0 (or 1). The LLR values are computed for $c = 0 \sim C-1$ and for all the bits in the symbol. Turbo decoding is performed using these LLR values as soft input after rate matching. Then, error detection is performed and retransmission is requested if errors are detected.

The throughput performance in bps/Hz of SC-CDMA with MMSE-FDE when turbo coded HARQ is used are shown in **Figure 25** for $f_D T_{blk} = 0.001$ (f_D denotes the maximum Doppler frequency of the fading channel and $T_{blk} = T_c(N_c + N_g)$ denotes the chip block length). L-path Rayleigh fading channel with uniform power delay profile is assumed. The equivalent spreading factor $SF_{eq}(=SF/C)$ is set to $SF_{eq} = 1$ (i.e., the transmission symbol rate is equal to the non-spread SC). Both CC and IR are considered. The data modulation is fixed to 16QAM. The coding rate is fixed at 3/4 for CC. For IR, the coding rate of the initial transmission is



(a) CC



(b) IR

Figure 25. Throughput performance

$R = 3/4$ and additional redundancy is transmitted with the second transmission. The following puncturing matrices are used (1 represents that the bit at that position is transmitted and 0 represents that it is not transmitted):

$$P_1 = \begin{bmatrix} 1\,1\,1\,1\,1\,1 \\ 1\,0\,0\,0\,0\,0 \\ 0\,0\,0\,1\,0\,0 \end{bmatrix}, P_2 = \begin{bmatrix} 0\,0\,0\,0\,0\,0 \\ 0\,1\,1\,1\,1\,0 \\ 1\,1\,0\,0\,1\,1 \end{bmatrix} \tag{51}$$

For CC, the same packet with puncturing matrix P_1 is transmitted until a positive acknowledge (ACK) is received. For IR, the puncturing matrix P_1 is used for the first transmission and P_2 for the second transmission and the order repeated for further transmissions. Code combining is employed if the same packet is transmitted more than once. For reference, the throughput obtained with coherent rake combining is also plotted; the throughput degrades drastically when the number L of paths increases. With the increase in L, the frequency-selectivity of the channel gets stronger and the orthogonality distortion is severer. Hence, the throughput decreases with the increase in L. However, with MMSE-FDE, the throughput is almost insensitive to L. This is because MMSE-FDE can partially restore the code orthogonality which is distorted due to the frequency selectivity of the channel and obtain the frequency diversity gain. For $L = 1$, the throughput is lower with MMSE-FDE compared to rake combining, due to the GI insertion loss. However in broadband channels characterized by time- and frequency-selective fading, the MMSE-FDE has a better performance.

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CHAPTER 4

FUNDAMENTALS OF MULTI-CARRIER CDMA TECHNOLOGIES

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Abstract: This chapter introduces and compares two kinds of techniques based on combination of CDMA and multicarrier transmission, such as Multicarrier CDMA and Multicarrier DS/CDMA. Several detection and combining schemes are derived for both the techniques, including a serial interference cancellation in uplink and a rake combining in downlink for MC-DS/CDMA whereas a decorrelating multiuser detection and a minimum mean square error (MMSE) multiuser detection in uplink and an orthogonality restoring combining (ORC), an MMSE combining, a maximum ratio combining (MRC) and an equal gain combining (EGC) in downlink for MC-CDMA. The bit error rate (BER) lower bounds for the two techniques are theoretically analyzed and furthermore the BERs with the several detection/combining schemes are demonstrated by computer simulations

Keywords: Multi-carrier transmission, MC-CDMA, MC-DS/CDMA, and maximu ratio combiner

1. INTRODUCTION

CDMA technique is robust to frequency-selective fading and it has been successfully introduced in commercial cellular mobile communications systems such as IS-95 and 3G systems. On the other hand, multicarrier transmission technique is also inherently robust to frequency-selective fading and in the name of orthogonal frequency division multiplexing (OFDM), it has been also successfully introduced in commercial wireless systems such as wireless local area networks (LANs) and terrestrial digital video broadcasting (DVB-T). Therefore, it would be quite natural to think of no synergistic effect in combination of these two techniques.

Whether the combination will be beneficial or not depends on a bandwidth and a data transmission rate we intend to support. In fact, for a 2 Mbits/sec-data transmission rate which 3G systems are now supporting, the combination of CDMA and multicarrier transmission techniques brings no benefit at all. However, if we intend to support much higher data transmission than this, such as in future

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4G systems, the combination does bring a benefit, in other words, it becomes a promising data transmission technique.

This chapter introduces and compares two kinds of combination of CDMA and multicarrier transmission techniques. One is Multicarrier (MC-) CDMA, which was independently proposed by three different research groups in 1993, and another is MC-DS/CDMA, which was also proposed in 1993 and then its variant was proposed in 1996. The difference between the original and variant of MC-DS/CDMA is that the former allows overlapping of subcarrier spectra whereas the latter does not. The subcarrier non-overlapped MC-DS/CDMA is mathematically tractable, so in this chapter, we will use the (subcarrier non-overlapped) MC-DS/CDMA.

This chapter is organized as follows. **Section 2** shows a fatal problem of DS/CDMA in high-speed data transmission and **Section 3** introduces combination of multicarrier transmission and CDMA as a solution of the problem. **Section 4** explains several assumptions required for introducing and comparing MC-CDMA and MC-DS/CDMA. After **Section 5** outlines single-carrier DS/CDMA (In Chapter 3, single-carrier CDMA is referred to as DS/CDMA. In this chapter, on the other hand, to clearly show the structural difference between multi-carrier signaling and single-carrier signaling, the single-carrier CDMA is called "single-carrier DS/CDMA."), MC-DS/CDMA is first introduced in **Section 6** because MC-DS/CDMA has a similarity to single-carrier DS/CDMA, and then MC-CDMA is introduced in **Section 7**. **Section 8** demonstrates numerical results on the performance of MC-DS/CDMA and MC-CDMA systems, and finally **Section 9** concludes this chapter.

2. A FATAL PROBLEM OF DS/CDMA IN HIGH-SPEED DATA TRANSMISSION

Let us assume that a signal is emitted at a DS/CDMA transmitter, it goes through a frequency selective fading channel and then it arrives at a DS/CDMA receiver. **Figure 1** shows a block diagram of the DS/CDMA receiver with four rake finger processors. At the receiver, a received signal is fed to a bandpass filter (BPF), down-converted and then analog-to-digital (A/D) converted with I and Q branches. At each rake finger processor, the A/D-converted baseband samples are despread and integrated by a code generator and a correlator, and the differences in the phases and arrival times among the correlator outputs are compensated for by a phase rotator and a delay equalizer. Finally, a combiner sums up the channel impairment-compensated symbols to recover user data symbols.

The matched filter output, namely, observation of a channel impulse response is very important for DS/CDMA receiver, because it determines the number and positions of the paths captured by the rake combiner to collect the energy of received signal. When a receiver observes a channel, how finely it can analyze the temporal structure of the channel is called "time resolution." Defining the sampling rate as R_{smp} samples/sec, the time resolution Δt is given by $1/R_{smp}$ sec, so the number of resolvable paths in an observed impulse response of a channel is in proportion to

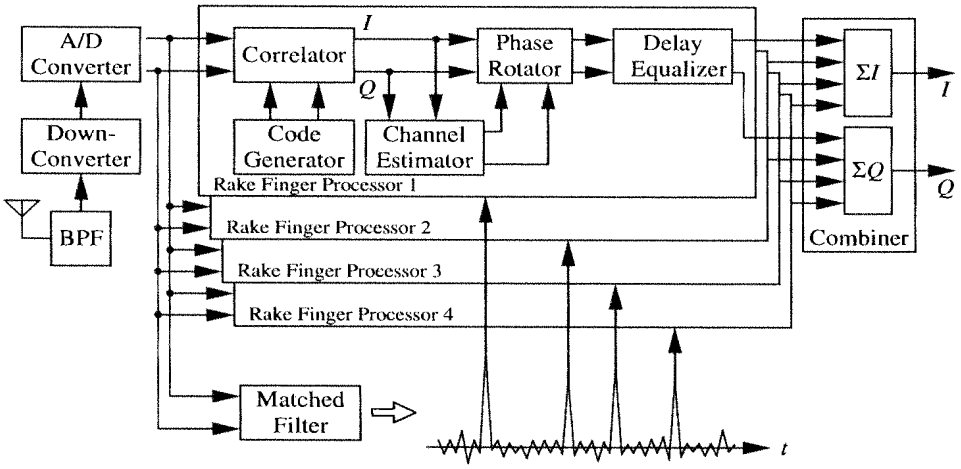


Figure 1. A block diagram of a DS/CDMA rake receiver

the sampling rate. For DS/CDMA system, the sampling rate is determined by the chip rate, so consequently, the number of resolvable paths is in proportion to the chip rate.

Let us consider a case where we intend to support a data transmission rate of up to 2 Mbits/sec in a wireless communication channel with carrier frequency of f_c. In this case, assuming spreading codes employed in 3G systems, a DS/CDMA receiver always sees less than around ten paths in matched filter outputs of the channel, as shown in **Figure 2 (a)**. Therefore, the receiver can collect almost all part of the received signal energy only with several rake finger processors. As shown in **Figure 1**, roughly speaking, the hardware complexity of DS/CDMA receiver is determined by the number of rake finger processors employed and this *mild* number of rake finger processors was acceptable in terms of cost, size and power consumption of 3G mobile terminals.

Now, let us consider a case where we intend to support a much higher data transmission rate such as 100 Mbits/sec, which is a typical data transmission rate discussed in 4G systems. This means that a DS/CDMA receiver will see several

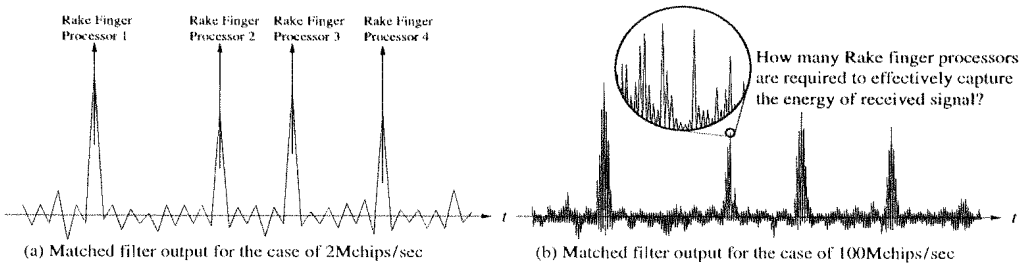


Figure 2. Comparison of matched filter output

hundreds of paths in impulse response of the channel, as shown in **Figure 2 (b)**, and hence it needs to have several hundreds of rake finger processors to effectively collect the energy of received signal. This will be prohibitive (Note that, using frequency domain equalizer instead of time domain rake combiner, the bit error rate (BER) of DS/CDMA system can be drastically improved as shown in Chapter 3).

3. COMBINATION OF MULTICARRIER TRANSMISSION AND CDMA

Reducing the data transmission rate results in lessening the number of rake finger processors, but it seems contradictory to achieving a high data transmission rate. However, as shown in **Figure 3**, a high data transmission rate is achievable with a number of lower data rate sub-channels with different carrier frequencies. This is the very idea of multicarrier transmission, which is the principle of transmitting data by dividing a data stream into a number of data streams, each of which has a much lower data rate and by using these substreams to modulate subcarriers. In **Figure 3**, the multicarrier system supports M parallel transmissions, reducing the transmission rate over each sub-channel by factor of M.

Limiting our discussion within application of CDMA technique to high data rate transmission, there are mainly two ways considered in combination of multicarrier and CDMA techniques. One way is to employ a mild number of sub-channels where there remains a frequency-selective fading in each sub-channel, and another way is to employ a huge number of sub-channels where frequency-selective fading has disappeared in each sub-channel. The former is called "multicarrier (MC)-DS/CDMA," which still requires a DS rake approach to effectively collect the energy of received signal over each sub-channel, whereas the latter is called "multicarrier (MC)-CDMA," which employs a spreading operation across the whole sub-channels to gain frequency diversity effect. **Figure 4** compares the power spectral densities (*PSDs*) among a Single-carrier (SC)-DS/CDMA, MC-DS/CDMA and MC-CDMA waveforms.

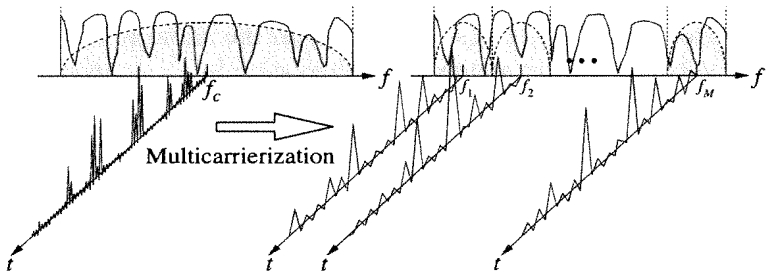


Figure 3. Multicarrierization

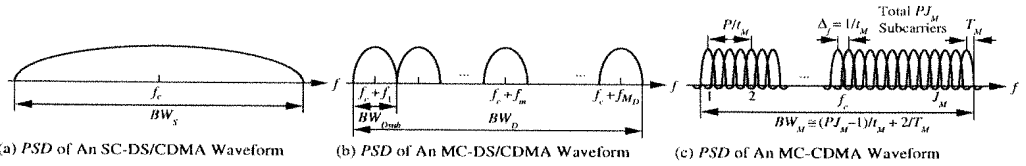


Figure 4. Power spectral densities

4. SYSTEM MODEL

4.1 Multiplexing/Multiple Access and Spreading Codes

It is assumed that SC-DS/CDMA, MC-DS/CDMA and MC-CDMA systems support K multiplexing/multiple access users employing spreading codes with spreading gain of J. In a downlink, a base station multiplexes K signals and then transmits the multiplexed signal to K users. On the other hand, in an uplink, each user transmits its own signal to a base station and the base station receives K signals through different channels. Here, the data symbol duration is defined as T whereas the chip duration as T_c. To distinguish the individual systems clearly, the subscripts for showing SC-DS/CDMA, MC-DS/CDMA and MC-CDMA systems are defined as S, D and M, respectively. In addition, the indices for spreading gain, user and subcarrier are defined as j, k and m, respectively, and furthermore, the indices for transmitted symbol and path gain in impulse response are defined as i and l, respectively.

The i-th data symbol for the k-th user is defined as a_{ki} for the single-carrier system whereas the i-th data symbol transmitted over the m-th subcarrier for the k-th user is defined as a_{kim} for the multi-carrier systems. Here, defining data symbol vectors $(K \times 1)$ as $\mathbf{a}_{iK} = [a_{1i}, \cdots, a_{Ki}]^T$ and $\mathbf{a}_{imK} = [a_{1im}, \cdots, a_{Kim}]^T$, they are assumed to respectively have the following statistical properties:

$$(1) \qquad E\left[\mathbf{a}_{iK}\mathbf{a}_{iK}^H\right] = \mathbf{I}_{K\times K}$$

$$(2) \qquad E\left[\mathbf{a}_{imK}\mathbf{a}_{imK}^H\right] = \mathbf{I}_{K\times K}$$

where $E[\cdot]$, $(\cdot)^T$ and $(\cdot)^H$ denote statistical average, transpose and Hermitian transpose of $(\cdot)$, respectively, and $\mathbf{I}_{K\times K}$ denotes the identity matrix with size of $K \times K$.

On the other hand, for spectrum spreading, the random codes are assumed. For the j-th chip of the k-th user c_{kj}, which takes +1 or -1 with the same probability, defining a code vector $(J \times 1)$ and a code matrix $(J \times K)$ as $\mathbf{c}_k = [c_{k1}, \cdots, a_{kJ}]^T$ and $\mathbf{C}_K = [\mathbf{c}_1, \cdots, \mathbf{c}_K]$, respectively, they are assumed to respectively have the following statistical properties:

$$(3) \qquad E\left[\mathbf{C}_K\mathbf{C}_K^H\right] = \frac{K}{J}\mathbf{I}_{J\times J}$$

$$(4) \qquad E\left[\mathbf{C}_K^H\mathbf{C}_K\right] = \mathbf{I}_{K\times K}.$$

4.2 Transmitter/Receiver

The carrier conveying information has a carrier phase ϕ_c as well as the frequency f_c, but the phase is ignored for the sake of analytical simplicity. In fact, assuming a perfect carrier synchronization, it gives no effect on derivation of the signal to noise power ratio (SNR) and the BER for the CDMA systems. In addition, the received signal is perturbed by different additive Gaussian noise at a base station in an uplink and a user in a downlink, but the same notation $n(t)$ is used in both the uplink and downlink for the sake of analytical simplicity. In fact, it also gives no effect on derivation of the SNR and the BER of the CDMA systems, because they are separately discussed in the uplink and downlink.

4.3 Channel and Noise

The channel for the k-th user is assumed to be a slowly varying frequency-selective Rayleigh fading one with impulse response of $h_k(t)$. When an SC-DS/CDMA receiver with spreading gain of J_S observes the channel, it sees the impulse response in a vector form with size of $J_S \times 1$. Here, the impulse response is assumed to have only L non-zero components, namely,

$$\mathbf{h}_k = [h_{k1}, \cdots, h_{kL}, 0, \cdots, 0]^T \tag{5}$$

where h_{kl} is a zero-mean complex-valued Gaussian-distributed amplitude (called "path"). The auto-correlation matrix of the channel ($J_S \times J_S$) is given by

$$E\left[\mathbf{h}_k \mathbf{h}_k^H\right] = \mathbf{H}_k = diag\{\sigma_{sk1}^2, \cdots, \sigma_{skL}^2, 0, \cdots, 0\} \tag{6}$$

where $diag\{\cdots\}$ and σ_{skl}^2 ($l = 1, \cdots, L$) denote the diagonal matrix with main diagonal elements of $\cdots$ and the l-th largest eigenvalues of $\mathbf{H}_k$, namely, the average power of the l-th component (path) of $h_k(t)$, respectively.

In addition to the impulse response vector, defining a noise vector ($J_S \times 1$) as $\mathbf{n} = [n_1, \cdots, n_J]^T$, it is assumed to have the following statistical property:

$$E\left[\mathbf{n}\mathbf{n}^H\right] = \mathbf{N} = \sigma_n^2 \mathbf{I}_{J \times J} \tag{7}$$

where σ_n^2 denotes the power of the noise.

5. SC-DS/CDMA SYSTEM

Figure 4 (a) shows the PSD of a SC-DS/CDMA waveform. If a root Nyquist filter $p_S(t)$ is employed for baseband pulse shaping, the bandwidth BW_S is given by

$$BW_S = \frac{1 + \alpha_S}{T_{cS}} \tag{8}$$

where α_S denotes a roll-off factor of the root Nyquist filter.

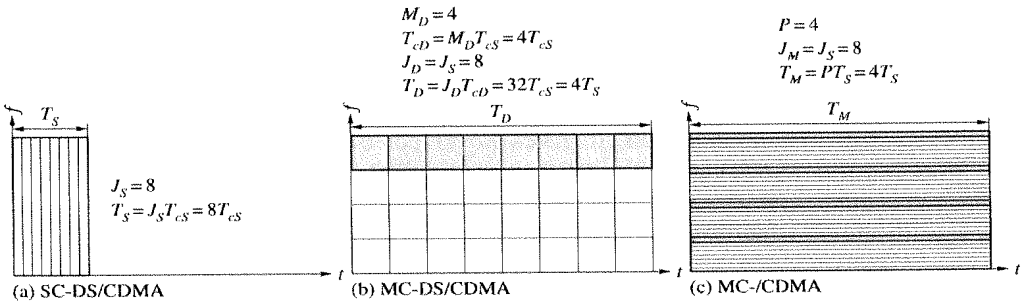


Figure 5. Tiling representations on a time-frequency plane

On the other hand, **Figure 5 (a)** shows a tiling representation of a SC-DS/CDMA waveform on a time-frequency plane, where $J_S = 8$ is assumed with $T_S = J_S T_{cS}$.

The structures of SC-DS/CDMA transmitter and receiver are all the same as those of SC-DS/CDMA transmitter and receiver for a certain subcarrier, respectively. Therefore, the BER of SC-DS/CDMA system will be discussed in the next section on MC-DS/CDMA system.

6. MC-DS/CDMA SYSTEM

6.1 Transmitter

Figure 4 (b) shows the PSD of an MC-DS/CDMA waveform, where the entire bandwidth is divided into M_D equi-width frequency sub-channels. Therefore, the entire bandwidth of MC-DS/CDMA waveform is the same as that of SC-DS/CDMA waveform, namely, $BW_D = BW_S$, whereas the bandwidth of each sub-channel is given by

$$BW_{D_{sub}} = \frac{BW_S}{M_D} = \frac{1+\alpha_S}{M_D T_{cS}}. \tag{9}$$

Note that, as compared with the SC-DS/CDMA system, the chip duration over sub-channels is widened into $T_{cD} = M_D T_{cS}$ and hence $T_D = M_D T_S$ if selecting the spreading gain as $J_D = J_S$. **Figure 5 (b)** shows a tiling representation of an MC-DS/CDMA waveform on a time-frequency plane, where $M_D = 4$ and $J_D = J_S = 8$ are assumed.

Figure 6 shows a block diagram of an MC-DS/CDMA transmitter for the k-th user. The data sequence, after spreading and baseband pulse shaping, modulates the M_D subcarrier signals and then is transmitted. The transmitted signal in the uplink is written as

$$s_{Dk}(t) = \sum_{m=1}^{M_D} s_{Dkm}(t) \tag{10}$$

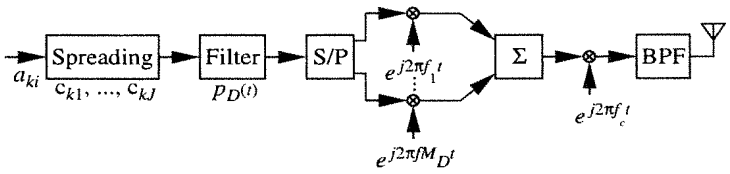


Figure 6. A block diagram of an MC-DS/CDMA transmitter for the k-th user

$$s_{Dkm}(t) = \sum_{i=-\infty}^{+\infty} \sum_{j=1}^{J_D} a_{kim} c_{kj} p_D(t - iT_D - (j-1)T_{cD}) \cdot e^{j2\pi(f_c+f_m)t} \tag{11}$$

where $s_{Dkm}(t)$ and $f_c + f_m$ denote the signal of the k-th user transmitted over the m-th subcarrier and the m-th subcarrier's center frequency, respectively. On the other hand, the transmitted signal in the downlink is written as

$$s_D(t) = \sum_{m=1}^{M_D} s_{Dkm}(t) \tag{12}$$

$$s_{Dkm}(t) = \sum_{k=1}^{K} \sum_{i=-\infty}^{+\infty} \sum_{j=1}^{J_D} a_{kim} c_{kj} p_D(t - iT_D - (j-1)T_{cD}) \cdot e^{j2\pi(f_c+f_m)t}. \tag{13}$$

6.2 Receiver

Figure 7 shows a block diagram of an MC-DS/CDMA receiver for the k-th user. The benefit of multicarrierization is to widen the chip duration by factor of M_D, so a quasi-synchronicity among all users can be assumed even in the uplink. In this case, setting the timing offsets among the users to zero, the received signal in the uplink is written as

$$r_D(t) = \sum_{m=1}^{M_D} r_{Dm}(t) \tag{14}$$

$$r_{Dm}(t) = \sum_{k=1}^{K} h_{km}(t) \otimes s_{Dkm}(t) + n_{Dm}(t) e^{j2\pi(f_c+f_m)t} \tag{15}$$

where $r_{Dm}(t)$, $h_{km}(t)$ and $n_{Dm}(t)$ denote the m-th subcarrier's received signal, a channel impulse response of the k-th user and a baseband Gaussian noise, respectively. On the other hand, the received signal in the downlink is written as

$$r_{Dk}(t) = \sum_{m=1}^{M_D} r_{Dkm}(t) \tag{16}$$

$$r_{Dkm}(t) = h_{km}(t) \otimes s_{Dm}(t) + n_{Dm}(t) e^{j2\pi(f_c+f_m)t}. \tag{17}$$

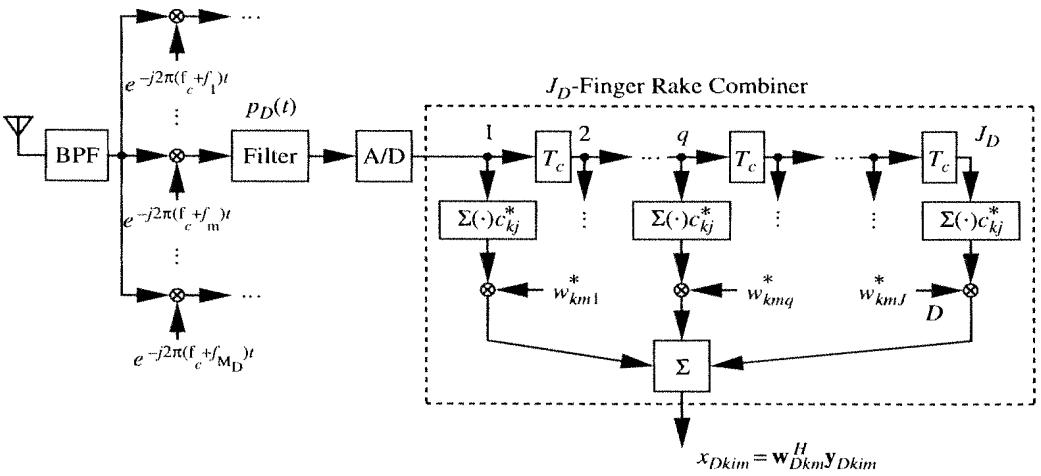


Figure 7. A block diagram of an MC-DS/CDMA receiver for the k-th user

Assuming that the number of rake finger processors is equal to J_D, the q-th rake finger output ($q = 1, \cdots, J_D$) for the i-th data symbol over the m-th subcarrier of the k'-th user is given by

$$y_{Dk'imq} = \sum_{j=1}^{J_D} d_{D\delta imqj} c_{k'j}^*. \tag{18}$$

In (18), $d_{D\delta imqj}$ denotes a received signal after down-conversion, baseband pulse shaping and sampling, which is written as

$$d_{D\delta imqj} = d_{D\delta m}(t = iT_D + (q-1)T_{cD} + (j-1)T_{cD}) \tag{19}$$

where $d_{D\delta m}(t)$ is given by

$$d_{D\delta m}(t) = p_D(t) \otimes \left(r_{D\delta m}(t) e^{-j2\pi(f_c + f_m)t}\right). \tag{20}$$

Note that, in (18)-(20), the subscript of δ is dropped for the uplink whereas replaced by k' for the downlink.

It is very important to relate $h_{km}(t)$ with $h_k(t)$ for a fair comparison of the BERs between the SC-DS/CDMA and MC-DS/CDMA systems, but here, we assume that $h_{km}(t)$ ($m = 1, \cdots, M_D$) has L_m-path gains when it is observed with chip rate of the MC system, namely, $1/T_{cD} = 1/(M_D T_{cS})$ for a while. The comparison of the BER lower bound between the SC-DS/CDMA and MC-DS/CDMA systems will be shown in the last part of this section, taking into account of the relationship between $h_{km}(t)$ and $h_k(t)$.

In this case, the channel impulse response is defined in a vector form ($J_D \times 1$) as $\mathbf{h}_{km} = [h_{km1}, \cdots, h_{kmL_m}, 0, \cdots, 0]^T$ with the following auto-correlation matrix ($J_D \times J_D$):

$$E\left[\mathbf{h}_{km}\mathbf{h}_{km}^H\right] = \mathbf{H}_{km} = diag\{\sigma_{skm1}^2, \cdots, \sigma_{skmL_m}^2, 0, \cdots, 0\} \tag{21}$$

where σ^2_{skml} $(l = 1, \cdots, L_m)$ denotes the l-th largest eigenvalues of $\mathbf{H}_{km}$, namely, the average power of the l-th path of $h_{km}(t)$.

Derivation on the rake finger output in the MC-DS/CDMA system is similar to that in the SC-DS/CDMA system. That is, the q-th rake finger output for the k'-user in the uplink is decomposed as

$$y_{Dk'imq} = g_{Dk'imq} + e_{Dk'imq} \tag{22}$$

$$g_{Dk'imq} = h_{k'mq} a_{k'im} \tag{23}$$

$$\begin{aligned} e_{Dk'imq} = & \sum_{\substack{k=1 \\ k\neq k'}}^{K} h_{kmq} a_{kim} \sum_{j=1}^{J_D} c_{kj} c^*_{k'j} \\ & + \sum_{k=1}^{K} \sum_{l=1}^{q-1} h_{kml} \left(a_{kim} \sum_{j=1}^{J_S-q+l} c_{k(q-l+j)} c^*_{k'j} \right. \\ & \left. + a_{k(i+1)m} \sum_{j=J_S-q+l+1}^{J_D} c_{k(q-l+j-J_S)} c^*_{k'j} \right) \\ & + \sum_{k=1}^{K} \sum_{l=q+1}^{L} h_{kml} \left(a_{k(i-1)m} \sum_{j=1}^{l-q} c_{k(q-l+j+J_S)} c^*_{k'j} \right. \\ & \left. + a_{kim} \sum_{j=l-q+1}^{J_D} c_{k(q-l+j)} c^*_{k'j} \right) \end{aligned}$$

$$+ \sum_{j=1}^{J_D} n'_{Dmqj} c^*_{k'j} \tag{24}$$

where n'_{Dmqj} is given by

$$n'_{Dmqj} = p_D(t) \otimes n_{Dm}(t)|_{t=iT_D+(q-1)T_{cD}+(j-1)T_{cD}}. \tag{25}$$

Note that the q-th rake finger output of the k-th user in the downlink is given by replacing h_{kmq} and h_{kml} by $h_{k'mq}$ and $h_{k'ml}$, respectively.

Dealing with $e_{Dk'imq}$ given by (24) jointly as a zero-mean complex-valued Gaussian random variable, no information on the k-th user $(k = 1, \cdots, K, k \neq k')$ is required to recover $a_{k'im}$. This is called "a singleuser detection," which is applicable to both the uplink and downlink. Defining the rake finger output vector $(J_D \times 1)$ as $\mathbf{y}_{Dk'im} = [y_{Dk'im1}, \cdots, y_{Dk'imJ_D}]^T$, it is written as

$$\mathbf{y}_{Dk'im} = \mathbf{h}_{k'm} a_{k'im} + \mathbf{e}_{Dk'im} \tag{26}$$

where $\mathbf{e}_{Dk'im}$ denotes an interference/noise vector $(J_D \times 1)$, which is defined as

$$\mathbf{e}_{Dk'im} = [e_{Dk'im1}, \cdots, e_{Dk'imJ_D}]^T. \tag{27}$$

Here, if the auto-correlation matrix ($J_D \times J_D$) of the interference and noise can be approximated as

$$E\left[\mathbf{e}_{Dk'im}\mathbf{e}_{Dk'im}^H\right] = \mathbf{E} \approx \sigma_e^2 \mathbf{I}_{J_D \times J_D} \tag{28}$$

where σ_e^2 is the power of the interference/noise, as shown in the Appendix A, a maximum ratio combiner is optimal in the sense of maximizing the SNR of the combiner output. That is, when the following weighted sum is considered:

$$x_{Dk'im} = \mathbf{w}_{Dk'm}^H \mathbf{y}_{Dk'im} \tag{29}$$

where $\mathbf{w}_{Dk'm}$ is a weight vector ($J_D \times 1$) defined as $\mathbf{w}_{Dk'm} = [w_{Dk'm1}, \cdots, w_{Dk'mJ_D}]^T$, selection of the weight vector as

$$\mathbf{w}_{Dk'm} = \mathbf{h}_{k'm} \tag{30}$$

maximizes the SNR of the combiner output at the m-th subcarrier.

By the way, in the uplink, the base station can know information on the parameters for all the users such as a_{kim}, c_{kj} and h_{kml} ($k = 1, \cdots, K$), so it can recover $a_{k'im}$ with the information. This is called "a multiuser detection." For instance, after finishing re-ordering k such that the received power of the k-th user's signal is greater or equal to that of the $(k+1)$-th user's signal, a serial interference cancellation (SIC) starts with decision on the data symbol for the first user with the highest reliability, namely, a_{1im}. When the SIC tries to decide $a_{k'im}$, it has decided a_{kim} ($k = 1, \cdots, k'-1$), so it can cancel the multiple access interference (MAI) associated with the k-th user from the received signal before the decision.

Now, to discuss the BER lower bound for the singleuser and multiuser detections, let us set $K = 1$, drop the subscript of k' in (26) and take into consideration only the contribution from the Gaussian noise in (27). In this case, the interference/noise vector given by (27) leads to

$$\mathbf{e}_{Dim} = [n'_{Dm1}, \cdots, n'_{DmJ_D}]^T \tag{31}$$

with the statistical property of

$$E\left[\mathbf{n}'_{Dm}{\mathbf{n}'_{Dm}}^H\right] = \mathbf{N}_D = {\sigma_n}^2 \mathbf{I}_{J_D \times J_D}. \tag{32}$$

As shown in the Appendix B, a maximum ratio combiner maximizes the SNR of the combiner output at the m-th subcarrier. Namely, the SNR and the BER at the m-th subcarrier are respectively given by

$$\mathrm{SNR}_m = \sum_{l=1}^{L_m} \gamma_{ml} \tag{33}$$

$$BER_{Dm} = \binom{2L_m - 1}{L_m} \prod_{l=1}^{L_m} \frac{1}{4\overline{\gamma}_{ml}} \tag{34}$$

where $\gamma_{ml} = |h_{ml}|^2/\sigma_n^2$ and $\overline{\gamma}_{sml} = \sigma_{sml}^2/{\sigma_n}^2$.

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Eq. (34) shows the BER lower bound when independent data symbols are transmitted over different subcarriers in the MC-DS/CDMA system, which also means the BER lower bound of an SC-DS/CDMA system, replacing L_m and $\overline{\gamma}_{ml}$ by L and $\overline{\gamma}_l = \sigma_{sl}^2/\sigma_n^2$, respectively. Therefore, the BER lower bound of the SC-DS/CDMA system is given by the BER lower bound is given by

$$BER_S = \binom{2L-1}{L} \prod_{l=1}^{L} \frac{1}{4\overline{\gamma}_l}. \tag{35}$$

Comparing the BERs between the MC-DS/CDMA and SC-DS/CDMA systems given by (34) and (35), respectively, it is clear that the BER of the MC-DS/CDMA system is inferior to that of the SC-DS/CDMA system, because the diversity order of the MC-DS/CDMA system is far less than that of the SC-DS/CDMA system.

The lowest BER in the MC-DS/CDMA system is achievable when the same data symbol is transmitted over different subcarriers, namely, $a_{ki1} = \cdots, a_{kiM} = a_{ki}$. Therefore, taking into account of the relationship between the channel impulse responses between the SC-DS/CDMA and MC-DS/CDMA systems, let us investigate the BER lower bound.

Defining rake finger output, composite impulse response and noise vectors $(J_S \times 1)$ as

$$\mathbf{y}_{Di} = [y_{Di1}, \cdots, y_{DiJ_S}]^T \tag{36}$$

$$\mathbf{h}_D = [\mathbf{h}_1^T, \cdots, \mathbf{h}_M^T]^T \tag{37}$$

$$\mathbf{n}_D = [\mathbf{n}_1'^T, \cdots, \mathbf{n}_M'^T]^T \tag{38}$$

the rake finger output vector $(J_S \times 1)$ is written as

$$\mathbf{y}_{Di} = \mathbf{h}_D a_i + \mathbf{n}_D \tag{39}$$

where $\mathbf{n}_D$ has the statistical property of

$$E[\mathbf{n}_D \mathbf{n}_D^H] = \sigma_n^2 \mathbf{I}_{J_S \times J_S}. \tag{40}$$

Furthermore, defining a weight vectors $(J_S \times 1)$ as $\mathbf{w}_D = [w_{D1}, \cdots, w_{DJ_S}]^T$, the rake combiner output is written as

$$x_{Di} = \mathbf{w}_D^H \mathbf{y}_{Di}. \tag{41}$$

In this case, a maximum ratio combiner selecting the weight vector as

$$\mathbf{w}_D = \mathbf{h}_D \tag{42}$$

maximizes the SNR hence minimizes the BER, that is

$$\mathrm{SNR}_D = \sum_{l=1}^{J_S} \gamma_{Dl} \tag{43}$$

where $\gamma_{Dl} = |h_{Dl}|^2/\sigma_n{}^2$. **Figure 8** shows the relationship between the channel impulse response of the SC-DS/CDMA system and the m-th channel impulse response of the MC-DS/CDMA system (note here the subscript k is dropped). Defining the J_S-point Discrete Fourier Transform (DFT) matrix ($J_S \times J_S$) as $\mathbf{U}_{J_S}$, namely,

$$\mathbf{U}_{J_S} = \{u_{\zeta\eta}\} \quad (\zeta, \eta = 1, \cdots, J_S) \tag{44}$$

$$u_{\zeta\eta} = \frac{1}{\sqrt{J_S}} e^{j2\pi \frac{(\zeta-1)(\eta-1)}{J_S}} \tag{45}$$

the frequency response vector ($J_S \times 1$) for the SC-DS/CDMA system is written as

$$\mathbf{f} = \mathbf{U}_{J_S}\mathbf{h}. \tag{46}$$

By dividing the frequency response over the whole bandwidth into M_D blocks, M_D partial frequency response vectors ($J_D \times 1$) $\mathbf{f}_1, \cdots, \mathbf{f}_M$ are obtained, and then by applying the J_D-point inverse DFT to the m-th partial frequency response vector $\mathbf{f}_m$,

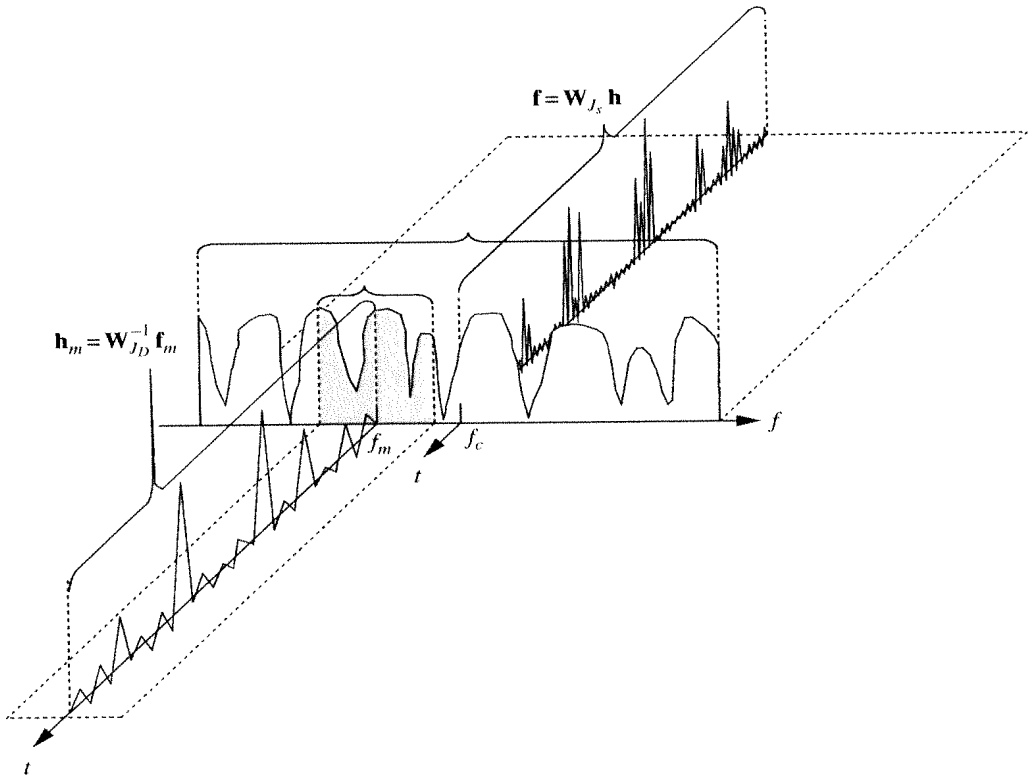


Figure 8. Relationship of impulse response between SC- and MC-DS/CDMA systems

the impulse response vector for the m-th subcarrier is finally obtained. Therefore, $\mathbf{y}_{Si}$ and $\mathbf{y}_{Di}$ have the following relationship:

$$\mathbf{y}_{Di} = \mathbf{T}_c \mathbf{y}_{Si} \tag{47}$$

$$\mathbf{T}_c = \widetilde{\mathbf{U}}_{J_S}^{-1} \mathbf{U}_{J_S} \tag{48}$$

$$\widetilde{\mathbf{U}}_{J_S}^{-1} = diag\{\underbrace{\mathbf{U}_{J_D}^{-1}, \cdots, \mathbf{U}_{J_D}^{-1}}_{M}\} \tag{49}$$

$$\mathbf{U}_{J_D}^{-1} = \{u'_{\zeta'\eta'}{}^{-1}\} \quad (\zeta', \eta' = 1, \cdots, J_D) \tag{50}$$

$$u'_{\zeta'\eta'}{}^{-1} = \frac{1}{\sqrt{J_D}} e^{-j2\pi \frac{(\zeta'-1)(\eta'-1)}{J_D}} \tag{51}$$

where $\widetilde{\mathbf{U}}_{J_S}^{-1}$ $(= \widetilde{\mathbf{U}}_{J_S}^{H})$ and $\mathbf{U}_{J_D}^{-1}$ $(= \mathbf{U}_{J_D}^{H})$ denote the block diagonal matrix composed of $\mathbf{U}_{J_D}^{-1}$ and the J_D-point inverse DFT matrix ($J_D \times J_D$), respectively. It is easy to show that $\mathbf{T}_c$ is a unitary matrix satisfying $\mathbf{T}_c \mathbf{T}_c^H = \mathbf{I}_{J_S \times J_S}$, so as shown in the Appendix C, any unitary transformation cannot change the value of the SNR and thus the BER. Consequently, the achievable BER lower bound of the MC-DS/CDMA system is the same as the BER lower bound of the SC-DS/CDMA system, which is given by

$$BER_D = \binom{2L-1}{L} \prod_{l=1}^{L} \frac{1}{4\overline{\gamma}_l}. \tag{52}$$

7. MC-CDMA SYSTEM

7.1 Transmitter

MC-CDMA transmitter spreads the input data symbols using a spreading code only in the frequency domain, in other words, a fraction of the data symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. For the MC-CDMA system, it is essential to have frequency non-selective fading over each subcarrier, so if the original data transmission rate is high enough to become subject to frequency-selective fading, the input data symbol needs to be first serial-to-parallel converted before spreading over the frequency domain.

Figure 9 shows a block diagram of an MC-CDMA transmitter for the k-th user, which is a hybrid of a DS/CDMA spreader and an OFDM modulator. The data sequence is first converted into P parallel sequences, each serial/parallel converter (S/P) output is spread with a spreading code, and then P parallel spread sequences are converted back to a serial data sequence through a parallel/serial converter (P/S). The obtained serial data sequence is fed into the OFDM modulator, namely, it is mapped onto subcarriers through an IDFT, and then a cyclic prefix is inserted in each OFDM symbol to avoid inter-symbol-interference (ISI) caused by multipath fading. Finally, the OFDM symbols are

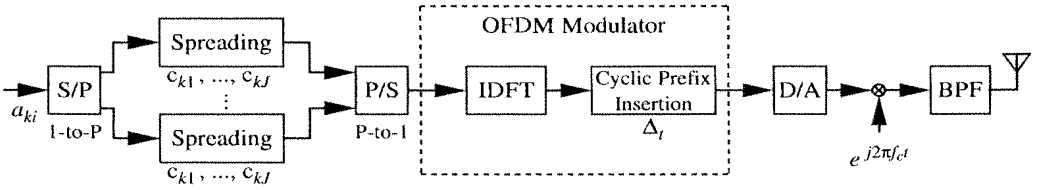


Figure 9. A block diagram of an MC-CDMA transmitter for the k-th user

transmitted after D/A and up-conversions. The transmitted signal in the uplink is written as

$$s_{Mk}(t) = \sum_{i=-\infty}^{+\infty} \sum_{p=1}^{P} \sum_{j=1}^{J_M} a_{kip} c_{kj} p_M(t - iT_M) \cdot e^{j2\pi(f_c + f_{(j-1)P+p})t} \tag{53}$$

where

$$p_M(t) = \begin{cases} 1 \ (-\Delta_t \le t \le t_M) \\ 0 \ (otherwise) \end{cases} \tag{54}$$

$$f_{(j-1)P+p} = ((j-1)P + p - PJ_M/2)\Delta_f \tag{55}$$

$$t_M = T_M - \Delta_t \tag{56}$$

$$\Delta_f = \frac{1}{t_M} \tag{57}$$

$$T_M = PT_S = PJ_S T_{cS}. \tag{58}$$

In (53)-(58), $p_M(t)$ is a rectangular pulse waveform, Δ_t and t_M are a cyclic prefix length and a useful symbol length corresponding to the IDFT window width, respectively, $f_{(j-1)P+p}$ and Δ_f are the center frequency of the $((j-1)P+p)$-th subcarrier and the subcarrier separation, respectively. On the other hand, the transmitted signal in the downlink is written as

$$s_M(t) = \sum_{k=1}^{K} \sum_{i=-\infty}^{+\infty} \sum_{p=1}^{P} \sum_{j=1}^{J_M} a_{kip} c_{kj} p_M(t - iT_M) \cdot e^{j2\pi(f_c + f_{(j-1)P+p})t}. \tag{59}$$

Figure 4 (c) shows the PSD of an MC-CDMA waveform. The bandwidth is given by

$$BW_M = \frac{PJ_M - 1}{T_M - \Delta_t} + \frac{2}{T_M} \approx \frac{J_M/J_S}{T_{cS}(1 - \Delta_t/(PJ_S T_{cS}))} \tag{60}$$

$$\approx \frac{(1 + \alpha_M)J_M/J_S}{T_{cS}} \tag{61}$$

where α_M is a cyclic prefix factor, which is defined as

$$\alpha_M = \Delta_t/(PJ_ST_{cS}). \tag{62}$$

If we set $J_M = J_S$, the bandwidth results in

$$BW_M = \frac{(1+\alpha_M)}{T_{cS}} \tag{63}$$

so comparison between (8) and (63) reveals that there is no large difference in the bandwidth in terms of the mainlobe among the SC-DS/CDMA, MC-CDMA, and hence MC-DS/CDMA systems. In **Figure 4 (c)**, the hatched subcarriers convey the same data symbol with different chips of spreading code. The frequency separation between neighboring subcarriers is given by Δ_f whereas that between subcarriers conveying the same data symbol by $P\Delta_f$. This means that the waveform can obtain the maximum frequency diversity effect when it goes through a frequency-selective fading channel.

On the other hand, **Figure 5 (c)** shows a tiling representation of an MC-CDMA waveform in a time-frequency plane, where $J_M = J_S = 8$ and $P = 4$ are assumed. Here, it should be noted that the symbol duration (T_M) is widened into PT_S as shown in (58).

7.2 Receiver

Assuming that quasi-synchronicity is established in the uplink, the received signal in the uplink is written as

$$r_M(t) = \sum_{k=1}^{K} h_k(t) \otimes s_{Mk}(t) + n_M(t) \tag{64}$$

whereas that in the downlink is written as

$$r_{Mk}(t) = h_k(t) \otimes s_M(t) + n_M(t). \tag{65}$$

First of all, let us discuss the effect of frequency selective fading on the multicarrier transmission with cyclic prefix. The length of the inserted cyclic prefix is sufficiently larger than that of the channel impulse response, so it is written as

$$h_k(t) = \begin{cases} h_k(t) & (0 \le t \le \Delta_t) \\ 0 & (otherwise) \end{cases}. \tag{66}$$

Therefore, with (53), (54), (64) and (66), the output at the $((j'-1)P+p')$-th subcarrier is written as

$$\begin{aligned} y_{Mij'p'} &= \frac{1}{t_M} \int_{iT_M}^{iT_M+t_M} r_M(t) e^{-2\pi f_{(j'-1)P+p'}(t-iT_M)} dt \\ &= \sum_{k=1}^{K} z_{kj'p'} c_{kj'} a_{kip'} + n'_{Mj'p'} \end{aligned} \tag{67}$$

$$z_{kj'p'} = \int_0^{\Delta_t} h_k(t) e^{-j2\pi f_{(j'-1)P+p'}\tau} d\tau \tag{68}$$

$$n'_{Mj'p'} = \int_0^{t_M} n_M(t) e^{-j2\pi f_{(j'-1)P+p'}\tau} d\tau. \tag{69}$$

Eq. (67) clearly shows that frequency-selective fading can be dealt with as a multiplicative noise at a subcarrier level. This is the very benefit of multicarrier transmission, that is, to compensate for frequency-selective fading at receiver, just one tap equalization effectively works at subcarrier level for multicarrier transmission whereas complicated convolutional operation is required for single-carrier transmission.

Next, let us derive several combining methods for the MC-CDMA system. To this end, it is more convenient to express the received signal and channel impulse response in vector forms, replacing the Fourier Transform in (67)-(69) by the DFT. **Figure 10** shows a block diagram of an MC-CDMA receiver for the k-th user. Defining the subcarrier output vector ($J_M \times 1$) for a fixed $p = p'$ as

$$\mathbf{y}_{Mip'} = [y_{Mi1p'}, \cdots, y_{MiJ_Mp'}]^T \tag{70}$$

it is written as

$$\mathbf{y}_{Mip'} = \sqrt{J_M}\widetilde{\mathbf{C}}_{Kp'}\mathbf{a}_{ip'} + \mathbf{n}'_{Mp'} \tag{71}$$

where

$$\widetilde{\mathbf{C}}_{Kp'} = [\widetilde{\mathbf{c}}_{p'1}, \cdots, \widetilde{\mathbf{c}}_{p'K}] \tag{72}$$

$$\widetilde{\mathbf{c}}_{p'k} = [z_{k1p'}c_{k1}, \cdots, z_{kJ_Mp'}c_{kJ_M}]^T \tag{73}$$

$$\mathbf{z}_{kp'} = [z_{k1p'}, \cdots, z_{kJ_Mp'}]^T \tag{74}$$

$$\mathbf{a}_{ip'} = [a_{1ip'}, \cdots, a_{Kip'}]^T \tag{75}$$

$$\mathbf{n}'_{Mp'} = [n'_{M1p'}, \cdots, n'_{MJ_Mp'}]^T. \tag{76}$$

In (72)-(76), $\widetilde{\mathbf{c}}_{p'k}$, $\mathbf{z}_{kp'}$, $\mathbf{a}_{ip'}$ and $\mathbf{n}'_{Mp'}$ are a distorted code vector ($J_M \times 1$), a frequency response vector ($J_M \times 1$), an information vector ($K \times 1$) and a noise vector ($J_M \times 1$),

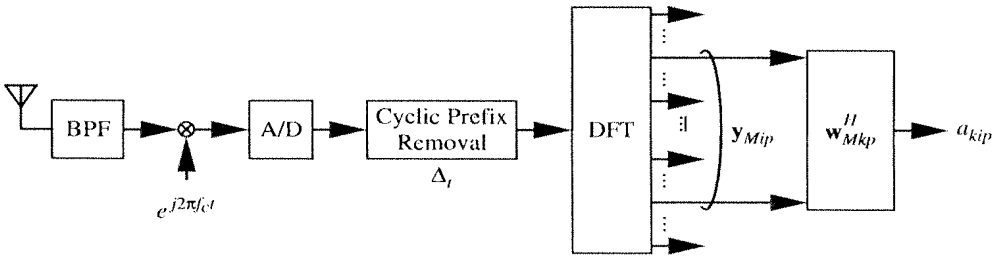


Figure 10. A block diagram of an MC-CDMA receiver for the k-th user

respectively, and $\widetilde{\mathbf{C}}_{Kp'}$ is a distorted code matrix $(J_M \times K)$. Furthermore, defining an impulse response vector $(PJ_M \times 1)$, a frequency response vector $(PJ_M \times 1)$ and noise vectors $(PJ_M \times 1)$ before/after the DFT over all the subcarriers as

$$\mathbf{h}'_k = [h_k(t=0), \cdots, h_k(t=(PJ_M-1)t_M)]^T \tag{77}$$

$$\mathbf{z}_k = [z_{k1}, \cdots, z_{k(PJ_M)}]^T \tag{78}$$

$$\mathbf{n}_M = [n_M(t=iT_M), \cdots, n_M(t=iT_M+(PJ_M-1)t_M)]^T \tag{79}$$

$$\mathbf{n}'_M = [n'_{M1}, \cdots, n'_{M(PJ_M)}]^T \tag{80}$$

they satisfy the following properties:

$$\mathbf{z}_k = \mathbf{U}_{PJ_M}\mathbf{h}'_k \tag{81}$$

$$\mathbf{n}'_M = \mathbf{U}_{PJ_M}\mathbf{n}_M \tag{82}$$

$$E\left[\mathbf{n}'_M \mathbf{n}'^H_M\right] = \sigma_n^2 \mathbf{I}_{PJ_M \times PJ_M} \tag{83}$$

where $\mathbf{U}_{PJ_M}$ denotes the PJ_M-point DFT matrix $(PJ_M \times PJ_M)$. Paying attention to the fact that $\mathbf{z}_{kp'}$ and $\mathbf{n}'_{Mp'}$ are composed of picking up the $((j-1)P+p')$-th elements $(j=1,\cdots,J_M)$ from $\mathbf{z}_k$ and $\mathbf{n}'_M$, respectively, it is clear that $\mathbf{n}'_{Mp'}$ satisfies the following properties

$$E\left[\mathbf{n}'_{Mp'}\mathbf{n}'^H_{Mp'}\right] = \sigma_n^2 \mathbf{I}_{J_M \times J_M}. \tag{84}$$

Now, with (70), define the following weighted sum:

$$x_{Mik'p'} = \mathbf{w}^H_{Mk'p'}\mathbf{y}_{Mip'} \tag{85}$$

where $\mathbf{w}_{Mk'p'}$ is a weight vector $(J_M \times 1)$, which is defined as

$$\mathbf{w}_{Mk'p'} = [w_{Mk'p'1}, \cdots, w_{Mk'p'J_M}]^T. \tag{86}$$

In the uplink, Eq.(73) clearly shows that the code orthogonality among the users is totally distorted by the multiplicative noise, namely, the frequency response, so a multiuser detection is required to recover $a_{k'ip'}$ in (71). One method may be to despread the subcarrier output vector given by (70) as

$$\widetilde{\mathbf{C}}^H_{Kp'}\mathbf{y}_{Mip'} = \sqrt{J_M}\widetilde{\mathbf{C}}^H_{Kp'}\widetilde{\mathbf{C}}_{Kp'}\mathbf{a}_{ip'} + \widetilde{\mathbf{C}}^H_{Kp'}\mathbf{n}'_{Mp'} \tag{87}$$

however, $\widetilde{\mathbf{C}}^H_{Kp'}\widetilde{\mathbf{C}}_{Kp'}$ in (87) cannot be the identity matrix, because the orthogonality among the spreading codes is totally distorted. A decorrelating multiuser detection

eliminates the cross-correlation among the distorted spreading codes by multiplying (87) with $(\widetilde{\mathbf{C}}_{Kp'}^{H}\widetilde{\mathbf{C}}_{Kp'})^{-1}$ as

$$(88)\qquad (\widetilde{\mathbf{C}}_{Kp'}^{H}\widetilde{\mathbf{C}}_{Kp'})^{-1}\widetilde{\mathbf{C}}_{Kp'}^{H}\mathbf{y}_{Mip'} = \sqrt{J_M}\mathbf{a}_{ip'} + (\widetilde{\mathbf{C}}_{Kp'}^{H}\widetilde{\mathbf{C}}_{Kp'})^{-1}\widetilde{\mathbf{C}}_{Kp'}^{H}\mathbf{n}'_{Mp'}.$$

This means that the decorrelating weight vector is written as

$$(89)\qquad \mathbf{w}_{Mk'p'}^{U,DEC} = \sum_{j=1}^{J_M}\left[(\widetilde{\mathbf{C}}_{Kp'}^{H}\widetilde{\mathbf{C}}_{Kp'})^{-1}\right]_{j,j}\widetilde{\mathbf{c}}_{p'k'}$$

where $[\bullet]_{j,j}$ denotes the (j, j)-element of matrix $\bullet$. In (88), the noise vector is multiplied with a matrix $(\widetilde{\mathbf{C}}_{Kp'}^{H}\widetilde{\mathbf{C}}_{Kp'})^{-1}\widetilde{\mathbf{C}}_{Kp'}^{H}$. This is called "noise enhancement" resulting in degradation of the BER, because low-level subcarriers tend to be multiplied with high gains and hence the noise components are amplified at weaker subcarriers.

Another method is to solve the following minimization problem of the mean square error (MSE) for the k'-th user at the base station:

$$(90)\qquad \text{miminize}\quad MSE(\mathbf{w}_{Mk'p'}) = E_{\overline{\mathbf{z}}_{kp'}}\left[|a_{k'ip'} - \mathbf{w}_{Mk'p'}^{H}\mathbf{y}_{Mip'}|^2\right]$$

where $E_{\overline{\mathbf{z}}_{kp'}}[\cdot]$ denotes statistical average with $\mathbf{z}_{kp'}$ fixed. As the Wiener solution of (90), taking into consideration of the properties given by (2) and (84), the minimum mean square error (MMSE) weight vector is given by

$$(91)\qquad \mathbf{w}_{Mk'p'}^{U,MMSE} = \mathbf{R}_{Mk'p'}^{-1}\mathbf{o}_{Mk'p'}$$

$$\mathbf{R}_{Mk'p'} = E_{\overline{\mathbf{z}}_{kp'}}\left[\mathbf{y}_{Mip'}\mathbf{y}_{Mip'}^{H}\right]$$

$$(92)\qquad = J_M\widetilde{\mathbf{C}}_{Kp'}\widetilde{\mathbf{C}}_{Kp'}^{H} + \sigma_n^2\mathbf{I}_{J_M\times J_M}$$

$$(93)\qquad \mathbf{o}_{Mk'p'} = E_{\overline{\mathbf{z}}_{kp'}}\left[\mathbf{y}_{Mip'}a_{k'ip'}^{H}\right] = \sqrt{J_M}\widetilde{\mathbf{c}}_{p'k'}$$

where $\mathbf{R}_{Mk'p'}$ and $\mathbf{o}_{Mk'p'}$ denote the auto-correlation matrix $(J_M \times J_M)$ of the subcarrier outputs and the desired response vector $(J_M \times 1)$ for the k'-th user, respectively. This method is called "the MMSE multiuser detection".

On the other hand, in the downlink, setting $z_{kjp'} = z_{k'jp'}$ $(j = 1, \cdots, J_M)$ in (73), (71) changes to the subcarrier output vector of the k'-th user as

$$(94)\qquad \mathbf{y}_{Mk'ip'} = \sqrt{J_M}\mathbf{Z}_{k'p'}\mathbf{C}_K\mathbf{a}_{ip'} + \mathbf{n}'_{Mp'}$$

$$(95)\qquad \mathbf{Z}_{k'p'} = diag\{z_{k'1p'}, \cdots, z_{k'J_Mp'}\}.$$

Now, we introduce four combining methods, all of which are categorized into singleuser detection. The first method is obtained by solving the following minimization problem of the MSE for the k'-th user:

$$(96)\qquad \text{miminize}\quad MSE(\mathbf{w}_{Mk'p'}) = E_{\overline{\mathbf{z}}_{k'p'}}\left[|a_{k'ip'} - \mathbf{w}_{Mk'p'}^{H}\mathbf{y}_{Mk'ip'}|^2\right].$$

Like the MMSE weight vector in the uplink, as the Wiener solution of (96), the MMSE weight vector in the downlink is given by

$$\mathbf{w}_{Mk'p'}^{D.MMSE} = \mathbf{R}_{Mk'p'}^{-1}\mathbf{o}_{Mk'p'} \tag{97}$$

$$\mathbf{R}_{Mk'p'} = E_{\overline{\mathbf{z}}_{k'p'}}\left[\mathbf{y}_{Mk'ip'}\mathbf{y}_{Mk'ip'}^{H}\right] \tag{98}$$

$$\mathbf{o}_{Mk'p'} = E_{\overline{\mathbf{z}}_{k'p'}}\left[\mathbf{y}_{Mk'ip'}a_{k'ip'}^{H}\right]. \tag{99}$$

From (2), (3), (84), (94) and (95), (98) and (99) respectively result in

$$\begin{aligned}\mathbf{R}_{Mk'p'} &= E_{\overline{\mathbf{z}}_{k'p'}}\left[(\mathbf{Z}_{k'p'}\mathbf{C}_K\mathbf{a}_{ip'} + \mathbf{n}'_{Mp'})(\mathbf{Z}_{k'p'}\mathbf{C}_K\mathbf{a}_{ip'} + \mathbf{n}'_{Mp'})^H\right] \\ &= \mathbf{Z}_{k'p'}E_{\overline{\mathbf{z}}_{k'p'}}\left[\mathbf{C}_K\mathbf{a}_{ip'}\mathbf{a}_{ip'}^H\mathbf{C}_K^H\right]\mathbf{Z}_{k'p'}^H + \sigma_n^2\mathbf{I}_{J_M\times J_M} \\ &= diag\{K|z_{j'1p'}|^2 + \sigma_n^2, \cdots, K|z_{j'J_Mp'}|^2 + \sigma_n^2\} \qquad (100)\end{aligned}$$

$$\mathbf{o}_{Mk'p'} = \sqrt{J_M}\tilde{\mathbf{c}}_{p'k'} \tag{101}$$

so the MMSE weight vector is finally given by

$$\mathbf{w}_{Mk'p'}^{D.MMSE} = \left[\frac{z_{k'1p'}c_{k'1}}{K|z_{k'1p'}|^2 + \sigma_n^2}, \cdots, \frac{z_{k'J_Mp'}c_{k'J_M}}{K|z_{k'J_Mp'}|^2 + \sigma_n^2}\right]^T. \tag{102}$$

The method to recover the transmitted data symbols with (102) is called "the minimum mean square error combining (MMSEC)".

The denominator of (102) contains the noise power, so it means that calculation of the MMSE weights at users requires its estimation. To avoid estimation of the noise power, the second method ignores the noise term in the denominator, namely, $|z_{k'jp'}|^2 >> \sigma_n^2$ and furthermore ignores a common coefficient to all the elements of (102), that is

$$\mathbf{w}_{Mk'p'}^{D.ORC} = \left[\frac{z_{k'1p'}c_{k'1}}{|z_{k'1p'}|^2}, \cdots, \frac{z_{k'J_Mp'}c_{k'J_M}}{|z_{k'J_Mp'}|^2}\right]^T. \tag{103}$$

The method to recover the transmitted data symbols with (103) is called "the orthogonality restoring combining (ORC)". Indeed, this method can eliminate multiple access interference perfectly as

$$\begin{aligned}\widehat{a}_{k'ip'} &= \mathbf{w}_{Mk'p'}^{D,ORCH}\mathbf{y}_{Mip'} \\ &= \sqrt{J_M}a_{k'ip'} + \mathbf{w}_{Mk'p'}^{D,ORCH}\mathbf{n}'_{Mp'} \qquad (104)\end{aligned}$$

but the noise enhancement degrades the BER, from the same reason in the decorrelating multiuser detection in the uplink.

On the contrary, the third method picks up only the noise term in the denominator, namely, $|z_{k'jp'}|^2 << \sigma_n^2$ and also ignores a common coefficient to all the elements of (102), that is

$$\mathbf{w}_{Mk'p'}^{D,MRC} = [z_{k'1p'}c_{k'1}, \cdots, z_{k'J_Mp'}c_{k'J_M}]^T. \tag{105}$$

The method to recover the transmitted data symbols with (105) is called "the maximum ratio combining (MRC)". This method corresponds to the maximum ratio combining in normal diversity techniques, so it can minimize the BER only for the case of a single user.

Analogous to normal diversity techniques, the fourth method can be considered, which is located at the middle of the ORC and MRC, that is

$$\mathbf{w}_{Mk'p'}^{D,EGC} = \left[\frac{z_{k'1p'}c_{k'1}}{|z_{k'1p'}|}, \cdots, \frac{z_{k'J_Mp'}c_{k'J_M}}{|z_{k'J_Mp'}|}\right]^T. \tag{106}$$

The method to recover the transmitted data symbols with (106) is called "the equal gain combining (EGC)". Indeed, the magnitudes of the weights are kept to be the same, so this method compensates only for the phases of the chips of spreading code distorted by the frequency response of the channel.

We have introduced the two multiuser detection methods for the uplink whereas the four combining methods for the downlink. So now, to discuss the BER lower bound, let us set $P = 1$ and drop the subscripts of k and p' in (94). In this case, (94) leads to

$$\mathbf{y}_{Mi} = \sqrt{J_M}\mathbf{Z}\mathbf{c}a_i + \mathbf{n}'_M. \tag{107}$$

Defining a code matrix $(J_M \times J_M)$ as

$$\mathbf{C} = diag\{c_1, \cdots, c_{J_M}\}. \tag{108}$$

Pre-multiplying (107) with the code matrix results in

$$\begin{aligned}\mathbf{y}'_{Mi} &= \mathbf{C}\mathbf{y}_{Mi} \\ &= \sqrt{J_M}\mathbf{C}\mathbf{Z}\mathbf{c}a_i + \mathbf{C}\mathbf{n}'_M \\ &= \mathbf{U}_{J_M}((\mathbf{h}'/\sqrt{J_M})a_i + \mathbf{n}''_M) \qquad (109)\end{aligned}$$

$$\mathbf{n}''_M = \mathbf{U}_{J_M}^{-1}\mathbf{C}\mathbf{n}'_M. \tag{110}$$

Here, taking into consideration of

$$\mathbf{C}\mathbf{C}^H = \frac{1}{J_M}\mathbf{I}_{J_M \times J_M} \tag{111}$$

and (83), it is easy to show that $\mathbf{n}''_M$ has the following property:

$$E\left[\mathbf{n}''_M \mathbf{n}''^{H}_M\right] = E\left[\mathbf{U}^{-1}_{J_M} \mathbf{C}\mathbf{n}'_M \mathbf{U}^{-1}_{J_M} \mathbf{C}\mathbf{n}'^{H}_M\right]$$

$$= \frac{\sigma_n^2}{J_M} \mathbf{I}_{J_M \times J_M}. \tag{112}$$

Therefore, as shown in the Appendix C, the unitary matrix $\mathbf{U}_{J_M}$ cannot change the value of the SNR and thus the BER is given by

$$BER_M = \binom{2L-1}{L} \prod_{l=1}^{L} \frac{1}{4\overline{\gamma}_l}. \tag{113}$$

8. BER PERFORMANCE COMPARISON

From (35), (52) and (113), the BER lower bounds of the SC-DS/CDMA, MC-DS/CDMA and MC-CDMA systems are given by the same equation. That is, once a channel with a bandwidth and a data transmission rate are given, the BER lower bound is uniquely determined by the degree of freedom of the channel. We have assumed a slowly varying fading channel, so in this case, the BER lower bound is determined by the freedom in the frequency response of the channel, in other words, the frequency-selectivity of the channel.

Now, for the MC-DS/CDMA and MC-CDMA systems, let us investigate their BER performances with the multiuser detection schemes in the uplink and the singleuser detection schemes in the downlink. This investigation needs to resort to computer simulation.

As a modulation/detection format, a binary phase shift keying (BPSK)/coherent detection is assumed, and as spreading codes, Gold codes with length of 31 and Walsh-Hadamard codes with length of 32, which approximately satisfy the properties of (4) and (3), are assumed. In addition, the number of subcarriers (M_D) in the MC-DS/CDMA system is set to 2 and that of parallelizations (P) in the MC-CDMA system is set to 16. This implies that the number of subcarriers for the MC-CDMA system is 512. On the other hand, in a multipath delay profile employed, there are 18 exponentially decaying paths, where the path-by-path decay factor is 1.2 dB. The MC-CDMA system has a 10 % cyclic prefix length, which is assumed to be much larger than the delay spread of the multipath delay profile. In the following figures, the Average SNR is defined as $(\sum_{l=1}^{18} \sigma_{sl}^2)/\sigma_n^2$ and it is set to 10 dB.

Figures 11 (a) and **(b)** show the BERs versus the number of users for the MC-DS/CDMA and MC-CDMA systems in the uplink, respectively. An SIC multiuser detection is assumed for the MC-DS/CDMA system whereas a decorrelating multiuser detection and an MMSE multiuser detection are assumed for the MC-CDMA system. For the MC-DS/CDMA system, even if the number of paths is 18 when the impulse response of the channel is observed in the entire bandwidth, the number of paths becomes larger in the impulse response of each subchannel.

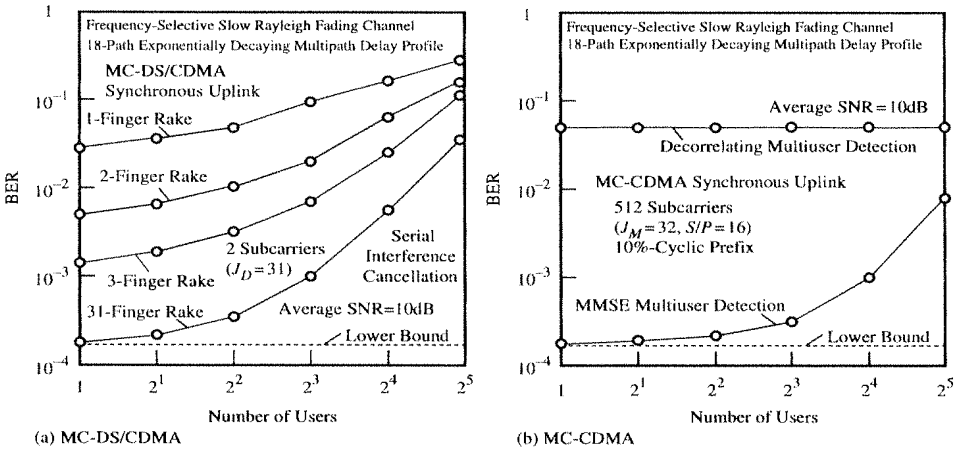


Figure 11. BER comparison in uplink: MC-DS/CDMA (a) and MC-CDMA (b)

Therefore, to achieve the lowest BER for the case of a single user, 31-finger rake processors are required in principle. The 1-, 2- and 3-finger rake processors mean picking up to the first, second and third largest paths in instantaneous channel impulse response, respectively. As the number of rake finger processors decreases, the BER performance is degraded because it losses more power of the received signal. For the MC-CDMA systems, on the other hand, the BER of the decorrelating multiuser detection is flat but poor. This is because it can perfectly eliminate the MAI but the noise enhancement introduces a lot of errors in subcarriers. The MMSE multiuser detection performs much better, but it needs to estimate the noise power correctly and also to invert the correlation matrix of the received signal.

Figures 12 (a) and **(b)** show the BERs versus the number of users for the MC-DS/CDMA and MC-CDMA systems in the downlink, respectively. For the MC-DS/CDMA system, the number of rake processors decreases, the BER is degraded because of the same reason for the uplink. As compared with the BER curves in the uplink, those in the downlink is more abruptly degraded as the number of users increases. For the MC-CDMA system, on the other hand, the BER of the ORC is flat and poor because of noise enhancement. The MRC is optimal only for the case of a single user, so it performs best only for the case, and as the number of users increases, the BER is abruptly degraded due to MAI. The MMSEC performs best except for the case of a single user but it needs to estimate the noise power. Among the combining methods which requires no estimation of the noise power, the EGC performs best except for the case of a single user.

These four figures may give us an impression that the MC-CDMA systems performs better than the MC-DS/CDMA system almost all region of the number of users. However, it should be noted that these figures are depicted keeping the average *received* SNR to be the same. Taking into consideration that the energy of the received signal in the cyclic prefix is not used for signal detection for the MC-CDMA system, to achieve the same BER performance among the

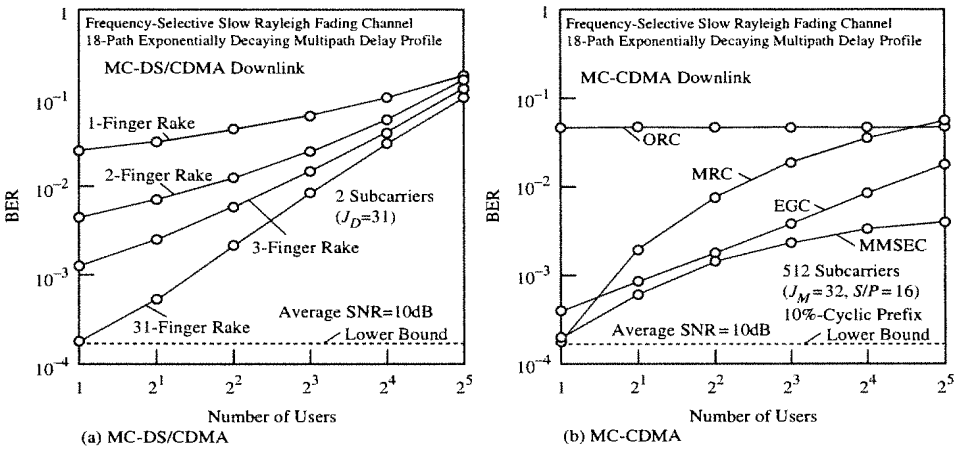


Figure 12. BER comparison in downlink: MC-DS/CDMA (a) and MC-CDMA (b)

MC-DS/CDMA and MC-CDMA systems,10 % more energy is required for the MC-CDMA transmitter, in other words, keeping the transmission power to be the same for the MC-DS/CDMA and MC-CDMA transmitters, the MC-CDMA receiver loses 10 % of the received signal power, so all the BER curves of the MC-CDMA system are shifted up a bit.

9. CONCLUSIONS

This chapter has presented the principle of Multicarrier based CDMA techniques, such as MC-DS/CDMA and MC-CDMA, and has introduced several detection and combining schemes for the two techniques. Their BER lower bounds have been theoretically analyzed and it has been shown that the BER lower bound is independent of signaling techniques we intended to use and is uniquely determined by the degree of freedom of the channel once a channel is given. Therefore, which signaling method we should use is dependent of hardware complexities of base station and user terminal. When we intend to support a data transmission rate in a channel where we see several tens of multipath components in its impulse response, the combination of multicarrier transmission and CDMA becomes only a solution to achieve a good BER while reducing the hardware complexity.

APPENDICES

A: Maximum Ratio Combiner

Assume that a transmitted signal carrying the same information goes through a J diversity channels and arrives at a receiver. Here, the l-th channel ($l = 1, \cdots, L$) is assumed to be frequency-nonselective and slowly fading with a zero-mean complex-valued Gaussian-distributed amplitude whereas the signal in the l-th channel

$(l = L+1, \cdots, J)$ experiences zero-gain. In addition, the signal in each channel is perturbed by an additive zero-mean complex-valued Gaussian noise, and the fading and noise processes are assumed to be mutually statistically independent, respectively, and also mutually statistically independent each other. The receiver, on the other hand, multiplies the received signal in each channel with an adequate weight and finally combines all the multiplier outputs. The combiner output is written as

$$r = \sum_{l=1}^{J} w_l^*(h_l s + n_l) = \mathbf{w}^H(\mathbf{h}s + \mathbf{n}) \tag{114}$$

where $\mathbf{h}$, $\mathbf{n}$ and $\mathbf{w}$ are the channel gain, noise and weight vectors $(J \times 1)$, respectively, which are given by

$$\mathbf{h} = [h_1, h_2, \cdots, h_L, 0, \cdots, 0]^T \tag{115}$$

$$\mathbf{n} = [n_1, n_2, \cdots, n_J]^T \tag{116}$$

$$\mathbf{w} = [w_1, w_2, \cdots, w_J]^T. \tag{117}$$

The following properties are defined for $\mathbf{h}$, $\mathbf{n}$ and s:

$$\mathbf{h}\mathbf{h}^H = \mathbf{H}_{\overline{\mathbf{h}}} \tag{118}$$

$$E[\mathbf{h}\mathbf{h}^H] = \mathbf{H} = diag\{\sigma_{s1}^2, \sigma_{s2}^2, \cdots, \sigma_{sL}^2, 0, \cdots, 0\} \tag{119}$$

$$E[\mathbf{n}\mathbf{n}^H] = \mathbf{N} = \sigma_n^2 \mathbf{I}_{J\times J} \tag{120}$$

$$E[\mathbf{h}\mathbf{n}^H] = \mathbf{0}_{J\times J} \tag{121}$$

$$E[|s|^2] = 1 \tag{122}$$

where $\mathbf{H}$ and $\mathbf{N}$ are called "the correlation matrix $(J \times J)$ of the diversity channels" with non-zero eigenvalues of $\sigma_{s1}^2, \sigma_{s2}^2, \cdots, \sigma_{sL}^2$," and "the correlation matrix $(J \times J)$ of the noise," respectively, $\mathbf{I}_{J\times J}$ and $\mathbf{0}_{J\times J}$ denote identity and zero matrices $(J \times J)$, respectively, and σ_n^2 denotes the power of noise. When $\mathbf{h}$ is fixed, the power of the combiner output is written as

$$\begin{aligned} E_{\overline{\mathbf{h}}}[|r|^2] &= E_{\overline{\mathbf{h}}}[(\mathbf{w}^H\mathbf{h}s + \mathbf{w}^H\mathbf{n})(\mathbf{w}^H\mathbf{h}s + \mathbf{w}^H\mathbf{n})^H] \\ &= \mathbf{w}^H\mathbf{H}_{\overline{\mathbf{h}}}\mathbf{w} + \sigma_n^2\mathbf{w}^H\mathbf{w} \end{aligned} \tag{123}$$

where $E_{\overline{\mathbf{h}}}[\cdot]$ denotes statistical average with $\mathbf{h}$ fixed. In (123), the first and second terms mean the powers of signal and noise, respectively, so the signal to noise power ratio (SNR) of the combiner output is written as

$$\gamma = \frac{S}{N} = \frac{\mathbf{w}^H\mathbf{H}_{\overline{\mathbf{h}}}\mathbf{w}}{\sigma_n^2\mathbf{w}^H\mathbf{w}}. \tag{124}$$

A solution of $\partial\gamma/\partial\mathbf{w}^* = 0$ leads to a weight vector which maximizes the SNR, where $(\cdot)^*$ denotes complex conjugate, but here we take another approach to reach the optimum weight vector.

Let us consider the following eigenvalue problem:

$$\mathbf{H}_{\bar{\mathbf{h}}}\mathbf{w} = \lambda\mathbf{w} \tag{125}$$

where λ denotes "an eigenvalue of $\mathbf{H}_{\bar{\mathbf{h}}}$." Defining λ_{max} and $\mathbf{w}_{max}$ as the maximum eigenvalue and the eigenvector associated with it, respetively, of course, they satisfy

$$\mathbf{H}_{\bar{\mathbf{h}}}\mathbf{w}_{max} = \lambda_{max}\mathbf{w}_{max}. \tag{126}$$

Pre-multiplying (126) by $\mathbf{w}_{max}$ leads to

$$\lambda_{max} = \frac{\mathbf{w}_{max}^H \mathbf{H}_{\bar{\mathbf{h}}}\mathbf{w}_{max}}{\mathbf{w}_{max}^H \mathbf{w}_{max}}. \tag{127}$$

Consequently, (124) and (127) lead to

$$\gamma_{max} = \frac{\lambda_{max}}{\sigma_n^2}. \tag{128}$$

Eq. (128) clearly shows that, *if we select the weight vector as the eigenvector corresponding to the maximum eigenvalue of* $\mathbf{H}_{\bar{\mathbf{h}}}$, *it maximizes the SNR of the combiner output.*

The rank of $\mathbf{H}_{\bar{\mathbf{h}}}$ is 1 because it is defined as $\mathbf{h}\mathbf{h}^H$, so the optimum weight vector is $\mathbf{w}_{max} = \mathbf{h}$. In fact, substituting the solution into (125) leads to

$$\mathbf{H}_{\bar{\mathbf{h}}}\mathbf{w}_{max} = \mathbf{H}_{\bar{\mathbf{h}}}\mathbf{h} = \mathbf{h}\mathbf{h}^H\,\mathbf{h} = |\mathbf{h}|^2\mathbf{w}_{max} \tag{129}$$

therefore, we have

$$\lambda_{max} = |\mathbf{h}|^2 = \sum_{l=1}^{L} |h_l|^2. \tag{130}$$

Finally, the maximized SNR of the combiner output is given by

$$\gamma_{max} = = \frac{\mathbf{h}}{\sigma_n^2} = \sum_{l=1}^{L} \gamma_l \tag{131}$$

$$\gamma_l = \frac{|h_l|^2}{\sigma_n^2}. \tag{132}$$

Eqs. (131) and (132) show that, the maximum SNR of the combiner output is the sum of the SNRs of the diversity branches. The combiner with selection of $\mathbf{w}_{max} = \mathbf{h}$ is called "the Maximum Ratio Combiner (MRC)." In this case, the received waves from $L+1$ to J are not used for data demodulation. Therefore, we call this "a diversity system with order of L."

B: Bit Error Rate Expression

For binary phase shift keying (BPSK)/ coherent detection, it is well known that the bit error rate (BER) is given by

$$(133) \qquad BER(\gamma_{max}) = \frac{1}{2} erfc(\sqrt{\gamma_{max}})$$

where $erfc(x)$ is the complementary error function defined as

$$(134) \qquad erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{+\infty} e^{t^2} dt.$$

In the Appendix A, γ_{max} in (133) has been derived with $\mathbf{h}$ fixed, so to calculate the average BER for the diversity system with order of L in the fading channel, we average (133) in terms of $\mathbf{h}$, namely, γ_{max}, because γ_{max} is a function of $\mathbf{h}$

$$(135) \qquad BER_{fading}^{div\ L} = E_{\mathbf{h}}[BER(\gamma_{max})] = E_{\gamma_{max}}[BER(\gamma_{max})]$$

where $E_{\mathbf{h}}[\cdot]$ and $E_{\gamma_{max}}[\cdot]$ denote statistical averages in terms of $\mathbf{h}$ and γ_{max}, respectively. If we know the probability density function (*pdf*) of γ_{max} as $p(\gamma_{max})$, then we can rewrite (135) as

$$(136) \qquad BER_{fading}^{div\ L} = \int_0^{+\infty} BER(\gamma_{max}) p(\gamma_{max}) d\gamma_{max}.$$

The amplitude h_l is complex valued-Gaussian-distributed with zero-mean, so γ_l given by (132) is exponentially distributed. The *pdf* of γ_l and the characteristic function defined as Laplace Transform of the *pdf* are respectively written as

$$(137) \qquad p(\gamma_l) = \frac{1}{\overline{\gamma}_l} e^{-\frac{\gamma_l}{\overline{\gamma}_l}}$$

$$(138) \qquad \overline{\gamma}_l = \sigma_{sl}^2 / \sigma_n^2$$

$$(139) \qquad \phi(s)_{\gamma_l} = \int_0^{+\infty} e^{-s\gamma_l} p(\gamma_l) d\gamma_l = \frac{1/\overline{\gamma}_l}{s + 1/\overline{\gamma}_l}$$

where $\overline{\gamma}_l$ denotes the average SNR. The characteristic function on the sum of independent variables is given by the product of the characteristic function on each variable, so it is written as

$$(140) \qquad \phi(s)_{\gamma_{max}} = \prod_{l=1}^{L} \frac{1/\overline{\gamma}_l}{s + 1/\overline{\gamma}_l}.$$

If $\overline{\gamma}_l$ is different each other, by taking the inverse Laplace Transform of (140), the *pdf* of γ_{max} becomes

$$p(\gamma_{max}) = \lim_{\beta\to\infty} \frac{1}{2\pi j} \int_{\alpha-j\beta}^{\alpha+j\beta} e^{s\gamma_{max}} \phi(s)_{\gamma_{max}} ds = \sum_{l=1}^{L} Res[\phi(s)_{\gamma_{max}}, \overline{\gamma}_l]$$

$$= \sum_{l=1}^{L} \prod_{\substack{l'=1 \\ l'\neq l}}^{L} \frac{1}{1-\overline{\gamma}_{l'}/\overline{\gamma}_l} \cdot \frac{1}{\overline{\gamma}_l} e^{-\frac{\gamma_{max}}{\overline{\gamma}_l}} \tag{141}$$

where $Res[f(x), y]$ denotes the residue of $f(x)$ at $x = y$. Therefore, substituting (133), (134) and (141) into (136) results in

$$BER_{fading}^{div\ L} = \sum_{l=1}^{L} \prod_{\substack{l'=1 \\ l'\neq l}}^{L} \frac{1}{1-\overline{\gamma}_{l'}/\overline{\gamma}_l} \cdot \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\gamma}_l}{1+\overline{\gamma}_l}}\right). \tag{142}$$

Furthermore, taking a Taylor series expansion up to the L-th derivative for (142) leads to

$$BER_{fading}^{div\ L} \approx \binom{2L-1}{L} \prod_{l=1}^{L} \frac{1}{4\overline{\gamma}_l}. \tag{143}$$

Note that (143) is also valid when $\overline{\gamma}_l$ is identical. Taking into consideration of $\overline{\gamma}_l = \sigma_{sl}^2/\sigma_n^2$, it is concluded that the BER is uniquely determined by the number and magnitude of eigenvalues for the channel, namely, the degree of freedom of the channel of interest.

C: Equivalence Through Linear Transformation

Now, assume that a receiver once linearly transforms the signals through J diversity channels and then combines all the multiplier outputs. In this case, the output of the combiner is written as

$$r' = \mathbf{v}^H\mathbf{F}(\mathbf{h}s + \mathbf{n}) = \mathbf{v}^H\mathbf{g}s + \mathbf{v}^H\mathbf{F}\mathbf{n} \tag{144}$$

$$\mathbf{g} = \mathbf{F}\mathbf{h} \tag{145}$$

where $\mathbf{F}$ is any unitary matrix $(J \times J)$ representing the linear transformation as

$$\mathbf{F}\mathbf{F}^H = \mathbf{I}_{L'\times L'} \tag{146}$$

and $\mathbf{v}$ is a weight vector $(J \times 1)$, which is given by

$$\mathbf{v} = [v_1, v_2, \cdots, v_J]^T. \tag{147}$$

Similar to the discussion in the previous section, defining $\mathbf{G}_{\overline{\mathbf{h}}}$ as $\mathbf{g}\mathbf{g}^H = (\mathbf{Fh})(\mathbf{Fh})^H$, the SNR of the combiner output is written as

$$\gamma' = \frac{\mathbf{v}^H \mathbf{G}_{\overline{\mathbf{h}}} \mathbf{v}}{\sigma_n^2 \mathbf{v}^H \mathbf{v}} = \frac{(\mathbf{F}^H \mathbf{v})^H (\mathbf{h}\mathbf{h}^H)(\mathbf{F}^H \mathbf{v})}{(\mathbf{F}^H \mathbf{v})^H (\mathbf{F}^H \mathbf{v})} \tag{148}$$

therefore, selecting the weight vector as

$$\mathbf{v}_{max} = \mathbf{Fh} \tag{149}$$

the maximun SNR is obtained, but the value is all the same as the one before the linear transformation, because

$$\begin{aligned} \mathbf{G}_{\overline{\mathbf{h}}} \mathbf{v}_{max} &= (\mathbf{Fh})(\mathbf{Fh})^H \mathbf{Fh} = |\mathbf{h}|^2 \mathbf{v}_{max} \\ &= |\mathbf{h}|^2 \mathbf{v}_{max}. \end{aligned} \tag{150}$$

Consequently, any linear transformation of received signals cannot change the resultant SNR, that is

$$\gamma'_{max} = \sum_{l=1}^{L} \gamma_l. \tag{151}$$

(151) means that the diversity system with J branches has the same BER as that with order of L.

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CHAPTER 5

CDMA2000 1X & 1X EV-DO

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Abstract: In this chapter, we will discuss CDMA2000 1x and 1x EV-DO systems. We will talk about channel structure, transmission scheme, call processing, protocol layer and etc. under the topic of radio access technology. And we will talk about coverage & LBA, capacity, scheduling strategy, quality management and etc. under the topic of Engineering & Operation technology. Also, core network structure of CMDA2000 1x system will be mentioned, explanation focused on its main functional elements. Also, characteristics and advancements of next generation technology of 1x EV-DO, EV-DO Rev A and EV-DO Rev-B, will be described in this chapter. Its relation to HSDPA and WiMAX will be looked into

Keywords: Mobile communication; CDMA2000 1X, Channel Structure, Transmission Scheme, Call Processing, Protocol Layers, Forward link, Reverse link, Dedicated channel, Common control channel, LAC, MAC, Engineering, Operation, Coverage, LBA, Capacity, Scheduling Strategy, QoS, LBA, Core network, IMS, EV-DO Rev A, EV-DO Rev-B, HSDPA, Mobile WiMAX

1. INTRODUCTION

CDMA technology was first proposed by Qualcomm as the standard for the digital cellular services in North America. Then, the CDMA technology was authorized as an IS-95 standard of the Telecommunications Industry Association (TIA) in July 1993. IS-95A revision was published in May 1995 and is the basis for many of the commercial 2G CDMA systems around the world. In addition to voice services, IS-95A provides circuit-switched data connections at 14.4 kbps. The IS-95B revision, also termed TIA/EIA-95, combines IS-95A, ANSI-J-STD-008 and TSB-74 into a single document and offers up to 115kbps packet-switched data

CDMA2000 1X is an ITU-approved as 3G standard. It can double voice capacity of IS-95A networks and delivers peak packet data speeds of 153 kbps (Release 0) or 307 kbps (Release A) in mobile environments in a single 1.25 MHz channel. To provide higher peak data rate to subscribers, 1xEV-DO technology, which part of a family cdma2000 1X digital wireless standards, stands for "Evolution, Data-only"

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and delivers forward link data rate up to 2.4 Mbps in a single 1.25 MHz channel, addressing data only-not voice. 1xEV-DO is based on a technology initially known as "HDR" (High Data Rate), developed by Qualcomm and the standard is known as IS-856.

CDMA technology shares a block of spectrum through the use of a spreading code (pseudo-random noise or PN code), which is unique to the individual use. It transmits data spread in a full available spectrum reducing the need to guard bands and increasing efficiency use. The CDMA technology accommodates users 10 to 20 times larger than those of the AMPS using FDMA. In addition, CDMA technology is the strong to high frequency selective fading characteristics due to multiple-path signals. So CDMA technology is suitable for areas with high user density or an urban area where high-rise buildings are concentrated.

The Korean government adopted CDMA as the official standard for mobile digital communication through the notice of the Ministry of Communication in November 1993. SK Telecom, a Korean cellular service provider, introduced commercial cellular service based on IS-95A technology for the first time in the world in 1996. And also, SK telecom commercialized CDMA2000 1x Service in October, 2000 and 1xEV-DO Service in February, 2002. 3GPP2, the Third Generation Partnership Project 2, is responsible for establishing specifications related to the synchronization-type CDMA2000, and to keep reflecting next-generation technologies (MIMO and OFDM. etc) regarding specifications to upgrade the data rate.

2. RADIO ACCESS NETWORK

2.1 CDMA2000 1x

- Channel Structure

– Structure and Characteristics of Forward Link Channel

As shown **Figure 1**, channels for fast data transmission and control channels for efficient signaling control have been added to the forward link in the IS-95 standard.

The forward link channels are divided into the dedicated channels and common channels. The *dedicated* channels are used for specific users, and include a fundamental channel for low-speed rate transmission, a supplemental channel for fast data transmission, and a dedicated control channel for the delivery of mobile-specific control information. And also, a dedicated Auxiliary pilot channel is used with antenna beam-steering techniques to increase the coverage or data rate for a particular user. One common channel includes the pilot channel that measures channel strength and supports coherent detection and hand-off. Handoff is a procedure where a mobile phone with an on-going call changes channel and/or base station under a supervisory system. Other common channels include the sync channel that transmits data necessary for synchronization between terminal and system, and the paging channel that provides system information and paging information. There is also the broadcast control channel added to provide broadcast

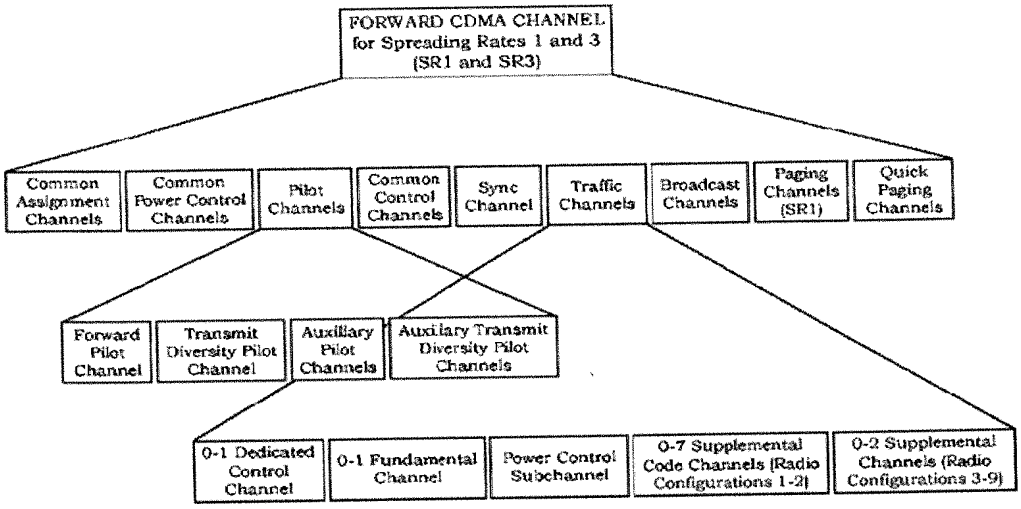


Figure 1. 1x Forward link channel structure

system-specific and cell-specific overhead data, and the quick paging channel that improves paging operations in slotted-mode.

– Structure and Characteristics of Reverse Link Channel

The below **Figure 2** shows the pilot channel, the data transmission dedicated channel, and the improved access channel to be used to transmit moderate-sized data packets have been added to the reverse link in the IS-95 standard.

Like the forward link channels, the reverse link channels consist of dedicated channels and common channels, both of which function similarly to dedicate and common channels in the forward link. Reverse dedicated channels include the fundamental channel, the supplemental channel, the dedicated control channel, and the power control sub-channel, which transmits the power control part

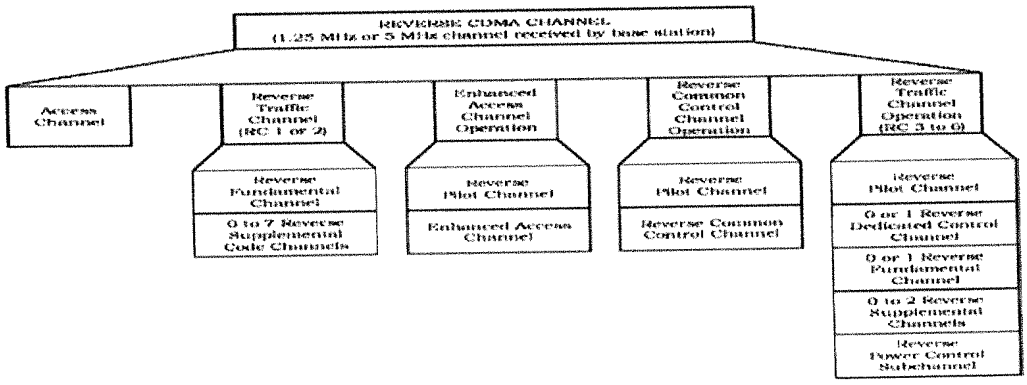


Figure 2. 1x Reverse link channel structure

related to reverse power control. Reverse dedicated control channels are used for the transmission of user and signaling information to the system during a call. The reverse common channels include the access channel used by a terminal for communicating to the base station for short signaling message exchanges, such as call originations, response to pages, and registrations, the common control channel used to transmit control data, an enhanced access channel that provides improved accessibility and a pilot channel that provides a phase reference for coherent demodulation and may provide a means for signal strength measurement.

- Transmission Scheme and Characteristics

– Transmission Channel Structure of the Forward

Major improvements to the forward link in the CDMA2000 1X are fast power control that can support up to 800Hz, increased capacity through Orthogonal Transmit Diversity (OTD), enhanced battery life by quick paging channel, and dedicated channel for fast data transmission.

Figure 3 shows the transmission scheme of the 9.6kbps fundamental channel. The CRC and the tail bits are added to a data bit to create a 9.6kbps bit stream. At this time, the bit stream passes through an encoder and the interleaver for power control puncturing. And then, orthogonal spreading and complex scrambling is made through the Walsh. A long PN code scrambles the channel. The rate of scrambling code depends on the code rate of input. And only PCH(Paging Channel), DCCH(Dedicated Control Channel), FCH(Fundamental Channel) and SCH(Supplemental Channel) are scrambled. A Walsh code running at the chip rate (1.2288Mcps) multiplies the data. The same code is used for both In-Phase and Quadrate components. Each channel is assigned a different Walsh code and might be of different lengths, to adjust to the spreading factor of the data required. The data is then complex PN multiplied, also at the chip rate.

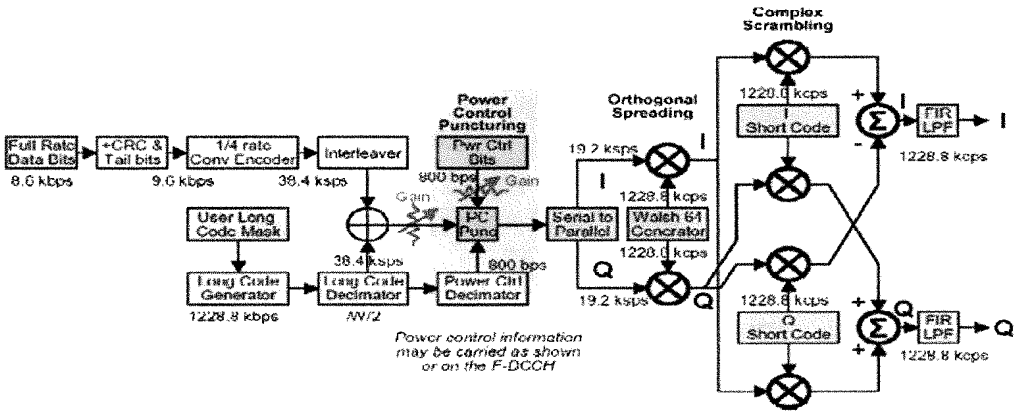


Figure 3. 9.6kbps FCH Transmission scheme

The transmission scheme of the SCH (153.6Kbps) is similar to that of the FCH. However, with 19.2Kbps or higher, the Turbo code is used for fast data transmission instead of a convolution code.

– Transmission Channel Structure in Reverse Link

One of the characteristics of the reverse link structure in CDMA2000 1X is that it uses the dedicated signaling channel. In IS-95, one channel is used to logically separate the frame. However, in the CDMA 2000 1X, a dedicated signaling channel is used so that several Walsh codes identify channels. The Walsh code applied to the reverse link has different lengths depending on the channel as shown in **Table 1**.

The following **Figure 4** illustrates the reverse link modulation and spreading process. The channel illustrated here is the Reverse Dedicated Channel. It consists of a Reverse Pilot Channel, which is always present, an R-FCH, an R-SCH, and an R-DCCH. The reverse link uses reverse pilot, hence greatly improving detection performance by only using the preamble. As shown in **Figure 4**, the reverse channels are spread by different-sized Walsh codes, and after gain scaling, the data is transmitted to I and Q channels. The gain scaling is used to apply the relative

Table 1. Walsh codes applied to reverse channel

Channel Type	Walsh Function
Reverse Pilot Channel	W_0^{32}
Enhanced Access Channel	W_2^8
Reverse Common Control Channel	W_2^8
Reverse Dedicated Control Channel	W_8^{16}
Reverse Fundamental Channel	W_4^{16}
Reverse Supplemental Channel 1	W_1^2 Or W_2^4
Reverse Supplemental Channel 2	W_2^4 Or W_6^8

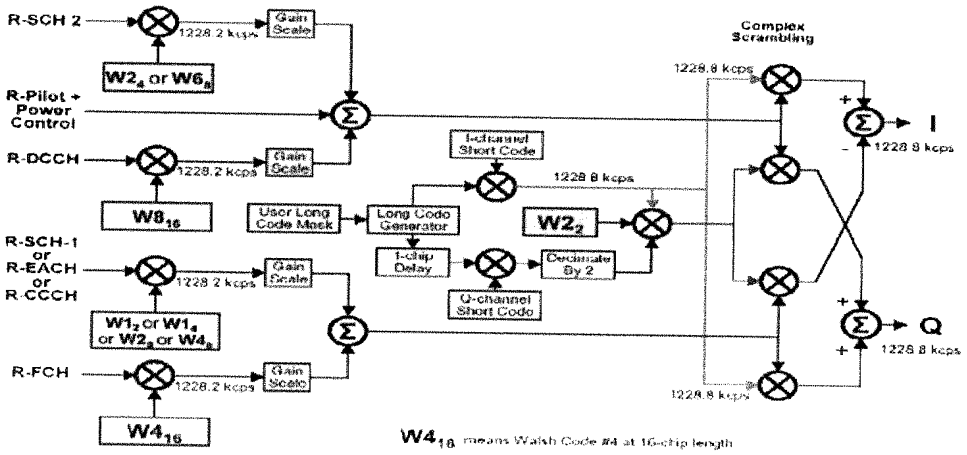


Figure 4. Reverse link transmission scheme

offset to each channel based on pilot channel power. The spread Pilot channel and the R-DCCH are mapped to the In-Phase components. The Spread R-FCH and R-SCH are mapped to the Quadrate components.

– RC, P_REV, MO and SO

The CDMA2000 1X system defines RC, P_REV, multiplex options, and service options that are related to the transmission.

Depending on Radio Configuration (RC), the transmission rate and the modulation characteristics are differed at the physical layer. P_REV (Protocol Revision) refers to the protocol version that the system and the terminal use while MIN_P_REV means the minimum protocol version that can be processed. The Multiplex Option specifically defines the traffic channel transmission method; rate set, maximum data block, data block size, the MUX PDU type, etc. The Service Option (SO) is an agreement to negotiate transmission media for communications. The SO identifies various service types, and currently the service types include voice call and data communication.

• Call Processing

The terminal passes through the initialization state, the idle state, and the access state to enter into the traffic state after initial power-up as shown in **Figure 5**.

When the user powers up the terminal, the terminal will enter into the initialization state where the terminal brings necessary information internally stored to decide the system to use and to receive the pilot channel and the sync channel to synchronize with the system. In its idle state, the terminal receives all of the system information and keeps monitoring the paging channel. The terminal in its idle state transits into the system access state through originating or receiving a call or registration and performing a series of operations to access the system. The information necessary for access to the system is received on the paging channel of Forward link. After successfully accessing the system, the terminal transits into the traffic state and

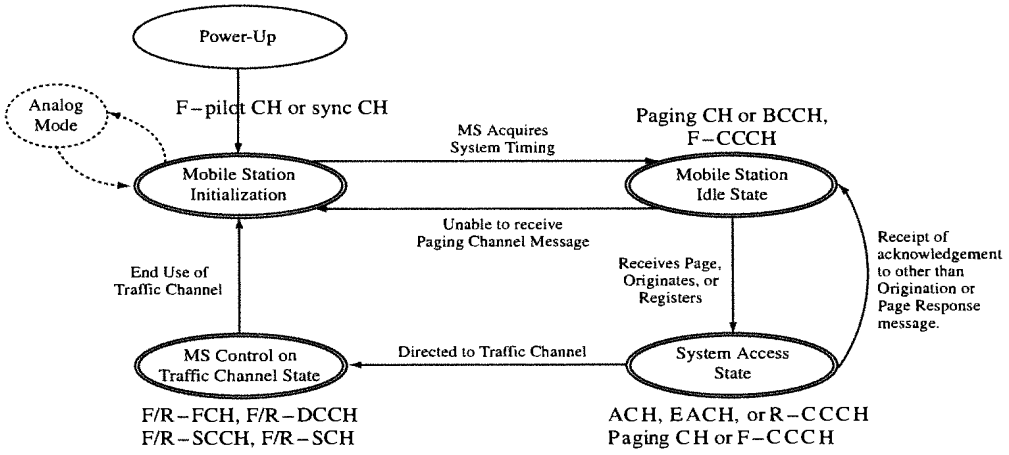


Figure 5. MS State transition diagram

establishes a voice call or a data communication. If a call is terminated, the terminal enters into, first the initialization state and then the idle state in order.

When a terminal in a traffic state crosses the cell boundary, the terminal performs a handoff to keep the call. During the handoff process, the user's serving cell may be changed. Major parameters used during the handoff process include Ec/Io of the base station pilot signal strength and T_add and T_drop sent from the system to the terminal, using system parameter messages over the paging channel Pilot Strength Measurement Message (PSMM), the Extended Handoff Direction Message (EHDM) and the Handoff Completion Message (HCM) are the main messages relating with the handoff. With handoffs, CDMA2000 1X system supports two types of handoff; make-before-break, known as soft handoff and break-before-make, known as hard handoff. The below **Figure 6** is an example about handoff procedure; T-add & T-drop Procedure.

• Protocol Layer

Figure 7 shows the protocol stack of the CDMA2000 1X data. In most cases, the mobile network does not use all OSI 7 layers defined in ISO1 The Protocol stacks that can be managed by CDMA2000 1X are Layers 1~2.

– Physical Layer

The physical layer manages hardware operations that are related to the transmission between terminal and BTS. The physical layer transmits the data coming from the MAC layer through the air through coding, modulation, spreading, and interleaving processes, and sends back the data coming from the air link to the upper MAC layer.

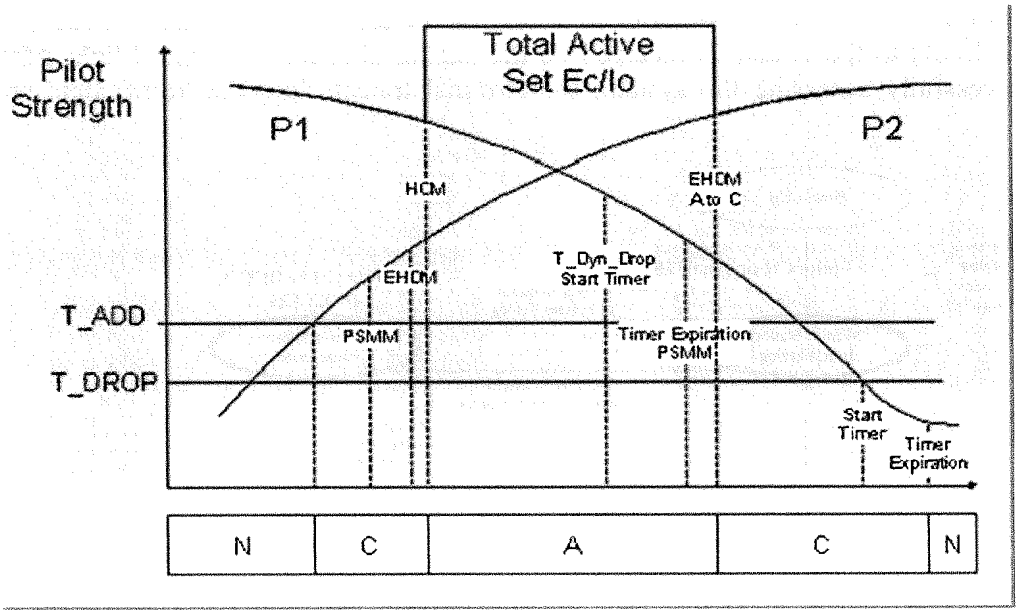


Figure 6. CDMA2000 1X Handoff procedure

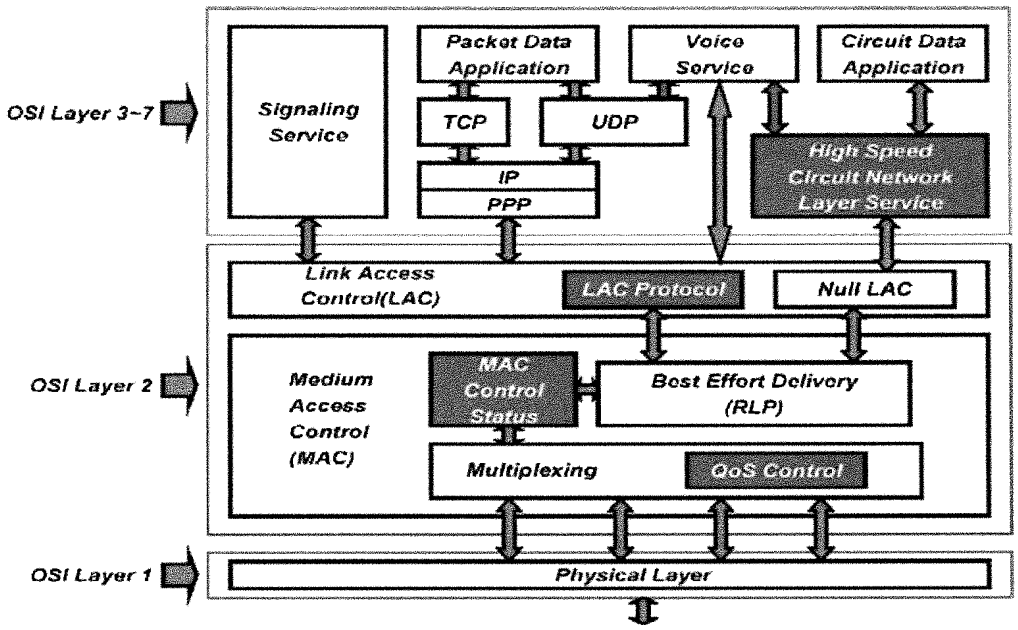


Figure 7. Protocol layer

– MAC Layer

The MAC layer classifies and manages (signaling and traffic) data, and performs operations such as multiplexing, Radio Link Protocol (RLP), and Quality of Service (QoS). The MAC layer properly allocates resources that various entities2 need and processes them for each media. The RLP, one of the major protocols at the MAC layer, is used to prevent errors in the wireless node. The MAC also defines how to process the physical layer in sync channels, paging channels, access channels, and the common control channels.

– LAC Layer

The LAC layer is an upper layer of the MAC layer, and manages operations for control, signals and data or voice communication that is the ultimate goal of traffic. The LAC layer is applied only to signaling, not to general (data or voice) traffic. The LAC layer is divided into five sub layers, and processes various operations including authentication, delivery, addressing, message identification, and CRC processing.

2.2 1xEV-DO Revision 0

• Channel Structure and Characteristics

– Structure and Characteristics of Forward Link Channels

The forward link channel of 1xEV-DO has been created based on the HDR of Qualcomm that supports 2.4Mbps of high data transmission. The transmission

channels include the pilot channel, the MAC channel, the control channel, and the traffic channel. MAC channels include reverse activity channel, the DRC lock channel, and the reverse power control channel. These forward link channels are shown in **Figure 8** and the EV-DO forward link channel structures are very simple relatively to those of CDMA2000 1x..

The pilot channel is used to aid not only as the coherent demodulation reference for the traffic channel and MAC channel, but also as a sampling reference for the channel state. The reverse activity channel of the MAC channel transmits system load data for a reverse link, and the DRC lock channel checks errors in the DRC channel and informs the terminal of a threshold-crossing state. The reverse power control channel is used to transmit power control information concerning a reverse link.

The control channel which can be transmitted at a data rate of 38.4Kbps or 76.8kbps transmits the overhead message and controls the terminal with a broadcast or directed message.

– Structure and Characteristics of Reverse Link Channel

The 1xEV-DO reverse link channels consist of Access channels and Traffic channels as shown **Figure 9**. The Access channels include pilot channels and the data

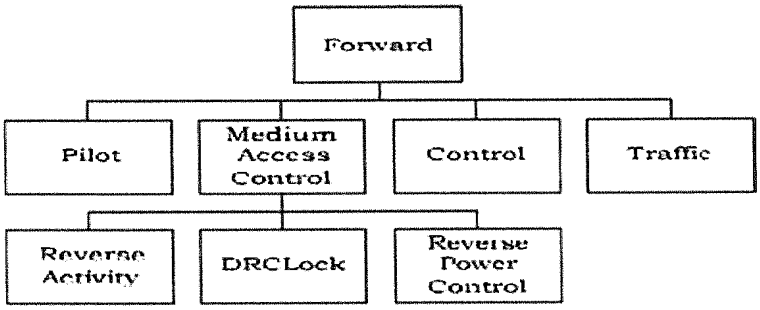


Figure 8. 1xEV-DO Rev. 0 Forward link channel structure

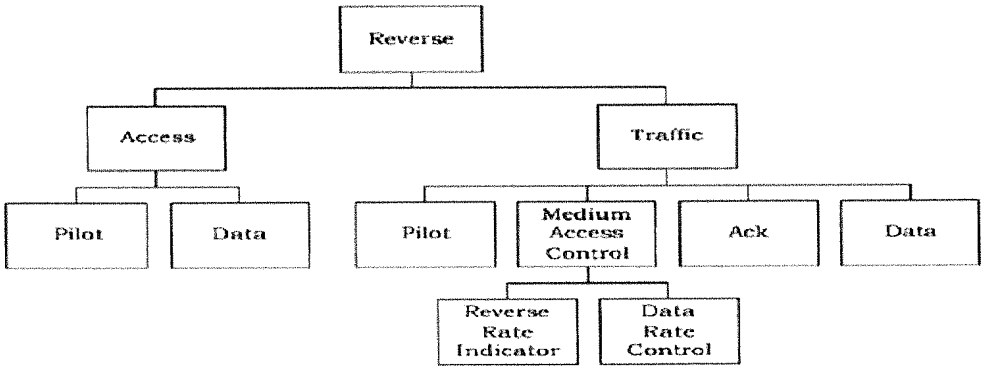


Figure 9. Reverse link channel structure

channels, and Traffic channels include the pilot channel, the MAC channel, the ACK channel, and the Data channel. The traffic MAC channel contains the Reverse Rate Indicator channel and the Data Rate Control channel.

The access channel enables the terminal to access the system or to respond to a message from the system. And the pilot channel is used for the coherent detection. The ACK channel of the traffic channel is related to the packet transmission on the forward link, and is used by the terminal to inform the system whether the data packet transmitted on the forward traffic channel has been received or not while supporting a H-ARQ operation. The Reverse Link Rate Indicator Channel (RRI) is used to inform the base station the data rate being transmitted by the terminal to help demodulation. The RRI is included as a preamble for reverse link frames. The DRC channel is used to determine the transmission rate in the forward link.

The reverse link data channel configures a packet based on the rate that is determined by the reverse rate decision algorithm and transmits the packet to the system. At this time, the power of the data channel is decided based on the reverse pilot power and pre-determined gain offset, which is assigned to each data rate as a different value.

- Transmission Scheme and Characteristics

With the 1xEV-DO system, each user takes turn in time to transmit their payload using the maximum base station power and time division multiplexing technique. It means that the 1xEV-DO system consists of a combination of CDMA and TDMA (Time Division Multiplexing Access). The basic transmission unit of the 1xEV-DO physical channel, as shown **Figure 10**, is a 1.67 ms long slot, and one slot consists of two half slots (with 1024 chips each) that have the same structure. Although the slot is the basic transmission unit of the forward link, practically 1xEV-DO systems supports packet repetition through the multi-slot. The repetition of the packet bits in a sub-packet is achieved through channel coding to further obtain coding gain. To allow time for the terminal to process each sub-packet and to feed back the information to the base station, each sub-packet is transmitted in disjointed time with 3 intervals in between. This is known as the 4 slots packet interlacing.

In 1xEV-DO, one traffic channel is divided based on time to separate the channel transmission node. When being served in EV-DO systems, a terminal receives the

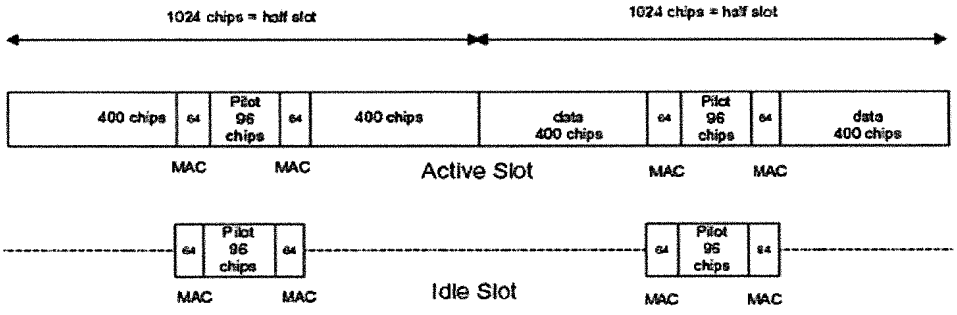


Figure 10. 1xEV-DO Forward link slot structure

full power of the cell transmitter. This is because the 1xEV-DO system employs a shared forward link and can serve a user at any instant to maximize the overall data throughput to a given sector. Therefore, unlike the CDMA 2000 1X, or the 1xEV-DO, every channel always can utilize maximum power.

In the 1xEV-DO, only one traffic channel is supported so that resource allocation must be scheduled in a multi-user environment. There are no predetermined time slots; the time the user is on the forward traffic channel depends on channel condition. When multiple users are waiting to be transmitted, RF conditions may be different. The base station can schedule the user with more favorable RF conditions to be transmitted first while the RF conditions from other users may improve before they are scheduled. This method of packet scheduling provides a gain known as the multi-user diversity gain. In EV-DO system, the proportional fairness scheduler is the default method for packet scheduling. In **Figure 11**, in the 1xEV-DO, the terminal decides the forward link data rate and requests, the decided rate to the system. The terminal measures the Carrier to Interface (C/I) of the pilot in its active set and selects the pilot PN with the best C/I as the best sector. Then, the terminal requests the data rate value (DRC value) corresponding to the measured C/I to the best sector using DRC cover assigned by the base station when the pilot is in transit to the active set of the terminal.

The forward link handoff in the 1xEV-DO system is considered a virtual hard handoff as shown in **Figure 12**. Because, although, the forward link for data

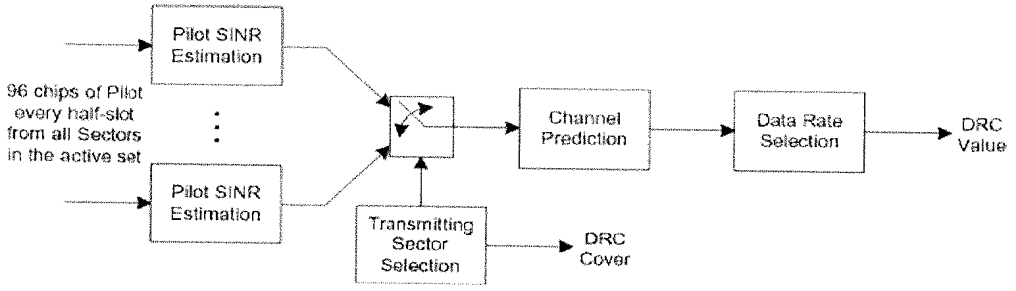


Figure 11. Best sector selection procedure

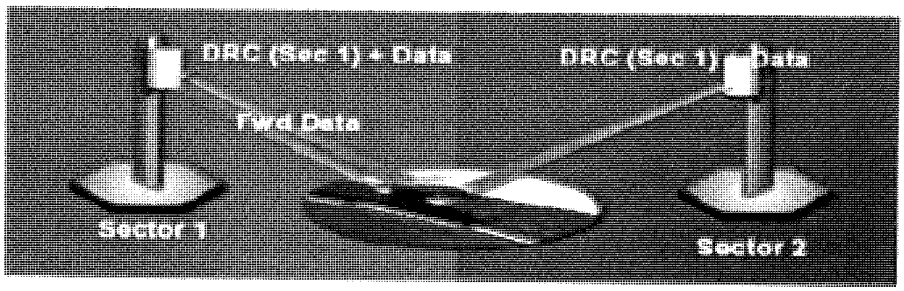


Figure 12. Data handoff (Virtual hard handoff)

transmission is connected only to one sector unlike the reverse link, which all sectors in the active pilot are connected, the best serving sector pilot is changed just by the terminal pointing without other handoff procedures. In **Figure 13**, the terminal is currently served by sector 1. But if C/I of sector 2 is higher than that of sector 1, the terminal shall point the DRC cover to sector 2.

The EV-DO forward link offers a range of different data rates. The data rates use each different modulation method as shown in **Table 2**. Modulation types used on the forward link are QPSK, 8PSK, and 16QAM. QPSK modulation is used to achieve 38.4Kbps through 1.2288Mbps data rates (with the exception of 921.6kbps), and 8PSK for 82.6 kbps and 1.8432Mbpsm and 16-QAM for 1.2288Mbps and 2.4576Mbps. The code rates used in the forward link are 1/5 and 1/3 and the maximum data bits per encoder packet range from 1024 to 4096 bits.

As shown in **Figure 14**, the data packet passes the turbo encoder, channel interleaver, Modulator, repletion, Walsh covering time-division-multiplexed with the MAC, Pilot, and the Packet Preamble and transmitted to the terminal after PN spreading.

The 1xEV-DO reverse link structure consists of fixed size physical layer packets (26.67ms frame unit). The reverse link uses a pilot-aided, coherently demodulated scheme. Traditionally IS-95/CDMA2000 1X power control mechanisms and soft handoffs are supported on the reverse link. The data rates used in the reverse link are in five ranges from 9.6Kbps to 153.6kbps, and the terminal deciding the data rate considering available power, the system load indicated by RRI, and the payload

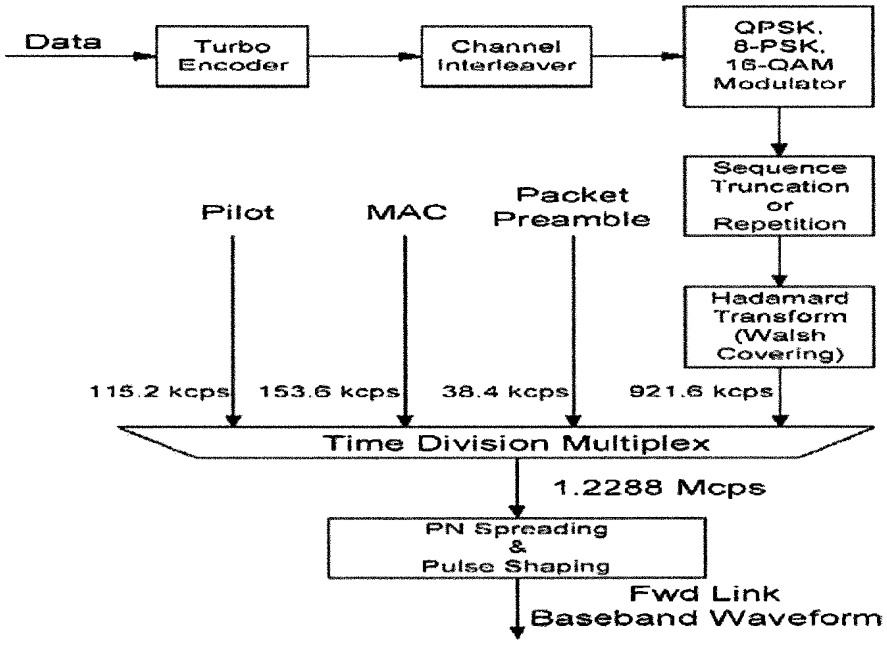


Figure 13. Transmission scheme of the forward link

Table 2. 1xEV-DO Forward Link Modulation

	Physical Layer Parameters											
Data Rates (kbps)	38.4	76.8	153.6	307.2	307.2	614.4	614.4	921.6	1228.8	1222.8	1843.2	2457.6
Modulation Type	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	8PSK	QPSK	16QAM	8PSK	16QAM
Bits per Encoder Packet	1024	1024	1024	1024	2048	1024	2048	3072	2048	4096	3072	4096
Code Rate	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
Encoder Packet Duration (ms)	26.67	13.33	6.67	3.33	6.67	1.67	3.33	3.33	1.67	3.33	1.67	1.67
Number of Slots	16	8	4	2	4	1	2	2	1	2	1	1

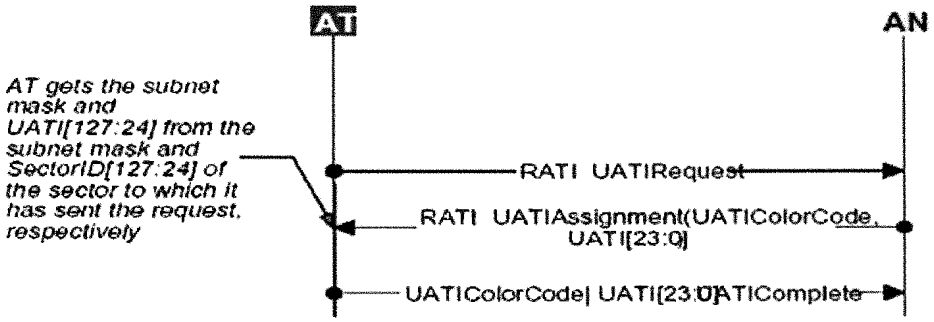


Figure 14. UATI Assignment flow

size to transmit. Main functions of the reverse link are transmission reverse data and the measured quality of the forward link, and the Ack function to support the hybrid ARQ for the forward link packet.

As shown **Figure 15** in **Table 3**, in the reverse link, there is just one modulation type- BPSK and two code rates; 4/1, 1/2. The bits per encoder packet range from 256 bits to 4096 bits. The basic transmission unit in the reverse link is a frame (26.67ms), so it is comparably long in length compared to a forward link transmission unit (1.67ms slot).

- Call Processing

– UATI Assignment Procedure

To process a call in the 1xEV-DO, the terminal must receive an address called the Unicast Access Terminal Identifier (UATI.). The UATI is an address that identifies the terminal, and the terminal attempts a call using the UATI. The terminal uses a Random access Terminal Identifier (RATI) to allocate the UATI. As we see in **Figure 14**, AT sends UATI Request message using RATI to get UATI and gets the subnet mask and other information to need for address assignment. Here, subnet means the area which UATI is assigned, so when terminal is moved another subnet area, the UATI should be updated as a new UATI.

– Connection and Session Procedure

After receiving the UATI, the terminal establishes a connection and a session. When the terminal attempts a call, the system transmits Pilot PN, MAC index, and a DRC

Table 3. 1xEV-DO Reverse link modulation

	Physical Layer Parameters				
Data Rates (kbps)	9.6	19.2	38.4	76.8	153.6
Modulation Type	BPSK	BPSK	BPSK	BPSK	BPSK
Bits per Encoder Packet	256	512	1024	2048	4096
Code Rate	1/4	1/4	1/4	1/4	1/2
Encoder Packet Duration (ms)	26.67	26.67	26.67	26.67	26.67
Number of Slots	16	16	16	16	16

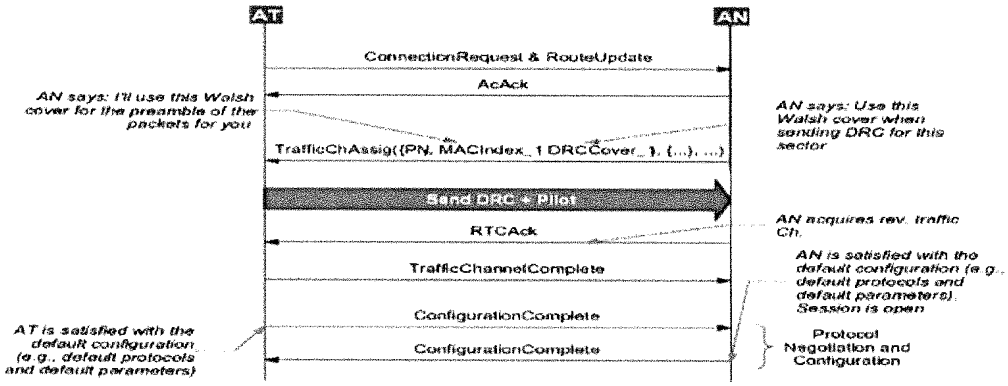


Figure 15. 1xEV-DO Connection procedure

cover to the terminal. After acquiring the traffic channel, the system sends the pilot and the DRC to the system. After a connection is established, the terminal and system negotiate to establish a session if needed. As known in **Figure 15**, AT shall send configuration message for session negotiation. If AN and AT are satisfied with the default configuration, AT and An shall send a configurationcomplete message to each other.

– Authentication Procedure

To receive the packet service in the 1xEV-DO, the terminal or the user must be authenticated, and the Challenge Handshaking Authentication Protocol (CHAP) is an example of such. In tThe CHAP procedure, the Network Access Identifier (NAI) is used to authenticate the user and the terminal. In case a mobile IP is used, the mobile IP authentication will be used between the terminal and the home agent instead of the CHAP. When the mobile IP is used, the home agent functions as the RADIUS server, and the foreign agent functions as the RADIUS client. The authentication procedure is described in detail in below **Figure 16**.

– Hybrid Operation

The 1xEV-DO network does not support voice communication so it uses the CDMA2000 1X network for voice communications. The hybrid terminal used in this case selects the CDMA2000 1X network first, acquires and registers the system, and searches and registers the 1xEV-DO network as shown in **Figure 17**. In case two systems are acquired, the hybrid terminal performs dual system scanning.

The 1xEV-DO terminal must interwork with the existing CDMA2000 1X network to use voice communication services. In its Idle state, the 1xEV-DO terminal must communicate with the CDMA2000 1X network, and when the user selects the packet data service, the terminal must connect the 1xEV-DO network.

• Protocol Layers

In the 1xEV-DO network, a total of seven layers are used below the Point-to-Point (PPP) and each layer defines the related protocol. IS-856 protocol stack shown in

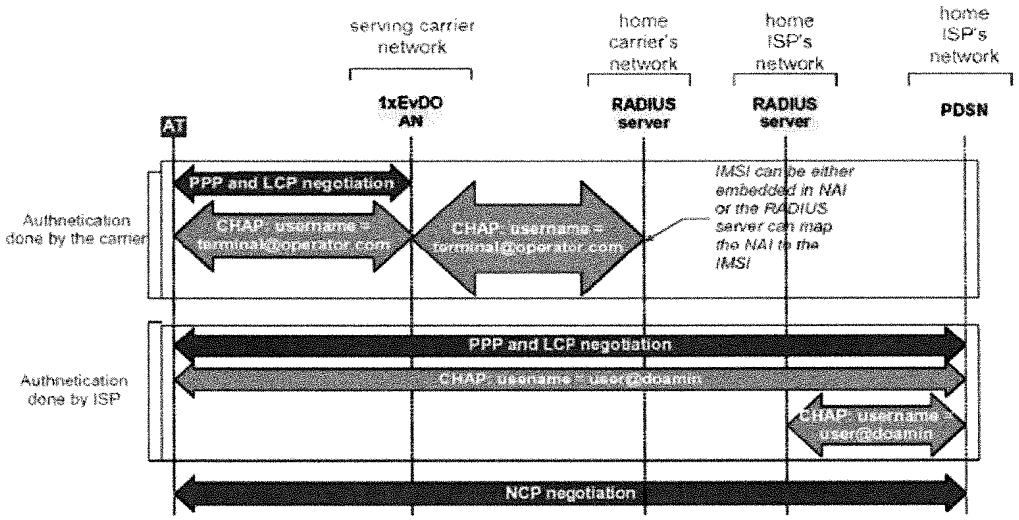


Figure 16. Authentication procedure

Figure 18 is divided up 7 layers. IS-856 stack is under TCP/IP/PPP protocol stack and supports RLP (Radio Link Protocol).

– Physical Layer
The Physical layer modulates, codes, and interleaves the data from the upper layer to transmit it to the air link.

– MAC Layer
The MAC layer defines the procedure used to receive and transmit over the Physical Layer, and performs various operations such as the transmission of MAC layer packets, mapping for packet transmission, multiplexing, demultiplexing, priority handling, identification, and channel supervision. The MAC Layer is a key component optimizing the efficiency of air links and allowing access to the

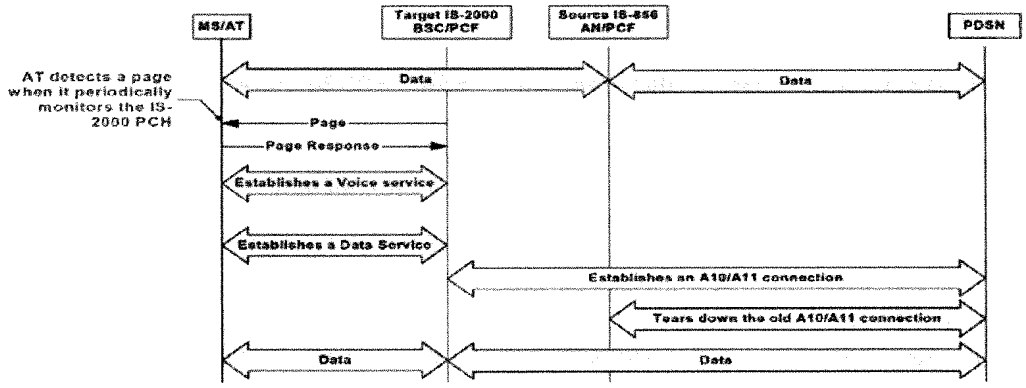


Figure 17. Hybrid operation procedure

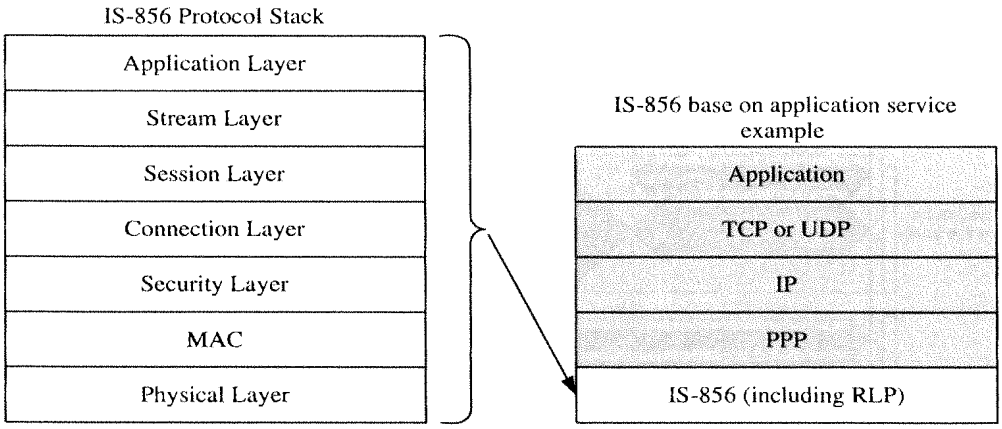


Figure 18. IS-856 Protocol stack

system. It is comprised of four protocols; Control Channel MAC Protocol, Access Channel MAC Protocol, Forward Traffic Channel MAC Protocol, and Reverse Traffic Channel MAC Protocol. The four protocols play a part transmitting data and system information over the air link.

– Security Layer

The security layer ensures security of the connection between the system and the terminal. The security layer provides four functions? key exchange, authentication, security, and encryption.

The upper connection layer packets are mapped on the MAC layer through passing the encryption protocol, the authentication protocol, and the security protocol.

– Connection Layer

The Connection layer is comprised of a group of protocols that are optimized for packet data. Combined they efficiently manage the 1xEV-DO air link, reserve resources, and prioritize each user's traffic. They are designed to enhance the user's experience while at the same time bring efficiency to the system. The connection layer consists of the protocols that control connections in the radio link. Protocols of the connection layer include air link management protocol, initialization state protocol, idle state protocol, connected state protocol, route reverse date protocol, overhead message protocol, and packet consolidation protocol.

– Session Layer

The Session layer provides a support system for the lower layers in the protocol stack. It manages the state between the base station and the terminal, and is responsible for address management, configuration negotiation, and protocol negotiation.

The session layer includes Session Management Protocol (SMP) that manages the session, Address Management Protocol (AMP) that manages the UATI of the terminal and Session Configuration Protocol (SCP) that negotiates the configuration during the session period.

– Stream Layer
The Stream layer tags all the information that is transmitted over the air link. This includes user traffic as well as signaling traffic. The stream layer maps the various applications to the appropriate stream and multiplexes the streams for one terminal. The stream layer multiplexes the data generated in the upper layer (the application layer) and divides the media based on the QoS. Stream 0 is assigned to the signaling application, and Stream 1 is used to manage the packet application. The stream protocol can process a maximum of four streams, and control the format and processing of the configuration message.

– Application Layer
The Application layer is a suite of protocols that ensure reliability and low reassure rate over the air link. The Application layer has two sub-layers, which are Default Signaling Application, which provides the best effort and reliable transmission of signaling messages, and the Default Packet Application that provides reliable and efficient transmission of the user's data.

Default Protocols of 1xEV-DO are shown in **Figure 19**.

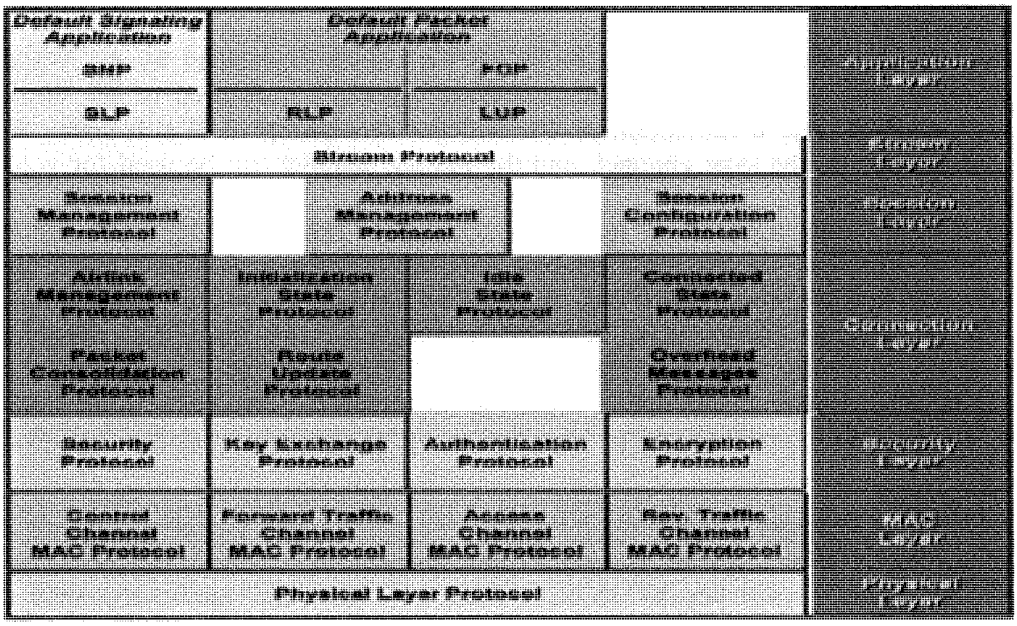


Figure 19. 1xEV-DO Default protocols

3. ENGINEERING & OPERATION

3.1 CDMA2000 1x

• Coverage & LBA (Link Budget Analysis)

The coverage of the CDMA2000 1x network is decided by Ec/I0 of the received signal. Ec/I0 refers to a ratio between the power of the pilot channel received by the terminal and the general signal power received in the band example of Forward LBA could be found in **Table 4**.

$$(1) \qquad E_c/I_1 = \frac{\xi_p P_1^e G_c G_m 1/L}{N_o W + I_o W + I_{oc} W} = \frac{\xi_p P_1^c 1/L_t}{N_o W + I_o W \left(1 + \frac{I_{oc}}{I_o}\right)}$$

Parameters	Descriptions
ξ_p	Portion of the cell power allocated to the pilot channel
P_1	Cell PA Output
G_c	Cell Ant. Gain
G_m	Mobile Ant. Gain
I_{oc}	Other Cell Interference Power Spectral Density
I_o	Same Cell Interference Power Spectral Density
$N_o w$	Thermal Noise at the Mobile LNA Input

• Capacity

The physical capacity of the CDMA2000 1x system is decided by the Walsh code count and the number of Channel Elements (CEs.). A total of 64 Walsh codes are used, and a maximum of 61 Walsh codes except 3 Walsh codes for the pilot channel, the sync channel, and the paging channel can be used for voice traffic.

In addition, the capacity of the radio channel is influenced by transmission power of the base station and terminal. The higher the traffic and noise, the greater the output power in the base station and terminal. When the transmission power of the base station and the terminal reach the threshold, call dropping will occur although there are Walsh codes and CEs available. Limited system capacity due to lack of the Walsh code, the CE and the power may appear in a different manner depending on user distribution in the sector and the use of the data service.

• Scheduling Strategy

The CDMA2000 1x scheduler is used for data transmission through the SCH. This scheduler is launched every 260 msec, and determines related parameters such as User, SCH Start Time, SCH Duration, SCH Data Rate, and SCH Tx Power. The BTS Resource Control (BRC) module requests the scheduler to allocate the SCH

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Table 4. Forward LBA

	1x Forward Link					
Morphology / Cell Model	Urban / Macro					
Service type	Voice		Data			
Spreading rate	1	1	1	1	1	1
Chip rate [bps]	1228800	1228800	1228800	1228800	1228800	1228800
Bit rate [bps]	9600	9600	76800	76800	153600	153600
Test invironment	Pedestrian	Vehicular	Pedestrian	Vehicular	Pedestrian	Vehicular
Handoff state(with SHO=1, without SHO=O)	1	1	0	0	0	0
Transmitter (Base Station)						
BS maximum transmitter power [dBm]	43	43	43	43	43	43
Maximum TCH fraction of total power. Ec/Ior [dB]	−16.7	−16.4	−9.8	−7.4	−6.8	−4.4
BS Max.transmitter power per Traffic channel [dBm]	26.3	26.6	33.2	35.6	36.2	38.6
Cable, Connector and Combiner losses [dB]	2	2	2	2	2	2
BS transmitter antenna gain [dBi]	17	17	17	17	17	17
BS transmitter EIRP per Traffic channel [dBM]	41.3	41.6	48.2	50.6	51.2	53.6
Receiver (Mobile)						
Thermal noise density [dBm/Hz]	−174	−174	−174	−174	−174	−174
Receiver noise figure [(dB)]	8	8	8	8	8	8
^lor/ltc	2	2	1	1	1	1
Ltc/loc	4	4	0.8	0.8	0.8	0.8

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Same cell interference density, Isc [dBm/Hz]	−160.0	−160.0	−164.3	−164.3	−164.3	−164.3
Other cell interference density, Ioc [dBm/Hz]	−166.0	−166.0	−160.3	−160.3	−160.3	−160.3
Total effective noise + interference density [dBm/Hz]	−158.3	−158.3	−158.1	−158.1	−158.1	−158.1
Information rate at full rate [dB-Hz]	39.8	39.8	48.9	48.9	51.9	51.9
Required Geometry, Ior/(No+Ioc) [dB]	6	6	−2	−2	−2	−2
Required Eb/(No+Io) [dB]	7.4	7.7	0.2	2.6	0.2	2.6
Receiver sensitivity [dBm]	−111.1	−110.8	−109.0	−106.6	−106.0	−103.6
MS receiver gain [dBi]	0	0	0	0	0	0
Body Loss [dB]	3	3	0	0	0	0
Max. path loss [dB]	149.37	149.37	157.17	157.17	157.17	157.17
Handoff Gain [dB]	3	3	3	3	3	3
Penetration loss [dB]	15	8	15	8	15	8
Log-normal fading margin [dB]	10.3	10.3	10.3	10.3	10.3	10.3
Maximum Allowable Path Loss [dB]	127.1	134.1	134.9	141.9	134.9	141.9
Cell Range [km]	0.92	1.46	1.53	2.44	1.53	2.44

every 260msec when data remains to be transmitted in the transmission buffer of the user. Then, the scheduler allocates the SCH according to the defined scheduler considering the number of users requesting for SCH. The user selection algorithm to define priorities is as follows:

$$\text{Priority\_Score} = A*\text{Starvation\_Number} + B*\text{Queue\_Length} + \Gamma * \text{Expected\_Data\_Rate}$$

The Starvation_Number increases by 1 when it does not receive an SCH after making a request. The higher the A, the greater fairness among users.

The Queue_Length is the number of Mux PDUs in the transmission buffer of the channel card. The higher the B, the greater the link efficiency is. The Expected_Data_Rate can be transmitted when the corresponding user is allocated with the SCH. The higher the Γ, the greater the entire throughput.

- Quality Management

Unlike the overhead channels (pilot channel, sync channel, and paging channel) that have a fixed value, the transmission power of the base station of the forward traffic channel in the CDMA2000 1x network is not fixed and changes according to variable vocoder and multipath fading.

This is because protocol is mainly for voice communication, and the base station and terminal control power to manage voice quality. The set point of the terminal changes according to the forward link Frame Error Rate (FER). The terminal compares the received Eb/Nt with the set point defined in the terminal and sends the Power Control bit (PCB) "1" or "0" to the base station. When the base station receives "1," it reduces the digital gain by Power_Control_Step, or when it receives "0," it increases the digital gain to maintain the target FER or the terminal.

The terminal transmission power in the reverse traffic channel is also determined in the same way. The Eb/N0 measured at the demodulator of the base station is compared with Eb/N0 predicted by the outer loop lower control. If the measured Eb/N0 is higher, the base station will send "1" PCB to the terminal to lower the transmission power, or when it is lower, the base station will send "0" PCB to the terminal to increase the transmission power to maintain target FER.

- Resource Assignment (Only for Samsung System)

For communication between the system and the terminal, necessary resources must be allocated to the terminal. The FA, the transmission power, the channel element, the Walsh code, and E1 link are allocated in order. When the resources are more than the threshold, it can be allocated. If there is no resource available, the call connection request will be denied. The system will control call admission based on the cell load, channel element resources per FA/sector, and transmission power.

3.2 1xEV-DO

• Coverage & LBA

The coverage of the 1xEV-DO network refers to a zone where the service is provided at a certain throughput or higher throughput, or a zone with a certain C/I level or higher level. C/I refers to the ratio between signal and interception. "C" indicates the transmission power from the base station, and "I" indicates all interception signal power except carrier power C among the received power example of forward LBA could be found in **Table 5**.

$$\left.\frac{C}{I}\right|_{DO} = \frac{P_{TX,M} \cdot g_{M,00}(d)}{\sum_{i=1}^{36}\sum_{j=0}^{2} P_{TX,M} \cdot g_{Mij}(d) + \sum_{j=1}^{2} P_{TX,M} \cdot g_{M,0j}(d) + N_0 \cdot W}$$

Parameters	Descriptions
$P_{TX,M}$	Transmission power of the cell
$g_{N,0}(d)$	Transmission loss between the AT and the AP
$g_{M,y}(d)$	Transmission loss between Ith AP and the AT in Jth sector
Now	Thermal noise

• Do System Capacity

The forward link capacity of the 1xEV-DO network is determined by the MACIndex count that physically identifies the users. **Table 6** shows the MAC Channel and preamble use versus MACIndex, and total 59 MACIndex values can be used as traffic channels:

In the channel card of the 1xEV-DO, there are 96 reverse channels. Therefore, when there are three sectors, each sector will have 32 channels.

Unlike the CDMA 2000 1x network, in the 1xEV-DO network, it is the sector throughput, not the number of subscribers, which must be managed for the operation of the system. Depending on the location of the user and the number of users, the actual sector throughput may drop below 2.4 Mbps, which is the maximum physical throughput. Major factors that affect the throughput include the early termination and multi-user diversity gain.

Early termination occurs when the terminal requests a DRC that uses multi slots with repeated symbols, see **Table 7**. The terminal responds by sending an ACK through the ACK channel when correct demodulation is made before receiving all slots that the base station sends. When the base station receives the ACK, it will terminate the transmission without repetition. In short, transmission will be completed within a shorter slot time and the throughput will increase.

Multi-user diversity gain refers to an increase in sector throughput caused by characteristics of the proportional fair scheduler. The scheduler allocates the slots to the user in a relative better condition. Therefore, when there are multiple users, it is highly likely that uses in better conditions will be selected, hence increasing

Table 5. Forward LBA

1x EV-DO Forward Link			
Parameters	Value	Symbol	Equation
Average Throughput [bps]	64300		
Bandwidth [Hz]	1228800		
Bandwith [dB-Hz]	60.895	a	
Tranmitter (Base station)			
BTS Tx Power [Watts]	20		
As above in dBm	43.01	b	
BTS Antenna Gain [dBI]	17	c	
BTS Cable Loss [dB]	2	d	
BTS EIRP [dBm]	58.01	e	b+c–d
Receiver (Mobile)			
MS Rx Antenna Gain [dBi]	0	f	
Body Loss [dB]	3	g	
Noise Figure (dB)	8	h	
Thermal Noise [dBm/Hz]	−166	I	(–174)+h
Target PER [%]	2		
(Ior/No)req per Antenna [dB]	4	j	
Multi-user Diversity Gain [dB]	2.25		
Rx Diversity Gain [dB]	–		
MS Receiver Sensitivity [dBm]	−101.105	k	1+j+a
Log-normal Std. Deviation [dB]	8		
Log-normal Fade Margin [dB]	10.3	l	
Handoff Gain [dB]	4.1	m	
Building Penetration Loss [dB]	15	n	
Maximum Pass Loss [dB]	134.92	o	e-k+f-g-l+m-n
Cell Range [km]	1.54		

the sector throughput. However, in case of the multi-user diversity gain, the sector throughput does not increase but is saturated when the number of subscribers reaches a certain level as shown in **Figure 20**:

- Scheduler

The 1xEV-DO system uses a proportional fair scheduler. The scheduler allocates the Nth slot to the user with the largest DRCi(N)/ Ri(N). DRCi(N)is the DRC that

Table 6. MAC Channel and preamble use Versus MACIndex

MACIndex	Use
0 And 1	Not Used
2	76.8kbps Control Channel
3	38.4kbps Control Channel
4	RA Channel
5 ~ 63	Forward Traffic Channel, RPC Channel

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Table 7. Number of slots and symbol repetition count for each DRC

Data Rate (kbps)	Values per Physical Layer Packet						Approximate Coding	
	Number of Slots	Number of Bits	Number of Modulation Symbols Provided	Number of Modulation Symbols Needed	Number of Full Sequence Transmissions	Number of Modulation Symbols in Last Partial Transmission	Code Rate	Repetition Factor
38.4	16	1,024	2.560	24,576	9	1,536	1/5	9.6
76.8	8	1,024	2,560	12,288	4	2,048	1/5	4.8
153.6	4	1,024	2,560	6,144	2	1,024	1/5	2.4
307.2	2	1,024	2,560	3,072	1	512	1/5	1.2
614.4	1	1,024	1,536	1,536	1	0	1/3	1
307.2	4	2,048	3,072	6,272	2	128	1/3	2.04
614.4	2	2,048	3,072	3,136	1	64	1/3	1.02
1,228.8	1	2,048	3,072	1,536	0	1,536	2/3	1
921.6	2	3,072	3,072	3,136	1	64	1/3	1.02
1,843.2	1	3,072	3,072	1,536	0	1,536	2/3	1
1,228.8	2	4,096	3,072	3,136	1	64	1/3	1.02
2,457.6	1	4,096	3,072	1,536	0	1,536	2/3	1

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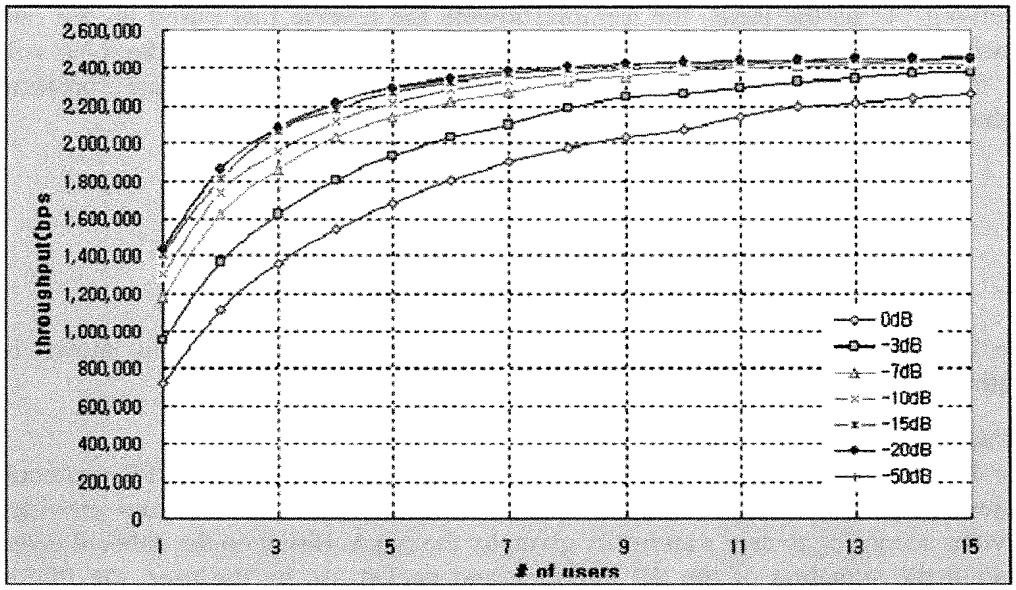


Figure 20. Throughput by number of users and idle slot gain

User i requests to the reverse link, and Ri(N) is the average rate of data that User i received during Tc, the time constant in the scheduler. Ri(N) can be updated as follows:

$$\mathrm{Ri(N)} = (1 - 1/\mathrm{Tc})^{*}\mathrm{Ri(N-1)} + (1/\mathrm{Tc})^{*}$$

(Served Rate In Slot N-1 To User i)

As the default of Ri(N) is "0", the terminal that attempts to use the service for the first time in the cell will have priority. The user for whom the data transmission has not been allocated in the current slot will have a served rate of 0, and even the average rate of the user who does not have data to transmit in the buffer will be updated. This leads to giving a higher priority to the user who has not recently received the data.

- Quality Management

The 1xEV-DO controls the rate to manage traffic quality. The terminal measures the C/I and requests the maximum data rate to meet PER 1% using the DRC channel in the reverse link. Then, the system allocates the data rate each user requested. If the PER of received data is higher or lower than 1%, the terminal adjusts the DRC rate to maintain PER 1%.

The reverse rate control is for quality management of the reverse traffic channel, and the base station controls the reverse rate of the terminal based on probability. In case reverse traffic increases, the system load will also rise. However, if the reverse traffic crosses the threshold, the base station will set the Reverse Activity Bit (RAB) as "1" and sends the RAB to the terminal through the RA channel. After

receiving "1" as the RAB, the terminal lowers the reverse rate based on the rate transition probability. If the system load is smaller than the threshold, the RAB will be "0" and the terminal will increase its transmission rate based on rate transition probability.

4.

4.1 Network Structure and Functional Elements

The data core network in the CDMA2000 network is configured as shown in **Figure 21**:

- Packet Data Serving Node (PDSN)

The PDSN allocates the IP addresses to the terminal through the PPP protocol, routes the packets between the terminal and the Internet network, and provides services according to user's authority given by the AAA. Based on the data collected through the signaling of the RP interface and packet use by the user, the PDSN creates the charging data and sends it to the charging equipment.

- Authentication, Authorization, Accounting (AAA) Server

When the user makes a new data call, the AAA server allocates the IP address and authenticates the user. Also, the AAA sends user authority data to the PDSN so that the PDSN can judge which users have access to which services. The AAA server

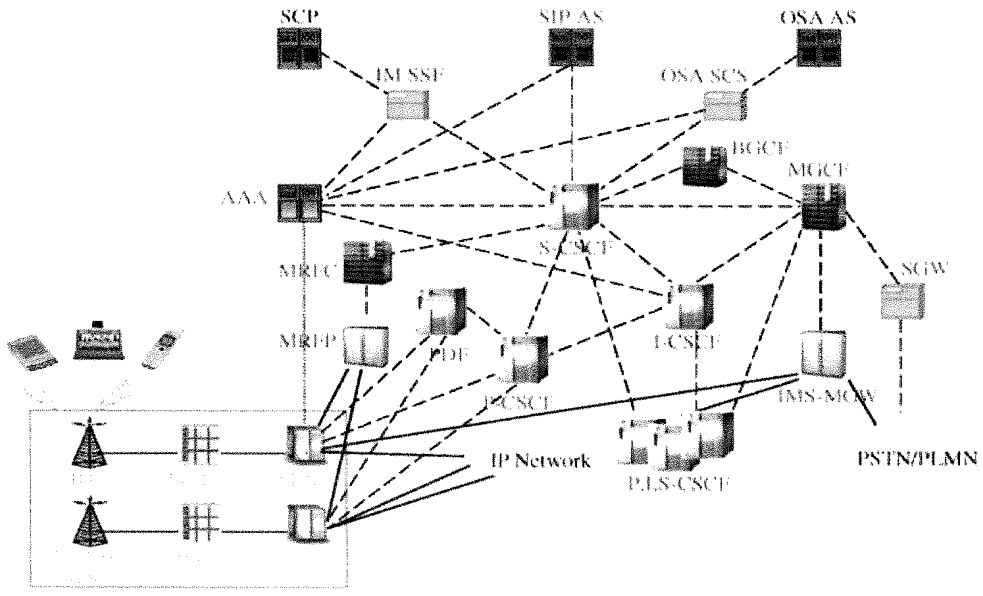


Figure 21. Core network structure

receives the charging data created when the user uses the packet data service from the PDSN, and executes charging features.

- Home Agent (HA)

When the user requests mobile IP service, the PDSN sends mobile IP user data to the HA. After receiving this data, the HA allocates the IP address to the terminal, and uses two addresses to transmit packets using the PDSN as a foreign agent. Tunneling protocol is used between the PDSN and the HA.

4.2 IMS

IMS stands for the IP Multimedia CN Subsystem, and is a core network domain that provides various IP-based multimedia services that are controlled by the SIP. The term "IMS" was first introduced when the 3GPP adopted the All-IP concept in Release 5, and since then, the IMS has been evolving through R5 and R7. Recently, the 3GPP2 and the fixed NGN network also adopted the IMS and are standardizing the related technologies, see **Figure 22**. The IMS adopted IETF standard protocols such as SIP and Diameter, and defined various capabilities necessary for the communication services to support global roaming and interworking.

4.3 Standardization Trend

The IMS, a standard for the IP multimedia service in the GPRS network was first defined in R5 specification of the 3GPP. In the same period, the 3GPP2 was also standardizing a technology similar to the IMS of the 3GPP. Later, to harmonize these two technologies, the 3GPP2 adopted the IMS of the 3GPP, not the All-IP standard, as the MMM standard. This has not yet changed. In addition, the 3GPP developed the IMS standard into R6 IMS through complementing the specification to give access independence to R5 IMS.

In this period, the TISPAN and ITU-T also recognized a need to introduce IMS technology to a fixed network. To meet this need, a work item called Fixed Broadband Access to IMS (FBI) is underway to integrate the IMS in a fixed-mobile convergence network as part of works for establishing the R7.

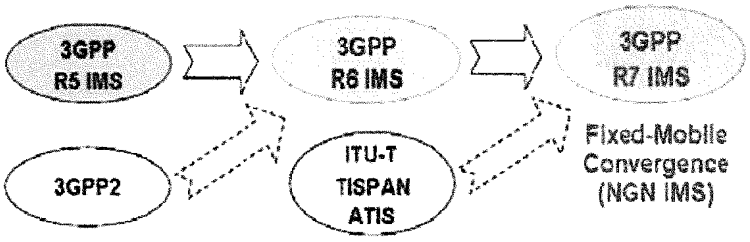


Figure 22. IMS Standard development

4.4 Terminal

The terminal is the endpoint that provides users with the services through the wireless communication network. The terminal has been developed in a way to meet various demands of users supporting multiple access networks and high data rate multimedia data services.

• Terminal H/W Architecture

The hardware of the terminal mainly consists of three parts: the modem that processes the call processing, the application that provides various value-added functions and services, and I/O peripherals such as keypad and display as shown in **Figure 23**.

The modem part is one of the core hardware elements of the terminal and deals with connections to the access network and manages data reception and transmission. Major modem parts includes the modem chip for baseband signal processing, the RF chip for the reception and the transmission of RF signals, the power management chip, and the antenna.

The application part is to handle various supplementary functions and multimedia services other than basic call processing. The application part includes various application processors and memory devices.

The I/O peripherals are exposed to the user. The I/O peripherals include the LCD (Liquid Crystal Display), the camera, the speakers, the keypad, the external memory reader, and many other I/O devices.

• Terminal S/W Structure

The software of the terminal consists of the operating system (OS) and the applications as shown in **Figure 24**. The terminal S/W is based on Dual-Mode Subscriber Software (DMSS), an MSM S/W, and the REX OS for multitasking. The terminal S/W also includes a vendor-specific platform to support unique features of each terminal over the operating system. The DMSS controls the model chip and enables interworking between the modem chip and various application processors providing a basic frame work for terminal S/W operations. The vendor-specific platform

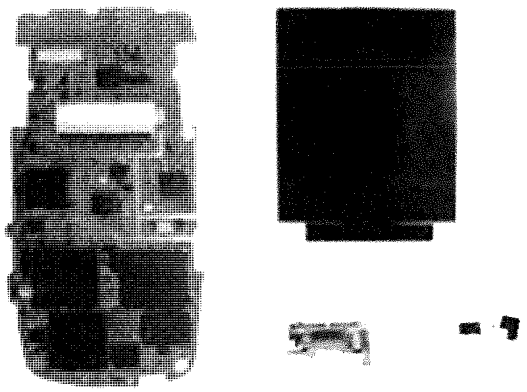


Figure 23. Example of terminal H/W component

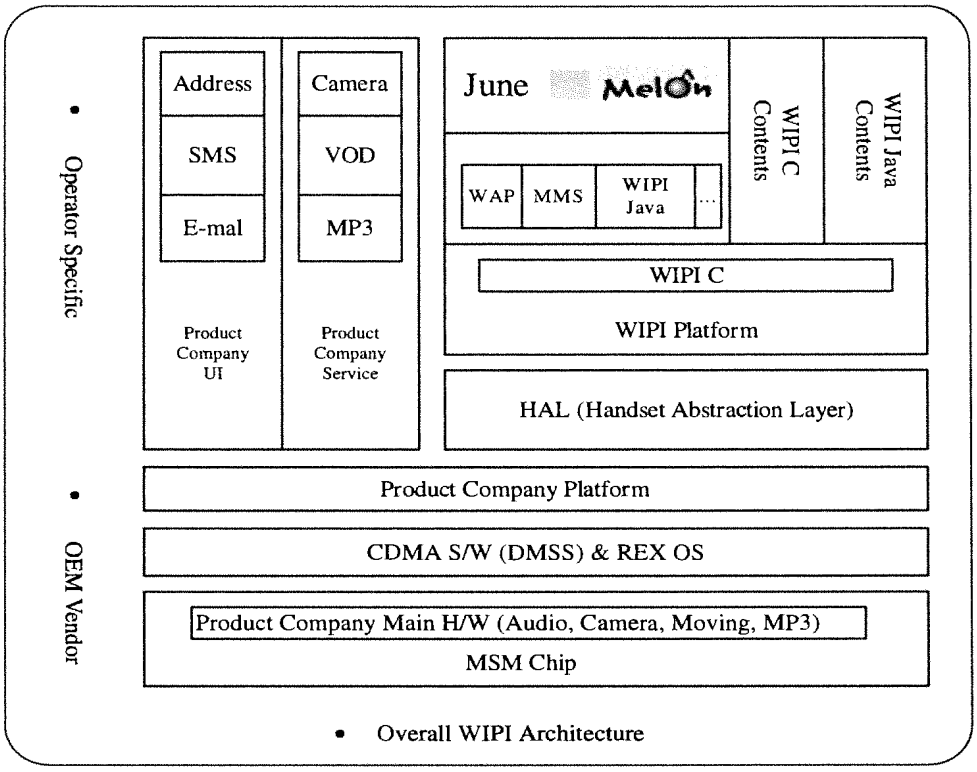


Figure 24. Example of terminal S/W architecture

processes features of each terminal such as address book, SMS and MP3 player and interworks with a higher layer platform. On the Hardware Abstraction Layer (HAL) above the vendor-specific platform, the application platform is installed to run various applications.

Korea adopted the Wireless Internet Platform for Interoperability (WIPI) platform as the standard, and all supplementary service applications are developed in C or Java language based on the WIPI.

• Terminal Evolution

The terminal evolution trend is mainly divided into two major streams: the support for the high data rate multi-access network and device convergence. The modem chipset is being developed in a way to support not only basic communication features of the IS-95A network in the early days but also various features of newly introduced access networks such as CDMA2000 1x, 1xEV-DO, and WCDMA to catch up with the access technology evolution. From the device convergence point of view, the terminal has been developed to have various designs and to reduce overall weight and size. Together with adopting System On Chip (SOC), the terminal is now developing into an integrated multimedia device that can support not only the basic voice calls but also the advanced and sophisticated multimedia service features.

5. FUTURE DEVELOPMENT

5.1 CDMA2000 TRM (Technology Road Map)

• IS-95

The IS-95A (Interim Standard 95A) is the first standardized CDMA technology. As the first digital mobile communication technology, the IS-95A was standardized in 1993 and upgraded later to the IS-95B. The IS-95 is recognized as the second-generation mobile communication technology by the International Telecommunication Union (ITU), see **Figure 25**.

• CDMA2000 1x

The CDMA2000 1x is the next-generation technology of the IS-95. 1x is an abbreviation of 1x Radio Transmission Technology, (1xRTT) which means a system that uses one 1.25MHz channel. The CDMA2000 1x system supports up to 3xRTT, and 1xRTT is the most basic system. The ITU classified the CDMA2000 1x technology as 3G technology (in November 1999).

• CDMA2000 1xEV-DO (1x Evolution-Data Optimized)

The 1xEV-DO is a dedicated standard for the data service and has been developed based on the CDMA2000 1x technology to provide mobile data service at a high speed. The ITU classified the 1xEV-DO as a 3G technology. Following 1xEV-DO Release 0 (CDMA2000 High Rate Packet Data Air Interface, IS-856) and 1xEV-DO Rev. A (TIA-856-A), 1xEV-DO Rev. B was standardized.

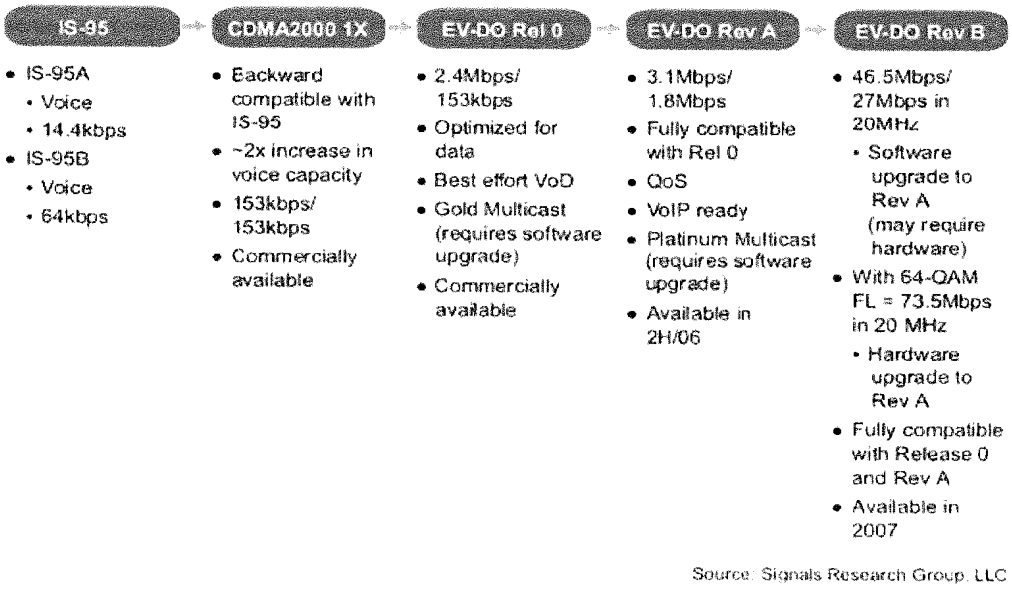


Figure 25. CDMA Technology TRM

5.2 1xEV-DO Revision A

1xEV-DO Revision A is the first upgraded version of 1xEV-DO Release 0 in the CDMA 2000 technology roadmap. It was first suggested to develop 1xEV-DO Release 0 into 1x EV-DV to support both voice and data, but this plan was suspended. Currently, 1xEV-DO Release 0 is being developed into 1xEV-DO Revision A dedicated to the data system.

The performance of the forward link in Revision A has increased by 20% due to the introduction of improved packet structure and equalizer compared to EV-DO Release 0, see the performance comparison in **Figure 26**. The improved packet structure and the equalizer increased the C/I of the signal received by the terminal so that a 1xEV-DO Revision A can support 3.1Mbps of the peak data rate.

However, the most significant characteristic of 1xEV-DO Revision A is greatly enhanced performance of the revers link compared to Release 0, see the performance comparison in **Figure 27**. While Release 0 supports 153.6kbps of the peak data rate, Revision A supports 1.8Mbps. This improvement was due to the introduction and application of new technologies such as higher modulation schemes, Rx civersity, pilot interference cancellation, and packet prioritization.

5.3 1xEV-DO Revision B

The next technology of Revision A that the 3GPP2 is now preparing is Revision B which is expected to completely standardize 1Q of 2006.

Revision B will support interference cancellation for both pilot and traffic signals and introduce 64QAM modulation to provide 3.7, 4.3, and 4.9Mbps of high peak data rates and to improve the efficiency of frequency use. Revision B will also adopt new technologies such as flexible carrier assignment and flexible duplexing to greatly improve the performance of the forward link so that it is expected that the the multimedia service can be provided through mobile Internet.

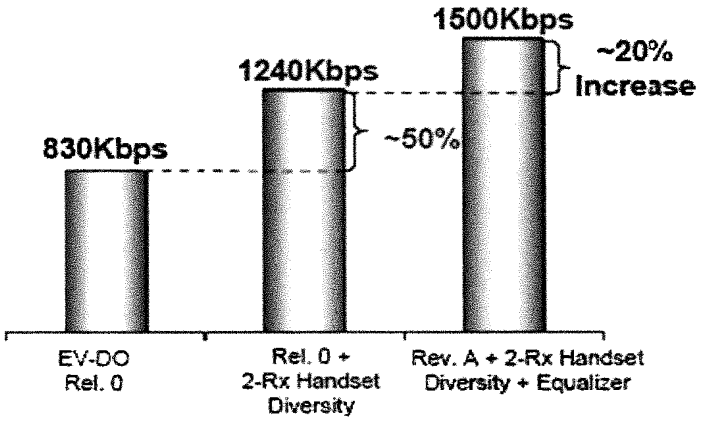


Figure 26. Forward link performance comparison (Aggregate throughput)

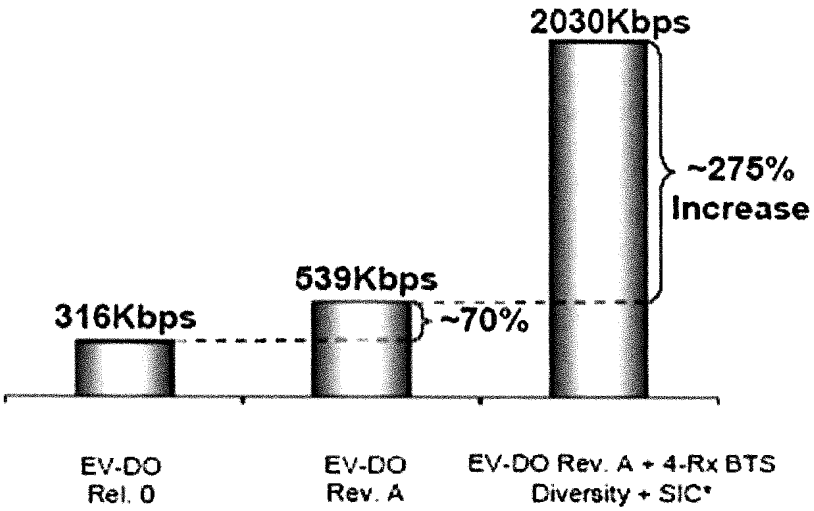


Figure 27. Reverse link performance comparison (Aggregate throughput)

Revision B introduced the scalable bandwidth technology and significantly enhanced the maximum throughput of each user in the forward and reverse link. **Figure 28** shows the comparison of the throughput of Revision A and Revision B.

- Flexible Carrier Assignment

The scalable bandwidth technology adopted by Revision B is to increase the throughput by using multiple carriers at the same time, as shown in **Figure 29**.

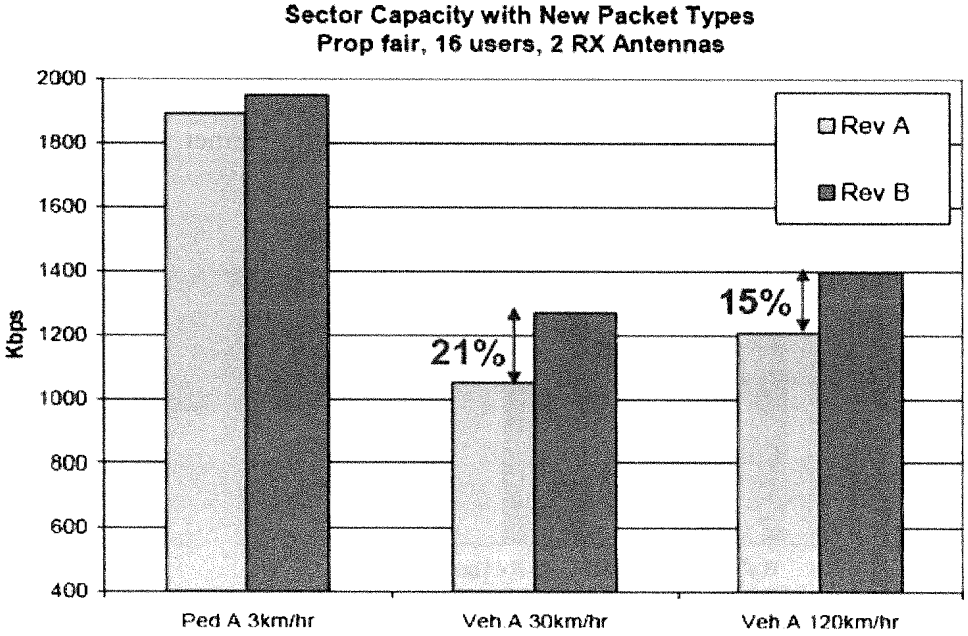


Figure 28. Comparison of throughput of Revision A and Revision B

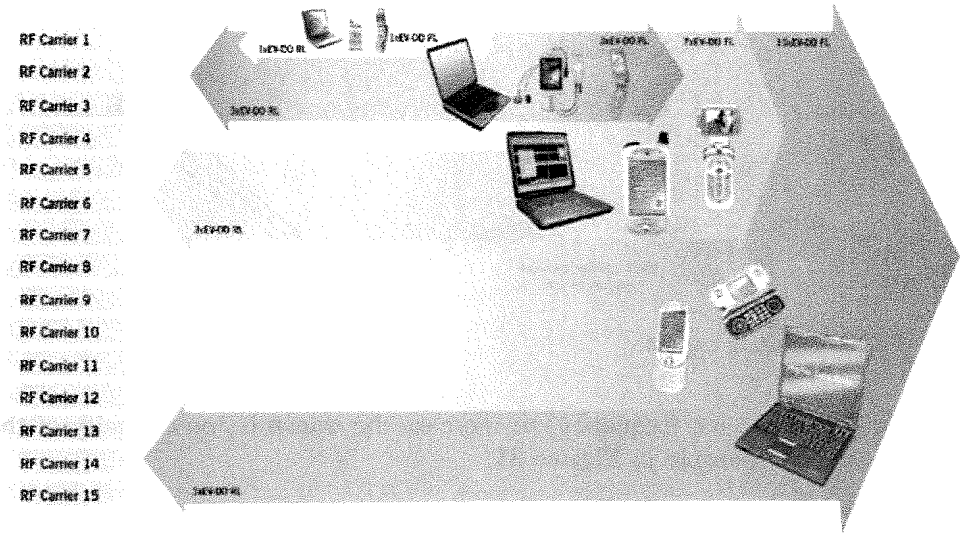


Figure 29. Flexible carrier assignment

Minimum one and maximum 15 carriers can be used at the same time. In case three 1.25MHz carriers are used, 14.7Mbps of the peak data rate will be possible, or in case 15 carriers are used, 73.5Mbps of the data rate will be possible. Therefore, one to three carriers can be used for the mobile terminal, and four or more carriers can be used to transmit 3D game data or high-resolution video data, which means more various types of services can be provided for users.

In the 1xEV-DO Revision B system, the spreading factor of the system is not changed and each 1.25MHz carrier is used as one unit. Therefore, unlike HSDPA (The carrier bandwidth : 5MHz), Wibro (The carrier bandwidth : 9MHz), and other technologies which use the carrier of broad bandwidth, the frequencies do not need to be adjacent so that frequency operation is more flexible, see an example of frequency allocation in **Figure 30**.

- Flexible Duplexing

The flexible duplexing feature has been adopted to Revision B. Flexible duplexing is an advanced form of scalable bandwidth technology. It uses an additional unpaired

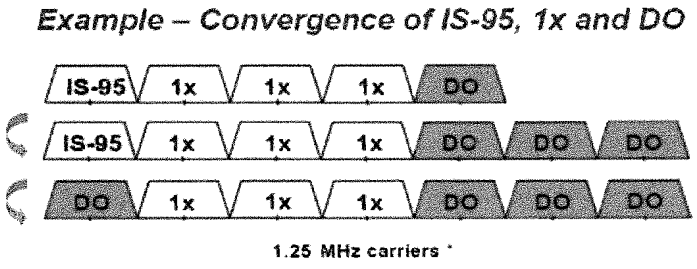


Figure 30. Example of frequency allocation

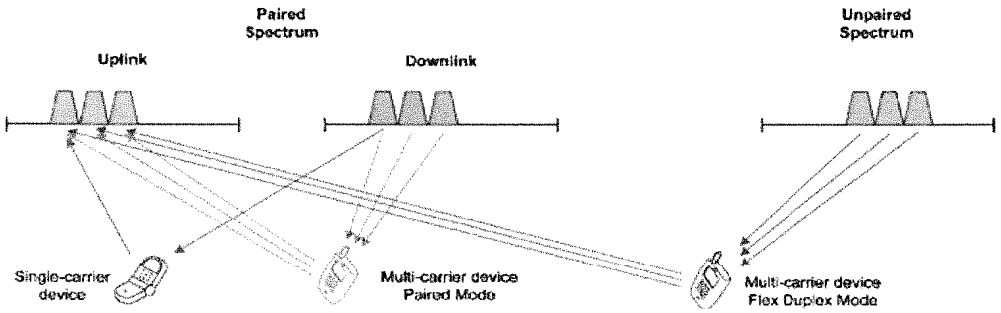


Figure 31. Flexible duplexing example

spectrum (for TDD service frequency) to increase the transmission capacity of the forward link, see an example in **Figure 31**.

- Upgrade From Revision A To B

As Revision A and Revision B are highly compatible, through a simple S/W upgrade, Revision A can evolve into Revision B. However, simple S/W upgrades does not provide all features of Revision B, and some features require H/W upgrades.

5.4 Major Rival Technologies

Revision B is expected to compete with standards that pursue High Data Rate (HDR) service. Major rivals will be HSDPA (or HSUPA) and Mobile WiMAX, and is expected to be commercialized between the end of 2006 and early 2008 like Revision B, see the comparison with major rival technologies in **Table 8**.

5.5 HSDPA (High Speed Downlink Packet Access)

The HSDPA is a fast forward link packet data service that is based on the WCDMA Release 5 standard. It includes a TDD mode that uses 5MHZ of broadband and

Table 8. Comparison with major rival technologies

Charateristics Title	1xEV-DO (Rev B)	WCDMA (R4)	HSDPA (R5)	WiBro
Bandwidth/FA	1.25 MHz	5 MHz	5 MHz	10 MHz
Service Type	Data only	Voice+Data	Voice+Data	Data Only
Peak Data Rate (F.L.)	4.9 Mbps	2 Mbps	14.4 Mbps	18 Mbps
Peak Data Rate (R.L.)	1.8 Mbps	2 Mbps	2.3 Mbps	6 Mbps
Mobility		250 Km/h		~60 Km/h
Throughput (DL, 1 FA/1 Sec)	700 kbps	838 kbps	1.213 Mbps	5.3 Mbps
QoS	Rarely Guaranteed	Guaranteed	Guaranteed	Partially Guaranteed

an FDD mode that supports 1.25MHz of a narrow band. In the TDD mode, the HSDPA supports 14Mbps of the peak data rate for the forward link and 2Mbps for the reverse link. The HSDPA is expected to have advantages over other services in the global roaming, because 85% of the mobile communication service providers adopt WCDMA compatible standards.

5.6 Mobile WiMAX

Mobile WiMAX is a mobile communication service that complies with 802.16e, and is the most similar to Korea's Wireless Broadband Internet (WiBro) that uses a 2.3 GHz band and is scheduled to be serviced early 2006. Unlike Revision B, an FDD-based service, the WiBro is based on the TDD and can change the time ratio between the forward and the reverse link. Therefore, the WiBro is more suitable for data services with large forward link traffic volume. Unlike existing data service technologies that adopted CDMA-based modulation technique, the WiBro adopted the OFDM-based modulation technique to provide more reliable performance in urban areas with high multipath fading and to more easily adopt broadband services.

6. ABBREVIATION

Access Channel. A Reverse CDMA Channel used by mobile stations for communicating to the base station. The Access Channel is used for short signaling message exchanges, such as call originations, responses to pages, and registrations. The Access Channel is a slotted random access channel.

Access Network (AN). The network equipment providing data connectivity between a packet switched data network (typically the Internet) and the access terminals. An access network is equivalent to a base station.

Access Terminal (AT). A device providing data connectivity to a user. An access terminal may be connected to a computing device such as a laptop personal computer or it may be a self-contained data device such as a personal digital assistant. An access terminal is equivalent to a mobile station.

Active Set. The set of pilots associated with the CDMA Channels containing Forward Traffic Channels assigned to a particular mobile station.

AMPS. Advanced Mobile Phone Service.

ARQ. Automatic Repeat Request. Technique for providing reliable delivery of signals between communicating stations which involves autonomous retransmission of the signals and transmission of acknowledgments until implicit or explicit confirmation of delivery is received.

Authentication. A procedure used by a base station to validate a mobile station's identity.

Base Station. A fixed station used for communicating with mobile stations. Depending upon the context, the term base station may refer to a cell, a sector within a cell, an MSC, or other part of the wireless system. See also MSC.

bps. Bits per second.
BPSK. Biphase shift keying.

Broadcast Control Channel. A code channel in a Forward CDMA Channel used for transmission of control information and pages from a base station to a mobile station.

CDMA. Code Division Multiple Access.

CDMA Channel. The set of channels transmitted between the base station and the mobile stations within a given CDMA frequency assignment.

Chip Rate. Equivalent to the spreading rate of the channel. It is either 1.2288 Mcps or 3.6864 Mcps.

Convolutional Code. A type of error-correcting code. A code symbol can be considered as the convolution of the input data sequence with the impulse response of a generator function.

CRC. Cyclic Redundancy Code. A class of linear error detecting codes which generate parity check bits by finding the remainder of a polynomial division.

Ec/I0. The ratio in dB between the pilot energy accumulated over one PN chip period (Ec) to the total power spectral density (I0) in the received bandwidth.

FDMA. Frequency Division Multiplexing Access

Forward CDMA Channel. A CDMA Channel from a base station to mobile stations. The Forward CDMA Channel contains one or more code channels that are transmitted on a CDMA frequency assignment using a particular pilot PN offset.

Forward Fundamental Channel. A portion of a Forward Traffic Channel which carries a combination of higher-level data and power control information.

Forward Common Control Channel. A control channel used for the transmission of digital control information from a base station to one or more mobile stations.

Forward Dedicated Control Channel. A portion of a Radio Configuration 3 through 9 Forward Traffic Channel used for the transmission of higher-level data, control information, and power control information from a base station to a mobile station.

Forward Power Control Subchannel. A subchannel on the Forward Fundamental Channel or Forward Dedicated Control Channel used by the base station to control the power of a mobile station when operating on the Reverse Traffic Channel.

Forward Supplemental Channel. A portion of a Radio Configuration 3 through 9 Forward . Traffic Channel which operates in conjunction with a Forward Fundamental Channel or a Forward Dedicated Control Channel in that Forward Traffic Channel to provide higher data rate services, and on which higher-level data is transmitted.

IS-95. Industry Standard – 95, or EIA/TIA-95

Long Code. A PN sequence with period 242 – 1 that is used for scrambling on the Forward CDMA Channel and spreading on the Reverse CDMA Channel. The long code uniquely identifies a mobile station on both the Reverse Traffic Channel and the Forward Traffic Channel. The long code provides limited privacy. The long code also separates multiple Access Channels and Enhanced Access Channels on the same CDMA Channel. See also Public Long Code and Private Long Code.

Mobile Station. A station in the Public Cellular Radio Telecommunications Service intended to be used while in motion or during halts at unspecified points. Mobile stations include portable units (e.g., hand-held personal units) and units installed in vehicles.

Multiplex Option . Used to specify the multiplex sublayer operation for a physical channel. Each Multiplex Option specifies the available data rates for the physical channel (FCH, DCCH or max SCH rate).

Orthogonal Transmit Diversity (OTD). A forward link transmission method which distributes forward link channel symbols among multiple antennas and spreads the symbols with a unique Walsh or quasi-orthogonal function associated with each antenna.

Paging Channel. A code channel in a Forward CDMA Channel used for transmission of control information and pages from a base station to a mobile station.

Protocol Data Unit (PDU). Encapsulated data communicated between peer layers on the mobile station and the base station.

Registration. The process by which a mobile station identifies its location and parameters to a base station.

Request. A layer 3 message generated by either the mobile station or the base station to retrieve information, ask for service, or command an action.

Response. A layer 3 message generated as a result of another message, typically a request.

Reverse CDMA Channel. The CDMA Channel from the mobile station to the base station. From the base station's perspective, the Reverse CDMA Channel is the sum of all mobile station transmissions on a CDMA frequency assignment.

Reverse Common Control Channel. A portion of a Reverse CDMA Channel used for the transmission of digital control information from one or more mobile stations to a base station.

Reverse Dedicated Control Channel. A portion of a Radio Configuration 3 through 6. Reverse Traffic Channel used for the transmission of higher-level data and control information from a mobile station to a base station.
Reverse Fundamental Channel. A portion of a Reverse Traffic Channel which carries higher-level data and control information from a mobile station to a base station.

Reverse Pilot Channel. An unmodulated, direct-sequence spread spectrum signal transmitted continuously by a CDMA mobile station. A reverse pilot channel provides a phase reference for coherent demodulation and may provide a means for signal strength measurement.

Reverse Power Control Subchannel. A subchannel on the Reverse Pilot Channel used by the mobile station to control the power of a base station when operating on the Forward Traffic Channel with Radio Configurations 3 through 9.

RLP Radio Link Protocol. Connection-oriented, negative-acknowledgment-based data delivery protocol.

Service Option. A service capability of the system. Service options may be applications such as voice, data, or facsimile.

Soft Handoff. This handoff is characterized by commencing communications with a new base station on the same CDMA Frequency Assignment before terminating communications with an old base station.

TIA. Telecommunications Industry Association.

QoS Quality of Service. Metrics that affect the quality of a data service that is delivered to an end user (e.g., throughput, guaranteed bit rate, delay, etc.).

UATI. Unicast Access Terminal Identifier.

LBA Link Budget Analysis

SCH Supplemental Channel

BRC BTS Resource Control

Mux PDU Multiplex Sublayer Protocol Data Unit

FER Frame Error Rate

PCB Power Control Bit

FA Frequency Assignment

MAC Medium Access Control

RA Reverse Activity

RPC Reverse Power Control

DRC Data Rate Control

RAB Reverse Activity Bit

PER Packet Error Rate

DMSS Dual-Mode Subscriber Software

HAL Hardware Abstraction Layer

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CHAPTER 6

EVOLUTION OF THE WCDMA RADIO ACCESS TECHNOLOGY

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Abstract: This chapter describes the evolution of WCDMA radio access technologies such as HSDPA (High-speed Downlink Packet Access), HSUPA (High-speed Uplink Packet Access), which is an enhanced uplink scheme, and MBMS (Multimedia Broadcast/Multicast Services) (i.e., Release 6 MBMS) Future WCDMA evolution including continuous connectivity and MIMO (Multiple-Input-Multiple-Output) channel transmission in WCDMA is also described.

Keywords: WCDMA, HSDPA, HSUPA (Enhance Uplink), Scheduling, Link Adaptation, Hybrid ARQ, MBMS, MIMO

1. INTRODUCTION

Already in its first release, the 3rd generation WCDMA standard developed by 3GPP allows for mobile-communication systems to provide packet-data services with a performance far exceeding what can be provided with mobile-communication systems based on earlier, 2nd generation standards such as GSM and PDC. However, user requirements and expectations in terms of packet-data services as well as other mobile-communication services are continuously expanding. As a consequence, 3G radio-access technologies such as WCDMA must evolve in order to match these requirements and expectations and stay competitive against other radio-access technologies. This section provides a description of the steps that have been taken on this WCDMA evolution and also provides an overview of the further WCDMA evolution steps that are currently being considered by 3GPP.

The first step of the WCDMA evolution consisted of the introduction of HSDPA or *High-Speed Downlink Packet Access* in 3GPP release 5 finalized during 2002. With HSDPA, the WCDMA support for packet-data services was significantly improved, especially in the downlink network-to-mobile-terminal direction.

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The introduction of HSDPA in 3GPP release 5 was followed by the introduction of *Enhanced Uplink*, also sometimes referred to as HSUPA or *High-Speed Uplink Packet Access,* in 3GPP release 6, finalized early 2005. Enhanced Uplink further improves the WCDMA support for packet-data services, as the name suggests with focus on improvements in the uplink mobile-terminal-to-network direction.

In parallel to the improved support for packet-data services provided by the introduction of the Enhanced Uplink feature, 3GPP release 6 also introduced improved support for broadcast/multicast services in the WCDMA standard by the introduction of the MBMS or *Multimedia Broadcast/Multicast Service* functionality.

Together these evolutionary steps have significantly enhanced WCDMA in terms of system performance and service provision. However, in order to continue to stay competitive also in the future the WCDMA radio-access technology must and will continue to evolve. As an example, at the time of writing 3GPP is finalizing the introduction of features for improved *Continuous Packet Connectivity* into the WCDMA standard. In parallel, 3GPP is also working on an introduction of MIMO or *Multiple Input Multiple Output* antenna processing for HSDPA.

In parallel to this step-by-step evolution of the WCDMA radio-access technology, there is also work ongoing within 3GPP on a more extensive long-term evolution of the 3GPP radio access technologies referred to as the *3GPP Long-Term Evolution* or *3GPP LTE.*

2. HSDPA – HIGH-SPEED DOWNLINK PACKET ACCESS

HSDPA or *High Speed Downlink Packet Access* was introduced in 3GPP release 5 with an aim to significantly improve the WCDMA support for packet-data services, more specifically targeting

- significantly improved downlink system capacity for packet-data services,
- possibility for significantly reduced delay/latency within the radio-access network, and
- possibility for significantly higher downlink data rates

To achieve these targets, HSDPA introduced the following performance-enhancing techniques into the WCDMA standard

- *Shared-channel transmission*, i.e. the possibility to dynamically share the downlink code resource between different users
- Possibility for *higher-order modulation* as a tool to provide higher data rates but also higher system efficiency
- Support for *fast channel-dependent scheduling* and *fast rate control* as tools to adapt to and utilize fast variations in the instantaneous channel conditions
- *Fast (hybrid) ARQ* with *soft combining* at the receiver side as a tool to reduce latency and improve system efficiency

HSDPA also introduced a shorter downlink *Transmission Time Interval* or TTI in order to allow for reduced radio-interface round trip time as well as to enable adaptation to fast variations in the channel conditions and fast ARQ.

2.1 Shared-channel Transmission

For downlink packet-data transfer in a mobile-communication system, *shared-channel transmission* is preferably used. Downlink shared-channel transmission implies that a certain amount of the downlink radio resources (channelization codes and transmit power in case of WCDMA) is seen as a common resource that is *dynamically* shared between users. Shared-channel transmission has two main benefits, both related to the efficient utilization of the available radio resources:

- As seen on a per-user basis, packet-data traffic typically has very bursty characteristics. Allocating a set of resources semi-statically for downlink transmission to a certain packet-data user may thus lead to in-efficient resource utilization. In contrast, dynamic resource allocation allows for radio resources to be instantaneously allocated/re-allocated for transmission to packet-data users on a per-need basis. This will allow for significantly improved resource utilization and a corresponding improved system efficiency.
- Dynamic resource allocation does not only imply that resources can be allocated to a user that momentarily needs them but also to a user that can, due to specific instantaneous downlink channel conditions, use the allocated resources most efficiently. The possibility for dynamic resource allocation by means of shared-channel transmission thus allows for so-called *channel-dependent scheduling*, see further Section 1.4.

It should be pointed out that dynamic power allocation by means of fast (closed-loop) power control was supported already in the first releases of the 3WCDMA standard. The key feature introduced into WCDMA as part of the introduction of HSDPA is the support also for dynamic sharing of the *channelization-code* resource.

To support shared-channel transmission, HSDPA introduced a new transport channel, the HS-DSCH or *High-Speed Downlink Shared Channel*, to which packet-data traffic can be mapped.

(1) HS-DSCH code- and time-domain structure

The code resource used for HS-DSCH transmission consists of a set of channelization codes at spreading factor 16, see **Figure 1**. Note that the first (left most) channelization code at spreading factor 16 can not be allocated for HS-DSCH transmission as the corresponding node within the code tree e.g. includes the pre-allocated primary common pilot channel CPICH as well as the channel carrying the system broadcast information. Thus, a maximum of 15 channelization codes can be allocated for HS-DSCH transmission. If a substantial part of the overall code space is needed for other downlink channels, e.g. for services that are not to be carried on HS-DSCH, the number of channelization codes that can be used for HS-DSCH transmission is reduced. As an example, **Figure 1** assumes that twelve channelization codes are allocated for HS-DSCH transmission.

The HS-DSCH code resource can be dynamically allocated on a 2 ms TTI or *Transmission-Time-Interval* basis. The use of a 2 ms TTI for HS-DSCH transmission, which is significantly shorter than the 10 ms minimum TTI of earlier WCDMA releases, allows for a significantly reduced radio-interface delay. A short TTI is also important in terms of supporting tight adaptation to fast variations

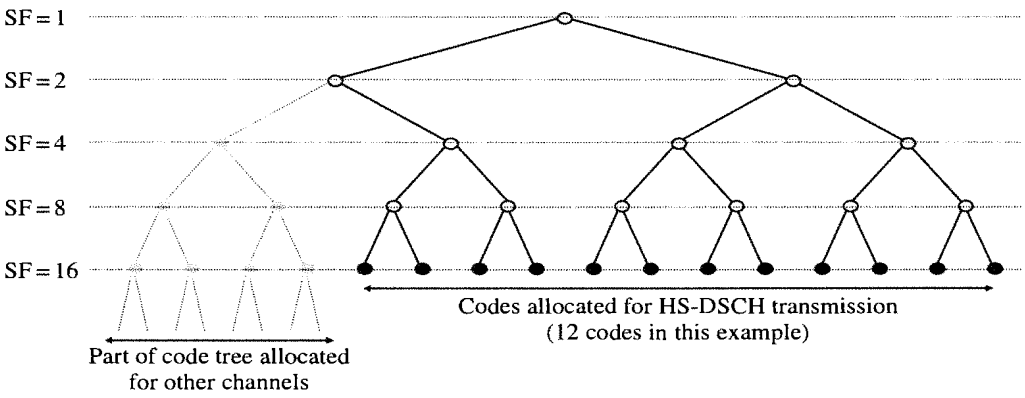


Figure 1. HS-DSCH code-domain structure assuming 12 channelization codes allocated for HS-DSCH transmission

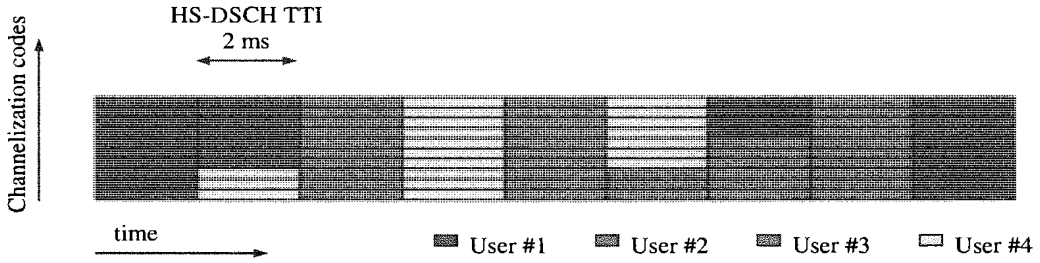


Figure 2. HS-DSCH time-domain structure, assuming 12 channelization codes allocated for HS-DSCH transmission

in the instantaneous channel conditions, i.e. channel-dependent rate control and scheduling, as described in Sections 1.3 and 1.4, as well as being an enabler for fast retransmissions, see Section 1.5.

As illustrated in **Figure 2** the full set of HS-DSCH channelization codes can be dynamically allocated for downlink transmission to a single user, see for example the first TTI of **Figure 2**. This obviously allows for an instantaneously very large resource allocation and the possibility for a corresponding very high instantaneous transmission data rate to a single user. Allocation of the entire HS-DSCH code resource for transmission to a single user at a time is often referred to as *Time Division Multiplexing* (TDM).

Alternatively, different sub-sets of the HS-DSCH channelization codes can be allocated to different users, see e.g. the second TTI of **Figure 2** Using different sub-sets of the HS-DSCH code resource for parallel transmission to different users is often referred to as *Code Division Multiplexing* (CDM). Although from a channel-dependent-scheduling point-of-view, see Section 1.4, TDM operation is fundamentally more efficient, there are several reasons why also CDM-based allocation of the HS-DSCH code resource is supported for HSDPA:

- Low-end mobile terminals may not be capable of receiving and demodulating the full set of HS-DSCH channelization codes (up to 15 codes of spreading factor 16 according to above) or support decoding of the corresponding potentially very high instantaneous data rates. As an example, there may be HSDPA-capable terminals that only support reception of a maximum of five HS-DSCH channelization codes. For efficient channelization-code usage, the possibility for sharing of the HS-DSCH code resource also in the code domain (CDM) is then required.
- Even if all mobile terminals are able to receive the full set of HS-DSCH channelization codes, the per-user payload available at the base station for transmission to a specific user may not be sufficient to efficiently fill up the full HS-DSCH code resource. Thus, once again, for efficient channelization-code usage, the possibility for CDM is required.

(2) HS-DSCH power-domain structure

In addition to being allocated a certain part of the overall channelization-code resource, HS-DSCH transmission should also be allocated a part of the total cell power. There are two main alternatives for the HS-DSCH power allocation, see also **Figure 3**.

- *Semi-static power allocation*, i.e. a fixed part of the overall cell power is allocated for HS-DSCH transmission. The remaining power is shared between other channels such as common-control channels with constant power and power-controlled dedicated channels.
- *Dynamic power allocation*, i.e. for each TTI HS-DSCH transmission can use the remaining power after power has been dynamically allocated to common-control channels and power-controlled dedicated channels. Consequently, with dynamic power allocation, a temporarily reduced need for power for the power-controlled

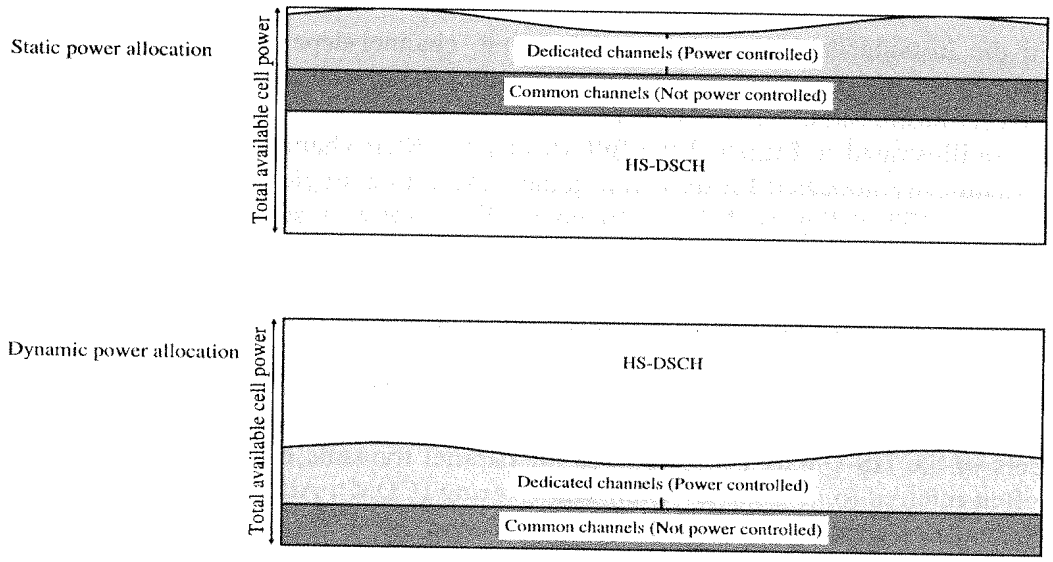


Figure 3. HS-DSCH power allocation, semi-static vs. dynamic

dedicated channels may immediately be used to provide increased HS-DSCH capacity. Thus dynamic power allocation is more efficient and should be employed in order to achieve maximum utilization of the overall cell transmit power.

The amount of power that can typically be used for HS-DSCH transmission depends on how much power is needed for other channels. In practice it can be expected that, as a maximum, in the order of 70–80% of the total cell power can be used for HS-DSCH transmission, leaving sufficient power for necessary (common and/or dedicated) control channels. If there are additional downlink channels, e.g. for circuit-switched speech, the power available for HS-DSCH transmission will obviously be lower.

2.2 Support for Higher-order Modulation

The first releases of the 3G standards, including WCDMA, only supported QPSK modulation for downlink transmission, thus allowing for two bits of information to be transmitted per modulation symbol. In order to support higher data rates within a given bandwidth, HSDPA introduced additional support for downlink 16QAM modulation, allowing for up to four bits per modulation symbol, i.e. twice the spectral efficiency of QPSK.

Together with the support for shared-channel transmission, the support for 16QAM modulation allows for significantly higher downlink data rates to a single user, compared to earlier 3GPP releases as well as other mobile-communication technologies. Assuming the largest possible HS-DSCH channelization-code allocation (15 codes), HSDPA allows for peak data rates up to 14 Mbps in the current releases. This is expected to increase further, in a first step to around 28 Mbps, by the introduction of e.g. *multi-layer transmission* for HSDPA, see Section 4.2.

It is important to understand that the introduction of 16QAM does not only allow for higher downlink peak data rates. In a cellular system only supporting QPSK modulation, a mobile terminal may, in some cases, experience such good downlink channel conditions (high signal-to-noise and signal-to-interference ratios) that the achievable data rate is bandwidth limited rather than noise/interference limited. In such cases, the possibility to use more spectrally efficient 16QAM modulation will allow for more efficient utilization of the good channel conditions with an overall increase in system capacity as a consequence.

Furthermore, certain data rates, although possible to support with QPSK modulation, may be more *efficiently* supported with higher order modulation (16QAM). This will e.g. be the case for data rates for which the use of QPSK modulation would allow for very limited channel coding. In such cases, the use of 16QAM will allow for additional channel coding, the coding gain of which may lead to an overall improved link efficiency.

2.3 Fast Link Adaptation / Rate Control

In a cellular system, the radio-channel conditions experienced by different network-to-user-terminal links will typically vary significantly, both in time and between

different positions within the cell. In general there are several reasons for these variations and differences in the instantaneous channel conditions:

- The channel conditions will differ significantly between different mobile-terminal positions due to distance-dependent path loss and shadowing.
- The instantaneous channel conditions will vary rapidly due to multi-path fading. The rate of these variations depends on the speed of the mobile terminal. However, typically there will be significant variations during a fraction of a second.
- The channel conditions will vary due to variations in the interference level. The interference level will depend on the position of the user terminal within the cell with typically higher interference level close to the cell border. The interference level will also depend on the instantaneous transmission activity of neighbor cells.

Downlink power control can be used to compensate for differences and variations in the instantaneous downlink channel conditions. In principle, downlink power control allocates a proportionally larger part of the total available cell power to communication links with instantaneously bad channel conditions. This can be seen as one example of so-called *link adaptation*, i.e. the adjustement of transmission parameters, in this case the transmission power, to compensate for differences and variations in the instantaneous channel conditions.

In general, the goal of link adaptation is to ensure sufficient received energy per information bit for all communication links, despite variations and differences in the channel conditions. Power control achieves this by adjusting the transmission power while keeping the data rate of each communication link constant. Keeping the data rate constant, regardless of the instantaneous channel conditions, is obviously often desirable and may even be required for some services. However, for services that do not require a specific data rate, such as many packet-data services, the energy per information bit can also be controlled by adjusting the data rate while keeping the transmission power constant. This kind of link adaptation can be referred to as *rate control* or *rate adjustment*. Especially in combination with shared-channel transmission and channel-dependent scheduling, see Section 1.4, rate control is a more efficient approach to link adaptation, compared to power control.

In case of HS-DSCH transmission, the instantaneous data rate can be controlled by selecting between different modulation schemes (QPSK vs. 16QAM) as well as selecting different channel-coding rates. Together this is referred to as dynamic selection of the HS-DSCH *transport format*. Selecting higher-order modulation (16QAM) and/or a higher channel-coding rate, allows for higher data rates over the radio interface. However, this is only applicable in case of instantaneously good channel conditions. In case of not-so-good channel conditions more robust QPSK modulation together with a lower channel-coding rate should be used.

Obviously, the downlink channel conditions are never known exactly at the base-station. Instead, some estimates of the instantaneous channel conditions must be used for the rate control. In case of HSDPA, the mobile terminal is continuously estimating the instantaneous downlink channel conditions based on measurements on the common pilot channel. Based on the estimated channel conditions the mobile terminal then estimates a suitable HS-DSCH transport format (modulation scheme and coding rate)

and reports this to the network in form of a *Channel Quality Indicator* CQI. The CQI reporting can be done as often as once every TTI, i.e. once every 2 ms, allowing for tracking also of fast variations in the instantaneous channel conditions.

The base station can then use the reported CQI for deciding on the actual transport format to use for HS-DSCH transmission to this specific mobile terminal. It should be pointed out though that the base station does not *need* to follow the reported CQI. Rather, the reported CQI should be seen as a *recommended* transport format or data rate.

It should also be pointed out that, despite the term *Channel Quality* Indicator, the CQI reported by the mobile terminal is not an objective measure of the channel quality such as the received signal-to-noise/interference ratio. Instead the reported CQI is, as already mentioned, expressed as a transport format, more specifically the transport format that the mobile terminal estimates would be a suitable transport format for the network to use, given the estimated channel conditions. The reason for reporting a (recommended) transport format instead of the actual estimated channel quality is that different mobile terminals may implement more or less advanced receiver structures, including multiple receive antennas and different types of equalization. Thus for the same channel quality, different mobile terminals may be able to receive HS-DSCH with different data rates (different transport formats). By specifying the CQI reporting as a supportable transport format rather than a mobile-terminal-independent channel-quality measure, a user may benefit from mobile terminal with a more advanced receiver by being served with higher data rates.

2.4 Channel-dependent Scheduling

As described above, link adaptation by means of rate control, i.e. the adjustment of the data rate to match the instantaneous channel conditions, can be used together with shared-channel transmission to improve overall system performance, assuming that variations and differences in the instantaneous data rate are acceptable. Another important question is how to select the mobile terminal(s) to which to transmit data on the shared channel in a given time interval. This is also referred to as the *scheduling strategy*.

In case of so-called *Round-Robin* (RR) scheduling, radio resources are basically allocated to communication links on a sequential basis and especially without any considerations to the downlink channel conditions experienced by different mobile terminals. However, further improvements in system performance can be achieved by taking the instantaneous channel conditions into account not only for link adaptation but also in the scheduling process. This is also referred to as *channel-dependent scheduling*.

To achieve maximum system throughput, data should as much as possible be scheduled on communication links with the best instantaneous channel conditions, also known as *max-C/I scheduling*. Combined with link adaptation based on rate control, max-C/I scheduling allows for the highest possible data rate at each scheduling instant and thus maximizes the overall cell throughput. However, this

is achieved at the expense of potentially large differences in the throughput experienced by different users, i.e. large differences in service quality between users. In the extreme case, no downlink data what-so-ever may be scheduled to users with bad channel conditions, e.g. users at the cell border.

As Round-Robin scheduling does not take the instantaneous channel conditions into account in the scheduling process it will lead to lower overall system performance but more equal service quality between different communication links, compared to max-C/I scheduling. Round-Robin scheduling can be seen as *fair scheduling* in the sense that the same amount of radio resources (the same amount of time) is given to each communication link. However, Round-Robin scheduling is not fair in the sense that it provides the same service quality to all communication links. In that case more radio resources (more time) must be given to communication links with bad channel conditions.

When discussing and comparing different scheduling algorithms it is important to distinguish between different types of variations in the service quality:

- Fast variations in the service quality corresponding to e.g. fast multi-path fading and fast variations in the interference level. For many packet-data applications, relatively large short-term variations in service quality are often acceptable or not even noticeable to the user.
- More long-term differences in the service quality between different communication links corresponding to e.g. differences in the distance to the cell site and shadow fading. In many cases there is a need to limit such long-term differences in service quality.

A practical scheduler should thus operate somewhere in-between the max C/I scheduler and the RR scheduler, i.e. try to utilize fast variations in channel conditions as much as possible while still satisfying some degree of fairness between users.

The *Proportional Fair* scheduling algorithm is an example of a scheduling algorithm that has been designed with an aim to achieve this. In a given scheduling instant, a proportional-fair scheduler schedules data on a communication link for which the data rate is highest relative to the average data rate of that communication link, with averaging based on some time constant T_{PF}.

To ensure efficient usage of the short-term channel variations and, at the same time, limit the long-term differences in service quality to an acceptable level, the time constant T_{PF} should be set longer than the time constant for the short-term variations. At the same time T_{PF} should be sufficiently short so that quality variations within the interval T_{PF} are not strongly noticed by a user. Typically, T_{PF} can be set to be in the order of one second.

It should be noted that there is little difference between different scheduling algorithms at low system load, i.e. when only one or, in some cases, a few users have data waiting for transmission at the base station at each scheduling instant. The differences between different scheduling algorithms are primarily visible at high load.

It should also be noted that the scheduling algorithm is a base-station-implementation issue and nothing that is typically specified in any standard. What

is needed in a standard to support channel-dependent scheduling is channel-quality measurements/reports and the signaling needed for dynamic resource allocation. For HSDPA, the same CQI measurements/reports as is used for the fast rate control can be used to also support fast channel-dependent scheduling at the base station.

2.5 Fast Hybrid ARQ with Soft Combining

Strictly speaking, the term *Hybrid ARQ* simply implies that a communication link relies on a combination (hybrid) of forward-error correction ("channel coding") and error-detection/retransmissions. The key properties of the Hybrid ARQ scheme adopted for HSDPA are instead the following:

- It allows for very fast error detection and sub-sequent retransmissions, with a retransmission round-trip time as low as 12 ms, thus the term *fast* Hybrid ARQ. This implies that the HSDPA retransmission protocol can operate with a significantly higher error rate and retransmission probability, without the radio link suffering from very large overall delays. Operating on a higher retransmission probability in general implies improved system efficiency.
- It allows for soft combining of different retransmissions at the receiver side, thus the term Hybrid ARQ *with soft combining*, see below. This also leads to a significant improvement in the efficiency of the retransmission protocol.

In order to minimize the signaling associated with a retransmission protocol, something which is especially important if fast retransmissions and a low round-trip time is to be achieved, a *Stop-and-Wait* ARQ protocol is often preferred. However, a Stop-and-Wait ARQ protocol suffers from bad link efficiency due to the constraint that no new transmissions can be carried out until an acknowledgement of a previous transmission has been received. Thus, in order to have a simple ARQ protocol with a minimum amount of signaling and still allow for full link efficiency, a so-*called N-channel stop-and-wait* ARQ protocol was adopted for HS-DSCH transmission. As outlined in **Figure 4**, an N-channel stop-and-wait protocol consists of N staggered stop-and-wait protocols. By selecting N equal to or larger than the ARQ protocol round-trip time, the radio link can be fully utilized by transmissions to a single mobile terminal.

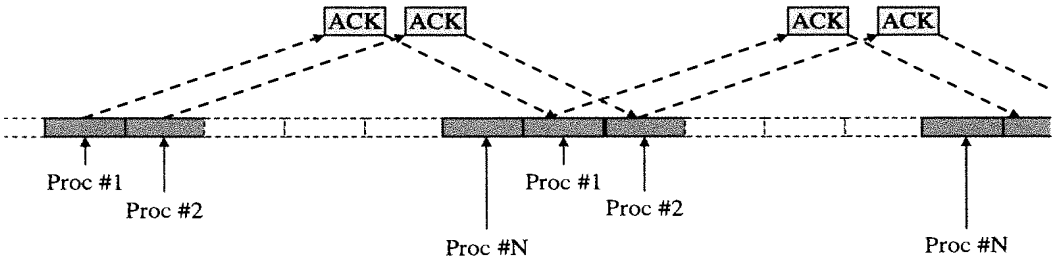


Figure 4. N-channel stop-and wait ARQ protocol

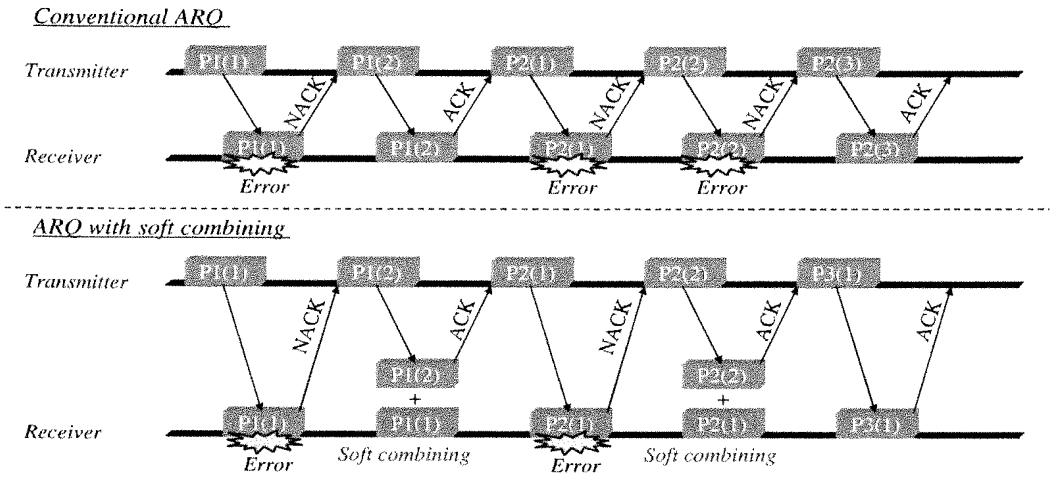


Figure 5. Conventional ARQ vs. ARQ with soft combining at the receiver side

The basic principle of Hybrid ARQ with soft combining is illustrated in **Figure 5**. With a conventional ARQ scheme, received data blocks that can not be correctly decoded are discarded by the receiver and received retransmitted data blocks are separately decoded. In contrast, in case of Hybrid ARQ with soft combining, received data blocks that can not be correctly decoded are not discarded. Instead the corresponding received signal is buffered and soft combined with later received retransmissions. Decoding is then applied to the combined signal.

The use of Hybrid ARQ with soft combining increases the total received energy per information bit and thus the effective received E_b/I_0 for each retransmission. As an example, assuming that the original transmission and a retransmission are received with an E_b/I_0 equal to γ_1 and γ_2 respectively, the effective or accumulated E_b/I_0 after the retransmission will be $\gamma_{tot} = \gamma_1 + \gamma_2$, compared to an E_b/I_0 equal to γ_2 in case of conventional ARQ (without soft combining). Clearly, with soft combining, the probability for correct decoding after the retransmission and subsequent soft combining will be improved, compared to conventional ARQ.

There are many different schemes for Hybrid ARQ with soft combining. However, there are two main approaches, frequently referred to as *Chase combining* and *Incremental Redundancy*, respectively. These two approaches differ in the structure of the retransmissions and in the way by which the soft combining is carried out at the receiver side.

In case of Chase combining each retransmission is an identical copy of the original transmission, i.e. each retransmission consists of exactly the same set of coded bits as the original transmission. As a consequence, soft combining can be done on the received signals before demodulation.

As each retransmission is an identical copy of the original transmission, the retransmissions with Chase combining can be seen as additional repetition coding. As an example, assume that the original transmission is coded with a rate-3/4 code.

The effective code rate after one retransmission is then 3/8. This can be seen as the original rate-3/4 code concatenated with rate-1/2 repetition coding. After two retransmissions, the effective code rate is 1/4, consisting of the original rate-3/4 code concatenated with rate-1/3 repetition coding. As the additional coding provided by the retransmissions is equivalent to repetition coding, Chase combining does not give any additional coding gain 'but only increases the accumulated received E_b/I_0 for each retransmission.

In contrast to Chase combining, with Incremental Redundancy each retransmission may be different compared to the original transmission, i.e. consist of a different set of coded bits. Typically, Incremental Redundancy is based on a low-rate code. In the first transmission only a sub-set of the coded bits is transmitted, effectively leading to a high-rate code. For the retransmissions, a different sub-set of the coded bits, i.e. additional redundancy, can be transmitted.

In addition to a gain in accumulated received E_b/I_0, Incremental Redundancy may thus lead to a true reduction in the channel-coding rate and thus to an additional coding gain for each retransmission. Thus, at least from a link-level-performance point-of-view, Incremental Redundancy should be superior to Chase combining. This can also be seen from **Figure 6**, which compares the error-rate performance of Chase combining and Incremental Redundancy after different number of retransmissions and for different initial coding rates. As expected, the gain with Incremental Redundancy is larger in case of higher a initial coding rate (right-hand figure). With a high initial coding rate, the initial coding gain is relatively small and the additional redundancy provided by Incremental Redundancy is more important. The gain with IR will also be larger in case of higher-order modulation.

As each retransmission will normally be different compared to the original transmission, i.e. consist of a difference set of coded bits, each IR retransmission must be separately demodulated and buffered at the receiver side. Soft combining is then done implicitly as part of the decoding process.

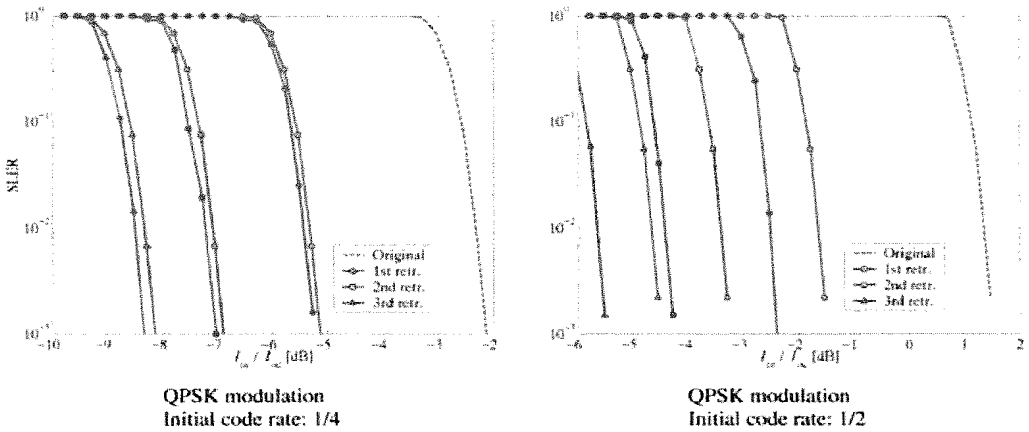


Figure 6. Gains of IR vs. Chase Combining. IR curves to the left in each figure

3. HSUPA – HIGH SPEED UPLINK PACKET ACCESS ("ENHANCED UPLINK")

Enhanced Uplink, also sometimes referred to as HSUPA or *High Speed Uplink Packet Access,* was introduced in 3GPP release 6 (finalized in 2005) to complement HSDPA and further improve the WCDMA packet-data support, with focus on the uplink, mobile-terminal-to-network, direction. Jointly, HSDPA and Enhanced Uplink are often referred to as HSPA or *High Speed Packet Access.*

The aim of Enhanced Uplink is to further improve the WCDMA support for packet-data services, targeting

- significantly improved uplink system capacity
- further reduced delay/latency with focus on the uplink
- possibility for significantly higher uplink data rates

To achieve these targets, Enhanced Uplink introduces improved *base-station-controlled uplink* scheduling allowing for more efficient utilization of the uplink radio resources. Base-station-controlled uplink scheduling also enables the possibility to provide significantly higher instantaneous uplink data rates to a single user, without the risk for system instability. With Enhanced Uplink, peak uplink data rates beyond 5.7 Mbps can be provided in the uplink in case of good channel conditions.

In addition, Enhanced Uplink also introduces support for fast Hybrid ARQ with soft combining also for the uplink. Similar to the downlink, fast Hybrid ARQ with soft combining for the uplink provides both improved system efficiency and possibility for significantly reduced delay. It should be noted that a reduced uplink delay is beneficial also for downlink data transfer due to its positive impact on the overall radio-interface round-trip time. Thus the introduction of Enhanced Uplink also implies a further improvement in the WCDMA downlink packet-data performance.

These techniques are introduced into the WCDMA standard as part of a new transport-channel type, the *Enhanced Dedicated Channel* or E-DCH. In addition to a 10 ms TTI, the E-DCH also supports a TTI of 2 ms, reducing the radio-interface delays, allowing for fast adaptation of the transmission parameters, and enabling fast retransmissions.

Unlike the downlink direction, the WCDMA uplink is inherently non-orthogonal even within the cell. Fast power control is therefore needed for the uplink also in the case of E-DCH transmission, in order to handle the so-called "near-far problem" and to ensure coexistence on the same carrier with terminals and services not relying on the E-DCH for uplink traffic. The E-DCH is transmitted with a power offset relative to the WCDMA power-controlled uplink control channel, the *DPCCH.* By adjusting the maximum allowed E-DCH/DPCCH power offset, the uplink scheduler at the base station can control the E-DCH data rate, see further below.

Enhanced uplink also retains the uplink *macro diversity* (*"soft handover"*) supported in earlier WCDMA releases. In practice, the support for uplink macro diversity implies two things:

(1) Uplink data transmissions can be received by multiple cells, more specifically the cells in the so-called *Active Set* of the mobile terminal

(2) Mobile terminals can be jointly power controlled by multiple cells, more specifically by all the cells in the Active Set

There are two reasons for supporting uplink macro diversity also for E-DCH:

- Receiving transmitted data at multiple cell sites provides a macro-diversity gain which offers the possibility for improved coverage and cell-edge data rates also for E-DCH
- Power control from multiple cells is beneficial in terms of limiting the amount of interference generated in neighbor cells.

One cell within the Active Set of a mobile terminal is defined as the *E-DCH serving cell*. The E-DCH service cell is the cell that has the main responsibility for scheduling of the uplink transmissions from the mobile terminal.

As discussed in Section 1.2, HSDPA introduced the support for higher-order modulation in case of downlink (HS-DSCH) transmission. As described, higher-order modulation for the downlink is useful in situations where the data rates, without the possibility for higher-order modulation, would be bandwidth limited rather than power/SIR limited.

However, on the uplink the situation is somewhat different with regards to higher-order modulation

- Due to the use of mutually non-orthogonal codes for different mobile terminals in WCDMA, there is no need to share channelization codes between mobile terminals on the uplink. Thus, there is less probability for the uplink to be "bandwidth" limited, compared to the downlink.
- Due to power limitations, very high SNR occurs less frequently for the uplink compared to the downlink. This further reduces the probability for the uplink to be bandwidth limited rather than power limited.

For these reasons and in order to reduce the mobile-terminal complexity, higher-order modulation was not introduced as part of the Enhanced Uplink. Once again, note that even without the support for higher-order modulation, uplink data rates beyond 5.7 Mbps can be supported with Enhanced Uplink.

3.1 Fast Base-station-controlled Scheduling

Similar to HS-DSCH, Enhanced Uplink introduces fast base-station-controlled scheduling also for the uplink. However, due to fundamental differences between the downlink and uplink transmission directions, the basic scheduling principles are quite different between the downlink and the uplink.

- For the downlink, the cell transmit power and the set of channelization codes are the shared radio resources. The task of the downlink scheduler at the base station is to ensure as efficient utilization as possible of these resources, e.g. by means of channel-dependent scheduling, while also taking e.g. quality-of-service requirements into account.
- For the uplink, the shared resource is instead the amount of tolerable interference at the cell site. The fundamental task of the uplink scheduler is to control the uplink transmissions from the different mobile terminals so that the overall uplink

interference is as close as possible to the maximum tolerable interference level without exceeding it. In this way, maximum system efficiency can be achieved. To achieve this, the scheduler controls what mobile terminals are allowed to transmit at a given time instant as well as with what rate each terminal is allowed to transmit. By moving the uplink scheduling functionality from the *Radio Network Controller* (RNC) to the base station, faster reaction to interference variations is possible. This allows for operation closer to the interference limit and thus allows for more efficient uplink resource utilization.

Channel-dependent scheduling, which typically is used for HSDPA, is possible also for the uplink. However the benefits with uplink channel-dependent scheduling are different and typically smaller, compared to the downlink. As fast closed-loop power control is used for the uplink, including E-DCH, a mobile terminal experiencing good instantaneous channel conditions will still be received with approximately the same power, and thus be able to transmit with similar data rates, as a terminal with more unfavorable channel conditions. This is in contrast to HSDPA and the downlink direction where, at least in principle, a constant transmission power is used and the data rates are adapted to the channel conditions, resulting in a possibility for higher data rates for users with good channel conditions, compared to users experiencing not-as-good channel conditions.

However, for the uplink, a difference in the channel conditions between two mobile terminals will lead to a difference in the *transmission* power of the two terminals and hence a difference in the amount of interference the two terminals will cause to neighbor cells. Thus, the gain in system performance due to uplink channel-dependent scheduling is more indirect, i.e. a reduction in inter-cell interference, compared to the more direct gains in the downlink HSDPA case.

The E-DCH scheduling framework is based on *scheduling requests* sent by the mobile terminal to the network to request uplink transmission resources and corresponding *scheduling grants* provided by the base-station scheduler to control the mobile-terminal transmission activity.

The scheduling requests sent by the mobile terminals contain information about the amount of available transmit power at the mobile terminal and the amount of data, including the traffic priority of that data, available for transmission.

The scheduling grants control the maximum allowed E-DCH transmit power or, more exactly, the maximum allowed E-DCH-to-DPCCH power ratio. More specifically, each mobile terminal maintains a *serving grant* which directly determines the maximum E-DCH/DPCCH power ratio, with a larger grant implying that the terminal can use a higher relative E-DCH power. Due to the use of fast closed-loop power control which, in principle, ensures a constant received DPCCH power at the base station, a larger serving grant indirectly implies a higher received E-DCH power allowing for a higher E-DCH data rate. At the same time, a higher relative E-DCH power implies that the terminal will cause more interference and thus use a larger part of the overall uplink radio resource.

The reasons for expressing the limitation imposed by the serving grant as a power ratio and not as a data rate or transport format are twofold:

- The fundamental quantity the scheduler is controlling is the interference caused to the system. This interference is directly proportional to the transmission power.
- It allows the E-TFC selection algorithm to autonomously select transport formats targeting different number of transmission attempts (and consequently different data rates and delays) for different MAC-d flows as long as the total E-DCH transmission power is within the limits set by the grant. This is further discussed in Section 2.2.

The serving grant can be updated by the network in two different ways

- By means of *Absolute Grants*, setting an absolute value for the serving grant at the mobile terminal.
- By means of *Relative Grants*, providing a relative, step-wise update of the serving grant of the mobile terminal

Absolute grants can be received by a mobile terminal only from the E-DCH serving cell and can either be set on a per-mobile-terminal basis ("*Dedicated scheduling*") or jointly for a group of mobile terminals ("*Common scheduling*"). Common scheduling is especially useful at low uplink loads as it allows for relatively large serving grants to be provided to multiple mobile terminals. When a mobile terminal has data to transmit it may then immediately transmit with a high data rate, without first going through a request phase.

Dedicated scheduling provides tighter control of the uplink load and is more suitable at high system loads. In case of dedicated scheduling, the base-station scheduler determines what user(s) are allowed to transmit and set the serving grant(s) specifically for the intended user(s). In this case, only one or a few users at a time are allowed to transmit any substantial amount of uplink data.

Relative grants can be sent from both the serving cell and non-serving cells. However, although the term 'relative grant' is used in both cases, there is a significant difference between relative grants received from the serving cell and from non-serving cells.

Relative grants received from the serving cell are targeting a specific mobile terminal and can take one out of three possible values: 'UP', 'HOLD', or 'DOWN'. An 'up' ('down') command instructs the mobile terminal to increase (decrease) the serving grant, i.e., to increase (decrease) the allowed E-DPDCH/DPCCH power ratio compared to the last used power ratio. The 'hold' instructs the mobile terminal not to change the upper limit. A schematic illustration of the operation due to relative grants received from the serving cell is given in **Figure 7**.

To implement the increase (decrease) of the serving grant, the mobile terminal maintains a table of possible E-DCH/DPCCH power ratios as illustrated in **Figure 8**. The up/down commands corresponds to an increase/decrease of the power ratio in the table by one step compared to the power ratio used in the previous TTI in the same hybrid ARQ process. There is also a possibility to have a larger increase (but not decrease) for small values of the serving grant. This is achieved by configuring two thresholds in the E-DCH/DPCCH power ratio table, below which the mobile terminal may increase the serving grant by three and two steps, respectively, instead of only a single step. The use of the table and the two indices allow the network to

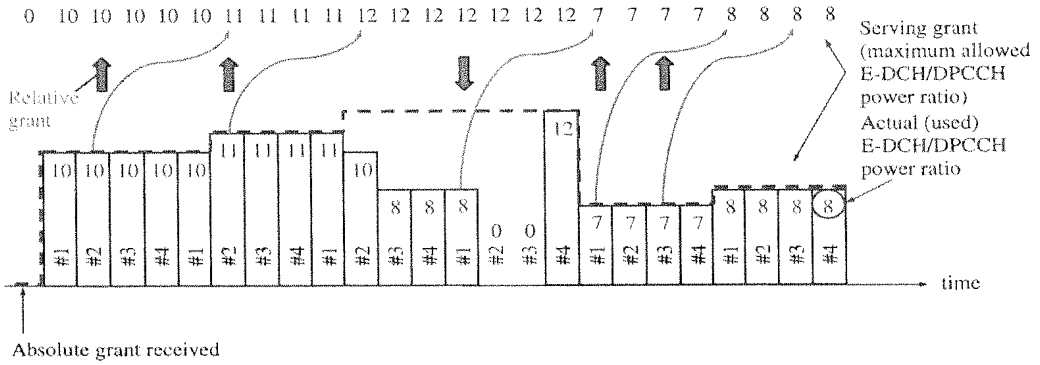


Figure 7. Schematic illustration of relative grant usage

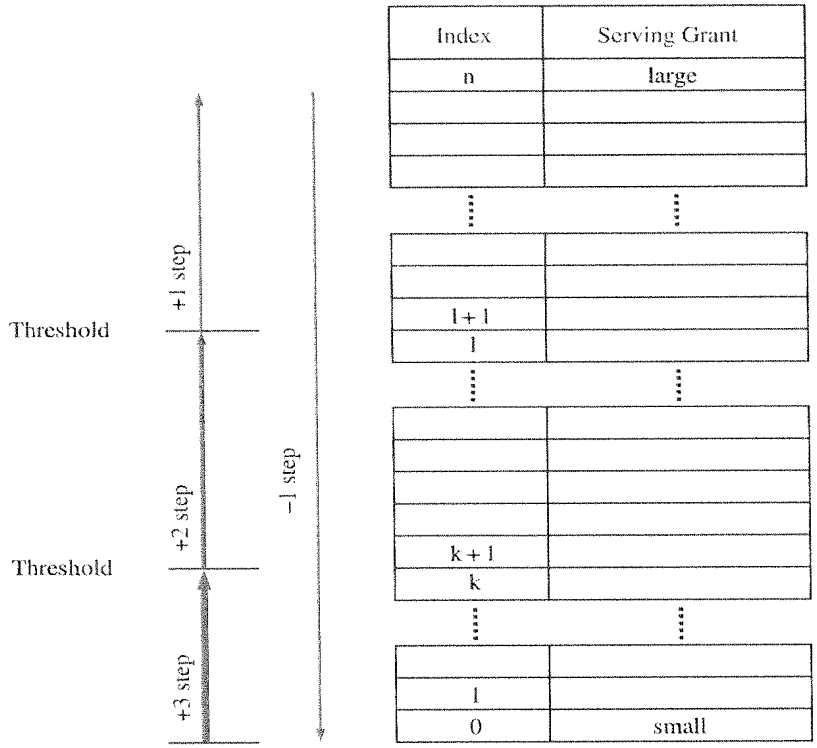


Figure 8. Example of grant table

increase the serving grant efficiently without extensive repetition of relative grants for small data rates (small serving grants) and at the same time avoiding large changes in the power offset for large serving grants.

Relative grants from non-serving cells provide the possibility for the non-serving cells in the Active Set to control the *inter-cell interference*, in contrast to the

grants from the serving cell which provide the possibility to control the *intra-cell interference*. From the non-serving cells, the relative grant is in essence an "overload indicator", used to limit the amount of inter-cell interference. The overload indicator can take two values: 'dtx' and 'down', where the former does not affect the mobile terminal operation. If the mobile terminal receives 'down' from any of the non-serving cells in the Active Set, the serving grant is decreased relative to the previous TTI in the same hybrid ARQ process.

In soft handover, the serving cell thus has the *main* responsibility for the scheduling operation but the non-serving cells can request all its non-served users to lower their E-DCH data rate by transmitting an overload indicator in the downlink. This mechanism ensures a stable network operation.

Fast scheduling allows for a more relaxed connection admission strategy. A larger number of bursty high-rate packet-data users can be admitted to the system as the scheduling mechanism can handle the situation when multiple users need to transmit in parallel. Without fast scheduling, the admission control would have to be more conservative and reserve a margin in the system in case of multiple users transmitting simultaneously.

3.2 Hybrid ARQ for E-DCH

The E-DCH hybrid ARQ scheme is similar to that supported for HS-DSCH on the downlink, see Section 1.5. For each transport block received in the uplink, a single bit is transmitted from the base station to the mobile terminal after a well-defined time duration from the reception to indicate successful decoding (ACK) or to request a retransmission of the erroneously received transport block (NACK). In a soft handover situation, if an ACK is received from at least one of the base stations in the Active Set, the mobile terminal considers the data to be successfully received by the network.

Hybrid ARQ with soft combining can be exploited not only to provide robustness against unpredictable interference and reduce delay, but also to improve the link efficiency in order to, in the end, improve capacity and/or coverage. As a straightforward example, consider a target data rate of x Mbps. This can obviously be achieved with a link data rate in the order of x Mbps with the power control set to target a low error probability in the first transmission attempt. However, as an alternatively, the same effective data rate can be achieved with a link data rate in the order of n times x Mbps at an unchanged transmission power. Clearly, the error rate at the first retransmission will be much higher in this case. However, if the hybrid ARQ scheme can ensure that the information is recovered at the receiver side after, on average, less than n retransmission, there is an overall gain is system efficiency, i.e. the same effective data rate have been achieved using overall less radio resources. Obviously, the same principle can be applied also for HS-DSCH in the downlink direction. The drawback is a somewhat larger radio-interface delay. Thus the Hybrid ARQ with soft combining can be used to trade-off efficiency vs. delay by adjusting the target settings (initial error rate) for the Hybrid ARQ scheme.

4. MBMS – MULTIMEDIA BROADCAST/MULTICAST SERVICES

MBMS or Multimedia Broadcast/Multicast Services, introduced in WCDMA release 6 in parallel to Enhanced Uplink, provides WCDMA with a powerful tool to offer true broadcast/multicast services over a mobile-communication network, in parallel to normal unicast services. With MBMS, the same content is transmitted to multiple users in a unidirectional fashion, typically over multiple cells to cover a large area in which the service is provided.

MBMS in 3GPP provides a full set of functionally to support broadcast/multicast services in a mobile-communication network, including both core-network and radio-access-network functionality.

Figure 9 illustrates the overall MBMS structure in a 3GPP-based radio-access network. A new core-network node, the BM-SC or *Broadcast Multicast Service Center* is introduced as part of MBMS. The BM-SC is responsible for authorization and authentication of content providers, charging, and the overall configuration of the data flow through the core network. The BM-SC is also responsible for so-called *application-level coding*.

One of the main benefits of MBMS is a general resource saving in both the core network and the radio-access network as a single stream of data may serve multiple

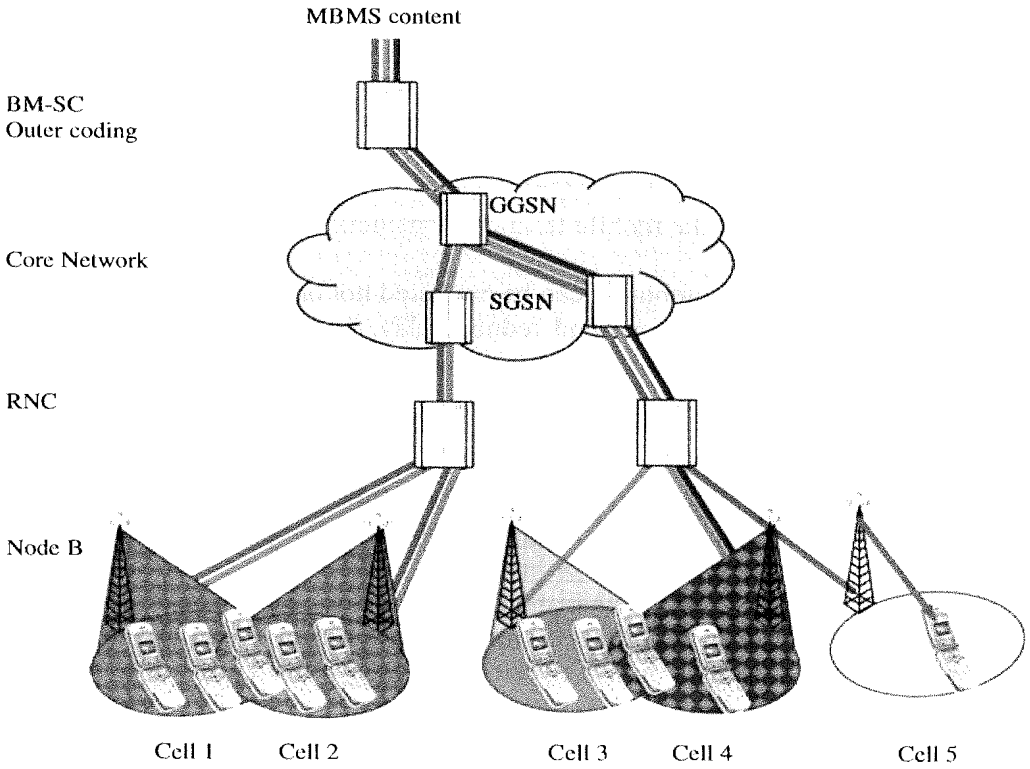


Figure 9. Overall structure of MBMS in 3GPP-based mobile-communication networks

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users. This can clearly be seen from **Figure 9** where three different services are offered in different areas. From the BM-SC, data streams are fed, via intermediate core- and radio-network nodes, to each of the base stations involved in providing the MBMS services over the radio interface. As seen in the figure, the data stream intended for multiple users is, in general, not split until necessary. For example, there is only a single stream of data jointly sent to all the users in cell 3. This is in contrast to earlier releases of WCDMA where one stream per user had to be configured throughout both the core network and the radio-access network, even when identical information was to be provided to multiple users.

As indicated above, one of the main benefits with MBMS is resource savings in the network as multiple users can share a single stream of data. This is valid also from a radio-interface point-of-view where a single transmitted MBMS signal may be received by multiple users. Obviously such point-to-multipoint radio-transmissions within a cell imply very different requirements on the radio interface compared to downlink unicast transmissions based on e.g. HDSPA. As an example, user-specific adaptation of the radio parameters (link adaptation, channel-dependent scheduling, etc.) cannot be used for MBMS as the transmitted signal is intended for multiple users experiencing different instantaneous channel conditions. Instead transmission parameters such as transmit power and transport format must be selected based on what may be required by the worst-case mobile-terminal position, typically at the cell border. This also implies that different forms of diversity to suppress the impact of multi-path fading on the radio channel are highly important when providing broadcast/multicast services over a radio interface. Furthermore, different types of ARQ protocols are obviously also not suitable when the broadcast/multicast information is to be received by a large number of mobile terminals within the cell.

The two main techniques for providing diversity for MBMS services in WCDMA are

- time-diversity against fast fading through a long 80 ms TTI and application-level coding
- downlink macro-diversity, i.e., combining of transmissions received from multiple cells.

Fortunately, MBMS services are not delay sensitive and the use of a long TTI is not a problem from the end-user perspective. Additional means for providing diversity can also be applied in the network, e.g., open-loop transmit diversity. Receive diversity in the terminal also improves the MBMS reception performance, but as the 3GPP mobile-terminal requirements for 3GPP release 6 are set assuming single-antenna mobile terminals, it is hard to exploit this type of diversity in the planning of MBMS coverage.

4.1 MBMS Macro Diversity

An MBMS services is often provided simultaneously over a large number of cells. This provides the opportunity for *multi-cell reception* of the MBMS signal for

mobile-terminals at or close to the border between cells, providing macro diversity and, as a consequence, substantially improved coverage for the MBMS service.

Combining transmissions of the same content from multiple cells provides a significant diversity gain, in the order of 4-6 dB reduction in transmission power, compared to single-cell reception only, as illustrated in **Figure 10**. Two combining strategies are supported for MBMS, *Soft Combining and Selection Combining*.

In case of soft combining the soft bits received from the different radio links are combined prior to (Turbo) decoding. In principle, the mobile terminal descrambles and RAKE combines the transmission from each cell individually, followed by soft combining of the different radio links. Note that WCDMA uses cell-specific scrambling of all data transmissions. Hence, the soft combining is performed by the appropriate mobile-terminal processing, which also is responsible for suppressing the interference caused by the transmission activity in the neighbor cells. To perform soft combining, the physical channels to be combined should be identical. For MBMS, this implies the same S-CCPCH content and structure should be used on the radio links which are soft combined.

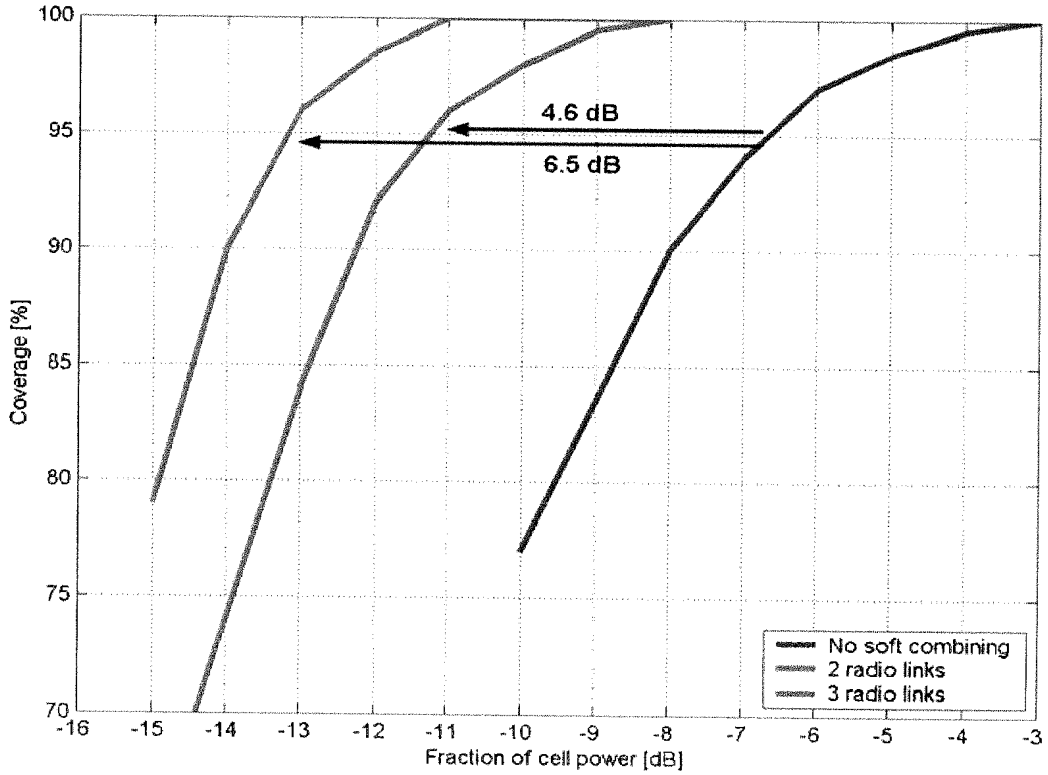


Figure 10. Gain with soft combining and multi-cell reception in terms of coverage vs. power for a 64 kbit/s MBMS service (Vehicular A, 3 km/h, 80 ms TTI, single receive antenna, no transmit diversity, 1% BLER)

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Selection combining, on the other hand, decodes the signal received from each cell individually and for each TTI selects one (if any) of the correctly decoded data blocks for further processing by higher layers. From a performance perspective, soft combining is preferred over selection combining as it provides not only diversity gains but also a power gain as the received power from multiple cells is exploited. Relative to selection combining, the gain with soft combining is in the order of 2–3 dB.

The reason for supporting two different combining strategies for MBMS is to handle different levels of asynchronism in the network. For soft combining, the soft bits from each radio link have to be buffered until the whole TTI is received from all involved radio links and the soft combining can start while, for selection combining, each radio link is decoded separately and it is sufficient to buffer the decoded information bits from each link. Hence, for a large degree of asynchronism, selection combining requires less buffering in the mobile terminal at the cost of an increase in turbo decoding processing. The mobile terminal is informed about the level of synchronism and can, based upon this information and its internal implementation, decide to use any combination scheme as long as it fulfills the minimum performance requirements mandated by the specifications.

4.2 Application-level Coding

Many end-user applications require very low error probabilities, e.g., in the order of 10^{-6}. Providing such low error probabilities on the radio-link level can be very costly from a transmit-power point-of-view. In point-to-point communications, for example for HS-DSCH and E-DCH, some form of ARQ mechanism is therefore typically used to reduce the residual error rate to the required level. However, as previously mentioned, it is not straightforward to apply an ARQ protocol for broadcast transmissions. For MBMS, application-level forward error-correcting coding has instead been adopted as a tool to reduce the overall error rates to the required level as shown in **Figure 11**.

The MBMS application-level coding resides in the BM-SC and is thus, strictly speaking, not part of the radio-access network, With application-level coding, the system can operate at a transport-channel block error rate in the order of 1%–10% instead of fractions of a percent, which significantly lowers transmit power requirement. As the application-layer coding resides in the BM-SC, it is also

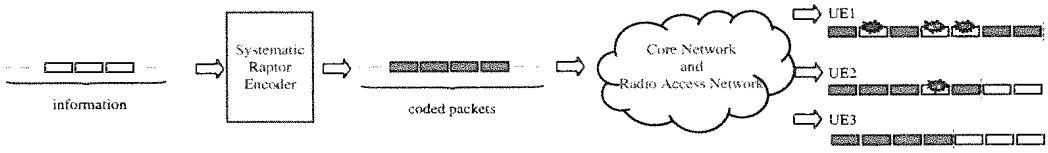


Figure 11. Illustration of application-level coding, depending on their different ratio conditions, the number of coded packets required for the mobile terminals to be able to reconstruct the original information differs

effective against occasional packet losses in the transport network, e.g., due to temporary overload conditions.

So called *Systematic Raptor codes* have been selected for the application-level coding in MBMS. Raptor codes belongs to a class of so-called *Fountain* codes, i.e., as many encoding packets as needed can be generated on-the-fly from the source data. For the decoder to be able to reconstruct the information, it only needs to receive sufficiently many coded packets. It does not matter which coded packets it receive, in what order they are received, or if certain packets were lost.

In addition to provide additional protection against packet losses and to reduce the required transmission power, the use of application-level coding also simplifies the procedures for mobile-terminal measurements, e.g., for cell reselection in case of MBMS reception. For HSDPA, the scheduler can avoid scheduling data to a given mobile terminal in certain time intervals. This allows for the mobile terminal to use the receiver for measurement purposes, e.g., to tune to a different frequency and possible also to a different radio-access technology. In a broadcast setting, scheduling measurement gaps is cumbersome as different mobile terminals may have different requirements on the frequency and length of the measurement gaps. Furthermore, the mobile terminals need to be informed when the measurements gaps occur. Hence, a different strategy for measurements is adopted in MBMS. The mobile-terminal measurements are done autonomously, which could imply that a mobile terminal sometimes miss (part of) an MBMS TTI. In some situations, the inner Turbo code is still able to decode the transport channel data, but if this is not the case, the outer application-level code will ensure that no information is lost.

5. FUTURE WCDMA EVOLUTION

Although the introduction of HSPA (HSDPA + Enhanced Uplink) provides substantial enhancements to the WCDMA support for packet-data services in terms of system as well as end-used performance, there continues to be a need to further enhance and evolve the WCDMA radio-access technology in order to ensure WCDMA competitiveness also in a longer time perspective. This section with briefly discuss two features currently being specified for WCDMA.

- *Continuous Packet Connectivity* (CPC) aiming at a further improvement in the WCDMA resource utilization and faster access to radio resources
- Downlink *multi-layer transmission* or "*MIMO*" aiming at a further increase in the downlink data rates supported by the WCDMA radio interface, at a first step up to 28 Mbps

5.1 Continuous Connectivity

In general, a WCDMA mobile terminal may be in one of different "states" as outlined in **Figure 12**, depending on the current "activity" of the mobile terminal. These states differ in terms of how fast the mobile terminal can get access to

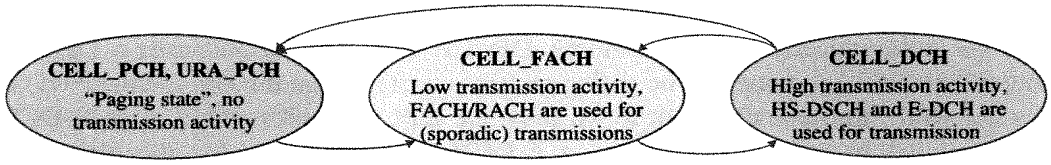


Figure 12. The WCDMA state model in conneceted mode

large radio resources for high speed downlink and/or uplink packet data transfer, with CELL_DCH providing the fastest (basically immediate) access to large radio resources.

However, at the same time as the CELL_DCH state provides the fastest access to large radio resources and thus, from this point-of-view, can provide the best user experience, the CELL_DCH state is also the most expensive state in terms of radio-resource usage. The reason is that, when in CELL_DCH state, a mobile terminal is continuously using a certain amount of radio resources on both uplink and downlink. These resources are used to keep the radio link between the mobile terminal and the network, including power control, up and running, to ensure a steady flow of uplink CQI reports for downlink scheduling, etc. Thus, in order to maximize the amount of radio resources available for actual packet-data transmission, the number of mobile terminals in CELL_DCH state should be limited. As a consequence, mobile terminals that have not transmitted or received any data for a certain time interval are "moved" to the, from a resource-utilization point-of-view, more efficient CELL_FACH state. However, CELL_FACH state also implies a certain delay when, eventually, there is data to transmit to or from the mobile terminal as the mobile terminal must then first move back to the CELL_DCH state. Thus there is a desire to improve the efficiency of the CELL_DCH state allowing for more mobile terminals to simultaneously be in CELL_DCH state without an unreasonably negative impact on resource availability. If this would be possible, a mobile terminal can also stay in CELL_DCH state for a longer time, reducing the time needed to get access to large radio resources and thus improve the overall user experience. This is the target for the specification of the *Continuous Packet Connectivity* to be part of WCDMA release 7.

(1) Uplink Overhead Reduction

In the current WCDMA releases (up to release 6), a mobile terminal in CELL_DCH state continuously transmits an uplink control channel, the *uplink DPCCH*. This control channel is used to maintain uplink synchronization as well uplink power control. At the same time, this control channel causes uplink interference and thus uses a certain amount of uplink radio resources. In order to reduce that uplink interference from the DPCCH while still maintaining uplink synchronization and power control, Uplink DPCCH Gating is considered to be introduced for WCDMA. Uplink DPCCH gating implies that, instead of being transmitted continuously even when there is no uplink data transmission, the DPCCH is transmitted only intermittently.

Basically, if there is neither E-DCH nor HS-DSCH transmissions in the uplink, the UE automatically stops continuous DPCCH transmission and uses a DPCCH on/off transmission pattern. The gating pattern, configured in the UE and the Node B by the RNC, defines when not to transmit the DPCCH unless there is an E-DCH transmission in the uplink. When an E-DCH transmission is to take place, the DPCCH is also transmitted, regardless of the on/off pattern. The DPCCH is also transmitted when uplink acknowledgements, corresponding to downlink HS-DSCH transmissions, are to be transmitted.

(2) Downlink Overhead Reduction

In the downlink, each mobile terminal in CELL_DCH state uses a certain amount of downlink radio resource (channelization code and transmission power) due to the fact that each terminal has been allocated and uses an associated physical control channel, a *Dedicated Physical Channel* DPCH, mainly used for power control of uplink transmission. The *Fractional DPCH*, F-DPCH, introduced in Release 6 improves efficiency by allowing for multiple mobile terminals to share a common physical channel thus significantly reducing the overhead in terms channelization-code space.

However, another source of downlink overhead is the scheduling information transmitted on the *High Speed Shared Control Channel* or HS-SCCH. In case of medium-to-large payloads on the HS-DSCH, the relative HS-SCCH overhead is small. However, for services such as VoIP with frequent transmissions of small payloads, the HS-SCCH overhead compared to the actual HS-DSCH payload may not be insignificant. Therefore, an additional HS-SCCH structure with reduced overhead can be used for such services. By limiting the possible transmission formats on the HS-DSCH, the number of bits on the HS-SCCH using the new format can be kept small, thereby reducing the overhead in terms of downlink power.

5.2 MIMO/Multi-layer Transmission

Strictly speaking, MIMO or *Multiple Input Multiple Output antenna process* in its most general interpretation denotes the use of multiple antennas at both the transmitter and the receiver side of a radio link. However, the term MIMO is commonly used to denote the transmission of *multiple layers* or *streams* as a mean to increase the maximum data rate that can be provided over a given radio link. Hence, MIMO, or *multi-layer transmission*, should mainly be seen as a tool to improve the *end-user throughput* by acting as a "data rate booster" (Note that another MIMO scheme called MIMO diversity was specified as transmit diversity in 3GPP. Thus, we focus on MIMO SDM in the section). However, similar to higher-order modulation, multi-layer transmission will also provide a possibility for an increased system throughput especially in scenarios with, in general, high signal-to-noise/interference ratios.

MIMO schemes are designed to exploit certain properties in the radio propagation environment to attain high data rates through multiple layers. However, in

order to achieve these high data rates, a correspondingly high received signal-to-noise and/or signal-to-interference ratios are required. Multi-layer transmission is therefore mainly applicable in smaller cells or close to the base station, i.e. in situations where high signal-to-noise/interference ratios are more often experienced. In situations where a sufficiently high signal-to-noise/interference ratios cannot be achieved, the multiple receive antennas, which MIMO-capable mobile terminals are equipped with, should instead be used for receive diversity in order to boost the received signal quality.

The MIMO scheme adopted for HSDPA-MIMO is referred to as *D-TxAA* or *Dual Transmit-diversity Adaptive Antennas*. D-TxAA is *multi-codeword* MIMO scheme with *rank adaptation* and *pre-coding*, in which per stream rate control is applied to each codeword. The scheme can be seen as a generalization of the closed-loop mode 1 transmit-diversity scheme, present already in the first WCDMA release.

Transmission of up to two streams is supported by HSDPA-MIMO, thus providing the possibility for peak data rates twice that of current HSDPA or approximately 28 Mbps. Each stream is subject to the same physical layer processing in terms of coding, spreading, and modulation as the corresponding single-layer HSDPA case. After coding, spreading, and modulation, linear pre-coding is used before the result is mapped to the two transmit antennas. There are several reasons for the pre-coding. Even if only a single stream is transmitted, it can be beneficial to exploit both transmit antennas. Therefore, the pre-coding in the single-stream case is identical to closed-loop transmit diversity mode 1. In essence, this can be seen as a simple form of beam-forming. Furthermore, the pre-coding attempts to pre-distort the signal such that the two streams are (close to) orthogonal at the receiver. This reduces the interference between the two streams and lessens the burden on the receiver MIMO processing.

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CHAPTER 7

EVOLVED UTRA TECHNOLOGIES

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Abstract: This chapter describes the radio access technologies and physical-layer channels for the Evolved UTRA (UMTS Terrestrial Radio Access, UMTS: Universal Mobile Telecommunications System) and UTRAN (UMTS Terrestrial Radio Access Network), which represent the long-term evolution of UMTS. Discussion on the Evolved UTRA is ongoing in the 3GPP (3rd Generation Partnership Project) with the target of completing the work item (WI) specifications by around September 2007

Keywords: WCDMA, Evolved UTRA, OFDM, Single-Carrier FDMA, Reference signal, Broadcast information, Paging information, Shared data channel, Scheduling, Link Adaptation, Hybrid ARQ, MBMS, L1/L2 control information, MIMO, Inter-cell interference coordination

1. INTRODUCTION

The 3GPP (3rd Generation Partnership Project) study item (SI) on Evolved UTRA (UMTS Terrestrial Radio Access, UMTS: Universal Mobile Telecommunications System) and UTRAN (UMTS Terrestrial Radio Access Network) was initiated in December 2004. Evolved UTRA and UTRAN (E-UTRA/E-UTRAN) represent the long-term evolution of 3G radio access intended to be highly competitive even in the future 4G era. Evolved UTRA will support emerging multimedia technology and ubiquitous traffic over cellular networks through the use of only packet domain, which has affinity to IP-based core networks. The system requirements and targets of Evolved UTRA were agreed by TSG RAN in June 2005 and documented in 3GPP Technical Report TR-25.913. After extensive studies on basic radio-access schemes and physical-layer technologies in TSG RAN WG1 , the use of OFDM-based and Single-Carrier (SC)-FDMA based radio access was decided for the E-UTRA downlink and uplink respectively. This section addresses the Evolved UTRA technologies with focus on physical-layer aspects.

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2. REQUIREMENTS IN EVOLVED UTRA AND UTRAN

The Evolved UTRA and UTRAN targets high-capacity high-speed radio access and radio-access networks with low latency in order to support full IP functionalities. With low-latency characteristics E-UTRA/E-UTRAN will be able to provide current circuit-switched mode services over the packet domain, such as Voice-over-IP (VoIP). The work plan for establishing SI and Work Item (WI) specifications was approved. The system requirements on E-UTRA were also agreed upon and specified. Major system requirements related to the physical layer are given below.

- In order to allow for deployments in differently-sized spectrum allocation, E-UTRA should support multiple transmission bandwidths on both uplink and downlink. The current assumption is that E-UTRA should support transmission bandwidths corresponding to spectrum allocations of size 1.25, 1.6, 2.5, 5.0, 10.0, 15.0, and 20.0 MHz.
- Peak data rates of at least 100 Mbps and 50 Mbps are to be supported for downlink and uplink respectively. These data rates are to be achievable with two-branch MIMO transmission.
- Compared to WCDMA release 6, gains in average user throughput of at least 3 – 4 times and 2 – 3 times are to be achieved for downlink and uplink respectively. Corresponding gains in cell-edge user throughput should be at least 2 – 3 times that of WCDMA release 6.
- Gains in spectrum efficiency (capacity), compared to WCDMA release 6, are to be at least 3 – 4 times and 2 – 3 times for downlink and uplink, respectively.
- The minimum achievable one-way transmission delay over the radio-access network should be less than 5 msec.
- The minimum transition time from idle mode to active mode should be less than 100 msec. Corresponding transition time from dormant mode to active mode should be less than 50 msec.

As addressed, a high user throughput and high capacity, i.e., spectrum efficiency, are the eternal requirements in cellular systems in order to offer high-speed multimedia services efficiently at low cost. In particular there is demand for improvement in the user throughput over the entire cell area including the cell boundary. Furthermore, it is no exaggeration to say that low latency (short delay) is a most important requirement in terms of providing real-time services such as VoIP. The flexibility for different spectrum arrangements is necessary from operators' point of view. Moreover, simple channel and protocol structures and optimization of control-signal formats are also highly desirable.

3. RADIO ACCESS SCHEMES

An important requirement on the Evolved UTRA is to support operation in both paired and unpaired spectrum. Thus, Evolved UTRA should support operation with both Frequency-Division Duplex (FDD) and Time Division Duplex (TDD).

Furthermore, in order to reduce terminal complexity, there should be maximum commonality between the transmission scheme used in paired and unpaired spectrum, i.e. between FDD and TDD. Thus, the same E-UTRA radio-access schemes has been adopted for both FDD and TDD: OFDM based radio access in the downlink and Single-carrier (SC)-FDMA based radio access in the uplink. The E-UTRA radio frame length is 10 msec, which is identical to that of UMTS (i.e., WCDMA).

3.1 OFDM Base Radio Access in Downlink

Especially for signal bandwidths wider than 5 MHz, increased multipath interference (MPI) impairs the achievable data rate and coverage. For this reason, Orthogonal Frequency Division Multiplexing (OFDM) based downlink radio access was adopted for E-UTRA due to the inherent immunity of OFDM to MPI. OFDM also provides access to the frequency domain for the scheduling. Moreover, OFDM has superior flexibility to accommodate different spectrum arrangements due to its small granularity in frequency domain. Finally OFDM provides specific benefits in case of downlink multi-cell transmission as will be further discussed below. OFDM signal is generated and separated by IFFT and FFT based implementations at the transmitter and receiver, respectively.

3.1.1 Radio parameters

Table 1 lists the current 3GPP assumptions regarding radio parameters for the E-UTRA OFDM based downlink radio access. As can be seen, the sub-carrier spacing is constant regardless of the transmission bandwidth. To allow for operation in differently sized spectrum allocations, the transmission bandwidth is instead varied by varying the number of OFDM sub-carriers. The major downlink parameters were decided as follows:

- **Radio frame length**

Considering the simultaneous use of UTRA and Evolved UTRA, i.e., dual-mode usage, and backward compatibility with WCDMA/HSDPA, the same radio-frame length as WCDMA is desirable. Therefore, a 10-msec radio frame was adopted for Evolved UTRA.

- **Sub-frame and TTI lengths**

The E-UTRA sub-frame length was set to 0.5 msec in both the downlink and uplink. The sub-frame length corresponds to the minimum Transmission Time Interval (TTI). As mentioned previously, the E-UTRA requirement for one-way radio-access-network (RAN) latency is 5 msec. The total RAN latency includes the transmission delay between the UE and Node B, the transmission delay in the backhaul network between the Node B and access router, and the processing delays of the UE, Node B, and access router[1]. In particular, the transmission delay in the

[1] The term "access router" refers to a higher-level node than Node B

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Table 1. Radio Parameters in Downlink OFDM Based Radio Access

Transmission BW		1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20MHz
Sub-frame duration					0.5 ms		
Sub-carrier spacing					15 kHz		
Sampling frequency		1.92 MHz	3.84 MHz	7.68 MHz	15.36 MHz	23.04 MHz	30.72 MHz
FFT size		128	256	512	1024	1536	2048
Number of occupied sub-carriers		76	151	301	601	901	1201
Number of OFDM symbols per sub frame (Short/Long CP)					7/6		
CP length (μs/samples)	Short	(4.69/9) × 6, (5.21/10) × 1	(4.69/18) × 6, (5.21/20) × 1	(4.69/36) × 6, (5.21/40) × 1	(4.69/72) × 6, (5.21/80) × 1	(4.69/108) × 6, (5.21/120) × 1	(4.69/144) × 6, (5.21/160) × 1
	Long	(16.67/32)	(16.67/64)	(16.67/128)	(16.67/256)	(16.67/384)	(16.67/512)

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wireless channel between the UE and the Node B contributes a significant part to the total RAN latency. This delay depends on the Transmission Time Interval (TTI) length, which directly determines the control delay of channel-dependent scheduling, link adaptation, and hybrid ARQ. Thus, the TTI length was set to 0.5 msec in the study item (SI) specification. However, in the work item (WI) evaluation, the necessity for a long TTI was presented in order to enable repetition of the L1/L2 control signaling bits over multiple sub-frames particularly in the uplink with a strict transmission power restriction. Moreover, one option for the TTI length was claimed commonly in the downlink and uplink for the sake of implementation simplicity. As a result, the TTI length was decided to be 1.0 msec based on the tradeoff relation between a short control delay and the repetition of L1/L2 control signaling bits to achieve wide coverage provisioning. Since one TTI comprises two sub-frames, intra-TTI frequency hopping is beneficial to achieving a larger frequency diversity effect.

- **CP length**

At an OFDM receiver, the coded data symbol of each sub-carrier is retrieved by sampling the received signal over the duration of an OFDM symbol and performing fast Fourier transform (FFT) processing. Thus, in the case of multipath propagation, inter-symbol interference (ISI) occurs since the delayed part of the previous OFDM symbol falls within the FFT processing window. In addition, since the orthogonality between sub-carriers is destroyed due to the delayed paths, inter-sub-carrier interference (ICI) is generated. To avoid ISI and ICI in multipath propagation, *Cyclic Prefix* (CP) *insertion* is used. Cyclic-prefix insertion implies that the last part of the OFDM symbol, of length T_g, is copied and attached to the beginning of the OFDM symbol. As long as the delayed paths are received within a delay window of size T_g , the orthogonality between sub-carriers is then retained, i.e., ISI and ICI do not occur. The CP length should be selected based on the maximum time delay of the multi-path channel, which depends on the inter-site distance (ISD), frequency reuse, i.e., influence of other-cell interference, transmission power, etc. Meanwhile, the shortest possible CP is desired from the viewpoint of achieving efficient radio resource usage as the CP implies a certain overhead and waste of bandwidth.

In E-UTRA, two CP lengths are specified for effectively supporting physical channels for system-dependent environments: short and long CPs.

- A short CP is used for Unicast services.
- A long CP is used for Multimedia Broadcast Multicast Services (MBMS) and for Unicast services in environments with an extraordinarily long time dispersion.

The required CP lengths were investigated in system-level simulations in multi-cell environments. In the evaluations, the received signal-to-interference plus noise power ratio (SINR) is calculated using the method in assuming Greenstein's power-delay-profile model, which well approximated the root mean square (r.m.s.) delay spread. It was reported that the required short CP is approximately 3 to 5 μsec from the viewpoint of accommodating delayed paths for the cell radius of less than 5 km, assuming the support of various environments with a low-to-high channel load in the surrounding cells. Furthermore, to provide high-data-rate MBMS, a long CP

is necessary to obtain benefits from soft-combining for long delays from far cell sites and to compensate for the residual inter-Node B synchronized timing error. It was reported that a long CP is required to accommodate the delayed paths in MBMS of approximately 10 to 15 μsec in order to gain the soft-combining effect including the delay of RF filtering in the relay station using simple RF conversion. To support a long ISD of greater than 10 km, a longer CP is not necessary because the major impairments are background noise and other-cell interference, and not the MPI from the target cell under such long ISD conditions. Therefore, the short and long CPs become 4.69 / 5.21 μsec and 16.67 μsec, respectively. Furthermore, in the WI evaluation, the necessity for a CP longer than 16.67 sec was presented for MBMS in the region with a very long ISD using high transmission power. In addition to the short and long CPs, a very long CP, which is twice as long as the long CP (= 33.3 μsec), was agreed only for dedicated MBMS carrier application together with 7.5-kHz sub-carrier spacing.

- **Sub-carrier spacing**

As mentioned above, the CP length should be selected based on the multi-path scenarios that are to be supported according to the coverage requirement. By reducing the sub-carrier spacing, i.e., by increasing the number of sub-carriers, the CP insertion loss decreases, which is important from the viewpoint of efficient radio-resource utilization. Accordingly, a narrow sub-carrier spacing with a long OFDM symbol duration is necessary to suppress the CP insertion loss to a low level.

On the other hand, the sub-carrier spacing should be selected such that the influence of the Doppler effect and phase noise is limited. However, the influence of inter-carrier interference caused by phase noise is small when the sub-carrier spacing is wider than approximately 10 kHz. Accordingly, the minimum sub-carrier spacing is determined such that the influence of the Doppler effect becomes small for the maximum terminal speed to be supported by E-UTRA, which is approximately 350 km/h, corresponding to a maximum Doppler frequency of 840 Hz at the carrier frequency of 2.6 GHz. This view is based on the system design concept which indicates that although the E-UTRA system including radio parameters should be optimized in low mobility environments, the mobility up to the maximum speed in the system is supported while minimizing the performance degradation. It is given that the sub-carrier spacing should be greater than approximately 11 kHz to suppress the loss in the achievable throughput at 350 km/h from that at 30 km/h to within less than approximately 0.5 Mbps (2%) when 64QAM is employed at a 2.6-GHz carrier frequency. As a result, the sub-carrier spacing was decided to be 15 kHz both for short and long CPs. However, in the WI evaluation, the necessity for a very long CP, which is twice as long as the long CP (= 33.3 μsec) was presented for MBMS in the region with a very long ISD using high transmission power. Thus, the use of 7.5-kHz sub-carrier spacing was agreed only for dedicated MBMS carrier application to generate such a very long CP.

A physical resource block (PRB) is defined as the minimum radio-resource unit that can be assigned to a UE for data transmission. The bandwidth for the minimum resource block (RB), in which a distinct gain from frequency domain

channel-dependent scheduling is obtained considering the control signaling overhead, is around 25 sub-carriers or approximately 375 kHz assuming the six-ray Typical Urban channel model. However, a narrower bandwidth for the minimum RB is considered such as 12 sub carriers or 180 kHz to support low-rate data, e.g., VoIP.

3.1.2 Modulation schemes

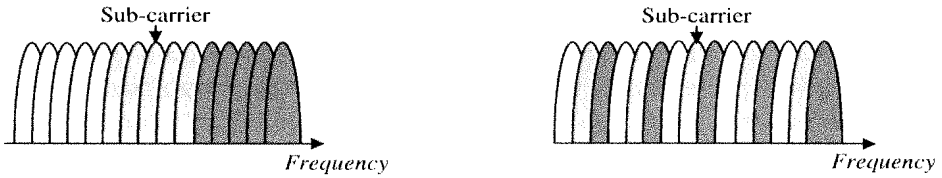
Higher-order modulation scheme such as 64QAM has been adopted for Evolved UTRA to provide higher data rates as well as high system efficiency due to the robust feature against time dispersion of OFDM based radio access. Consequently, data modulation schemes supported in the downlink are QPSK, 16QAM, and 64QAM.

3.1.3 Channel coding and interleaving

Turbo coding based on Release 6 is the working assumption for the Evolved UTRA SI.

3.1.4 Downlink data multiplexing

The channel-coded, interleaved, and data-modulated Layer 3 information is mapped onto OFDM symbols in the frequency and time domains. PRBs consist of a number of consecutive sub-carriers for a number of consecutive OFDM symbols. The Node B scheduler allocates frequency and time radio resources to map coded data symbols for a certain UE. The Node B scheduler also determines the channel-coding rate and the modulation scheme based on the reported channel-quality indicator (CQI) and quality-of-service (QoS). In the OFDM-based downlink, two types of data multiplexing were adopted for coded data symbols as illustrated in **Figures 1(a)** and **1(b)**, respectively: *Localized* OFDM transmission and *distributed* OFDM transmission. In case of localized transmission, the coded data symbols are transmitted block wise in the frequency domain. Meanwhile, coded data symbols are transmitted on non-consecutive sub-carriers in case of distributed transmission. To describe the operations of localized and distributed OFDMA transmissions, the notation of the virtual resource block (VRB) was introduced. The VRB is characterized by type and size. The type indicates either localized or distributed transmission. The size is defined as the numbers of sub-carriers and OFDM symbols. Distributed VRBs are mapped onto the PRBs in a distributed manner. Localized



(a) Localized transmission (b) Distributed transmission

Figure 1. Localized and distributed OFDMA transmissions

VRBs are mapped onto the PRBs in a localized manner. The multiplexing of localized and distributed transmissions within one sub-frame is accomplished using frequency division multiplexing (FDM).

3.2 Single-Carrier Based Radio Access in Uplink

Achieving wide-area coverage is one of the most important requirements in a cellular system. This is particularly critical for the uplink where UE transmission power and power consumption are restricted due to battery limitations. Accordingly, Single-Carrier Frequency Division Multiple Access (SC-FDMA) was adopted as the E-UTRA uplink radio access scheme. Single-carrier transmission achieves a lower peak-to-average power ratio (PAPR) and thus improves power-amplifier efficiency for a given transmitter output power, compared to multi-carrier based radio access such as OFDM. Moreover, signal-waveform generation in the frequency domain was proposed based on Discrete Fourier transform (DFT)-Spread OFDM, see **Figure 2**. Similar to OFDM, SC-FDMA also has flexibility for different spectrum arrangements. The Evolved UTRA DFT-Spread OFDM uplink radio access has high commonality in terms of radio parameters with the OFDM-based downlink radio access, for example in terms of, sampling rate and sub-carrier spacing.

The input of the DFT is sampled using the sampling clock, which corresponds to the symbol rate of the incoming coded data symbol. Either a localized or distributed FDMA signal is generated in the frequency domain. Let N_{DFT} and N_{IFFT} be the size of the DFT and inverse fast Fourier transform (IFFT), respectively. Then, the sampling rate at the output of the IFFT, R_{IFFT}, is given by the following equation.

$$(1) \qquad R_{IFFT} = R \times N_{IFFT} / N_{DFT}.$$

After mapping either to a localized or distributed FDMA signal format, the signal is converted into a time-domain signal by IFFT processing. After IFFT processing, cyclic-prefix (CP) is applied similar to basic OFDM. Cyclic-prefix insertion for SC-FDMA is used to avoid inter-block interference for frequency-domain equalization. Finally, a time-window filter suppresses out-of-band emissions due to

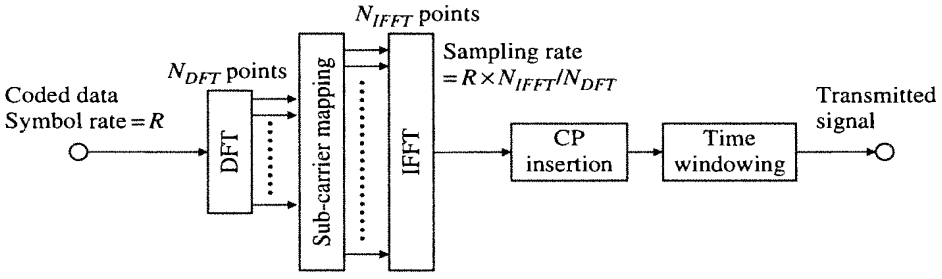


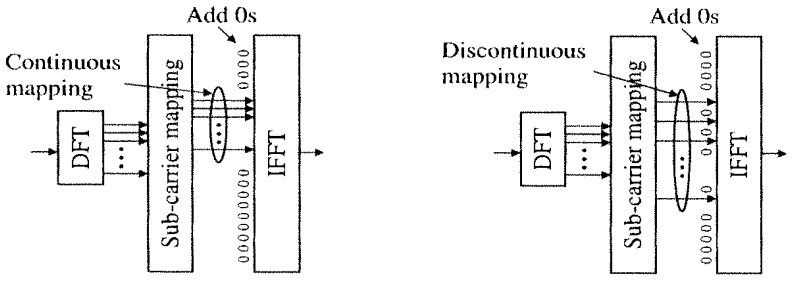
Figure 2. Transmitter block diagram of DFT-Spread OFDM

the discontinuity of contiguous blocks. The original DFT-Spread OFDM provides steep attenuation of the frequency domain power spectrum, which corresponds to a roll-off factor of zero in the raised cosine Nyquist filter. It was reported that the roll-off factor of zero achieves a higher user throughput than that for a roll-off factor value of greater than zero. On the other hand, the PAPR is reduced by increasing the roll-off factor value of the pulse-shaping filter. However, the effective channel rate, corresponding to the transmission bandwidth, is decreased. In other words, the channel coding rate becomes higher assuming the same information bit size, with a reduced coding gain as a consequence. The optimum roll-off factor value should thus be decided based on the trade-off relationship between the reduction in the PAPR and the decrease in the channel coding gain due to a decreasing channel coding rate. The results showed that the loss in the channel coding gain exceeds the gain from the PAPR reduction and thus roll-off of zero is preferred.

With DFT-Spread OFDM, sub-carrier mapping is possible in the frequency domain by inserting the output of the DFT and zeros at the input of the IFFT. **Figures 3(a)** and **3(b)** show the mapping schemes for the localized and distributed FDMA transmissions in DFT-spread OFDM, respectively. The sub-carrier mapping determines which part of the spectrum that is used for transmission by inserting a suitable number of zeros at the upper and/or lower end as indicated in the figures. As shown in the figures, between each DFT output sample, $L-1$ zeros are inserted. A mapping with $L=1$ corresponds to a localized transmission. In this case, the DFT output is mapped to consecutive sub-carriers to generate a normal localized FDMA signal. Meanwhile, when L is set to greater than 1, a distributed transmission signal is generated with a comb-shaped spectrum.

3.2.1 Radio parameters

Figure 4 illustrates the basic TTI structure comprising two sub-frames for uplink transmission. In the SI specification, a sub-frame comprises two short blocks (SBs) and six long blocks (LBs). SBs are used for reference signals for coherent demodulation and channel-quality measurement at the Node B and/or control and data



(a) Localized FDMA (b) Distributed FDMA

Figure 3. Mapping schemes for localized and distributed FDMA transmissions

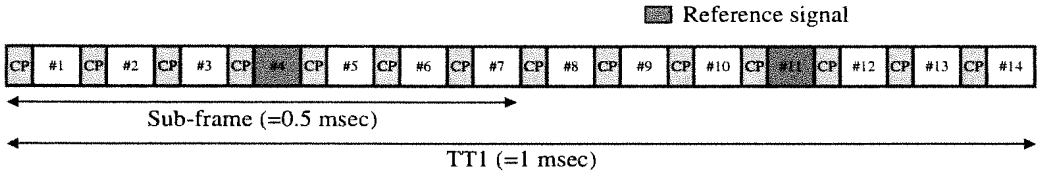


Figure 4. Basic sub-frame structure for uplink transmission

transmissions. Meanwhile, LBs are used for control and/or data transmissions. However, in the WI evaluation, the following two modifications were added for the uplink TTI structure.

First, the reference signal for channel-quality measurement is designed separately from the reference signal (RS) for coherent demodulation. Thus, it was decided that a LB at the beginning of each TTI (= 1.0 msec) would be used for the RS for channel-quality measurement. Second, to simplify the TTI structure, one LB instead of two SBs per sub-frame (i.e., two LBs instead of four SBs per TTI) is required in the design for the RS for coherent demodulation. The LB for the RS is multiplexed into the middle position of each sub-frame. The data part can include either contention-based data transmission or scheduled-based data transmission.

- **Sub-frame and TTI lengths**

In the SI evaluation, the TTI was set to the sub-frame duration, i.e., 0.5 msec. This setting was also established in the downlink.

However, in the WI evaluation, the necessity for concatenation, i.e., repetition, of multiple sub-frames into a longer TTI was presented to increase the area coverage for L1/L2 control signaling bits by multiplexing the information bits over a concatenated long TTI duration. The long TTI is particularly of interest for the uplink to extend the coverage area, since the achievable uplink data rate is often power limited rather than bandwidth limited. Moreover, one option for the TTI length was claimed commonly in the downlink and uplink for the sake of implementation simplicity. As a result, the TTI length was decided to be 1.0 msec based on the tradeoff relation between a short control delay and the repetition of L1/L2 control signaling in order to achieve wide coverage provisioning. Since one TTI comprises two sub-frames, intra-TTI frequency hopping is beneficial to achieving a larger frequency diversity effect particularly in the uplink with restricted transmission power at a UE.

- **CP length**

The required uplink CP length is decided from the time delays of multipaths to be supported and other impairment factors such as the path-timing-detection error, residual transmission-time-alignment error, and residual frequency drift between Node B and simultaneously accessing UEs. The E-UTRA uplink CP length is almost identical to that for the downlink because the influence from the impairment factors is slight. The CP lengths are slightly different in the respective transmission bandwidths.

- **Block size**

The LB size is constant regardless of the transmission bandwidth. The numbers of sub-carriers in the occupied bandwidth and samples per block are changed according to the transmission bandwidth. According to the reduction in the block size, the CP insertion loss becomes larger. Meanwhile, as the block size increases, the tracking ability for fast channel variation under high mobility conditions is degraded. Therefore, the optimum block size was investigated based on these tradeoff relationships. For instance, the LB comprises 512 samples in a 5-MHz transmission bandwidth case.

3.2.2 Modulation schemes

Currently assumed E-UTRA uplink data-modulation schemes are BPSK, QPSK, 8PSK, and 16QAM. Higher-order modulation schemes such as 8PSK and especially 16QAM, are especially applicable to small-cell environments and low-load conditions. To achieve efficient modulation with a low PAPR, phase-shift type and offset type modulation schemes were investigated. However, $\pi/4$-shifted QPSK and 16QAM modulations and offset QPSK and 16QAM modulations have only a slight effect in decreasing the PAPR although $\pi/2$-shifted BPSK modulation reduces the PAPR to some extent compared to that for BPSK assuming the same conditions. Furthermore, it was reported that (8, 8)-star 16QAM reduces the required average received E_b/N_0 considering a cubic metric (CM) compared to square 16QAM in the case of a low channel coding rate such as 1/3. However, when the adaptive modulation and coding (AMC) scheme is used, the merit of (8, 8)-star 16QAM is not gained since the application region of the (8, 8)-star 16QAM with R= 1/3 is concealed by a lower modulation and coding scheme (MCS) such as QPSK and R = 2/3. As a result, square 16QAM is the current working assumption for 16QAM modulation scheme.

3.2.3 Channel coding and interleaving

Similar to the downlink, Turbo coding based on WCDMA Release 6 is the working assumption for Evolved UTRA SI.

3.2.4 Uplink multiplexing

The channel-coded, interleaved, and data-modulated Layer 3 information is mapped onto SC-FDMA symbols in the time and frequency domains. The overall SC-FDMA time/frequency resource symbols can be organized into a number of resource units (RUs). Each RU consists of a number (M) of consecutive or non-consecutive sub-carriers during the N long blocks within one sub-frame. In order to support localized and distributed transmission, two types of RUs are defined: Localized RU (LRU) and distributed RU (DRU). The LRU consists of M consecutive sub-carriers during N long blocks, which is a conventional single-carrier signal generated in the frequency domain. The DRU consists of M equally spaced non-consecutive sub-carriers with a comb-shaped spectrum during N long blocks.

4. DOWNLINK PHYSICAL CHANNEL STRUCTURES

In this section, we explain the features and structures of the E-UTRA downlink physical-channel structure related to:

- Reference signals
- Broadcast Channel (BCH)
- Paging Channel (PCH)
- Synchronization Channel (SCH)
- Multimedia Broadcast Multicast Services (MBMS)
- L1/L2 Control Channel
- Shared Data Channel

4.1 Downlink Reference Signal

E-UTRA downlink reference signal(s) is used for the following purposes[2].

- Downlink channel-quality measurements
- Downlink channel estimation for coherent demodulation/detection at the UE
- Cell search and initial acquisition

4.1.1 Mapping of reference signal symbols in time and frequency domains

Figure 5 illustrates the multiplexing of reference symbols in the downlink. The basic downlink reference-signal structure consists of known reference symbols transmitted at known positions within the OFDM time/frequency grid. Reference symbols are multiplexed into the first and third last OFDM symbol of every sub-frame with a frequency-domain separation of six sub-carriers. Furthermore, the reference symbols at the third last OFDM symbol are staggered in the frequency

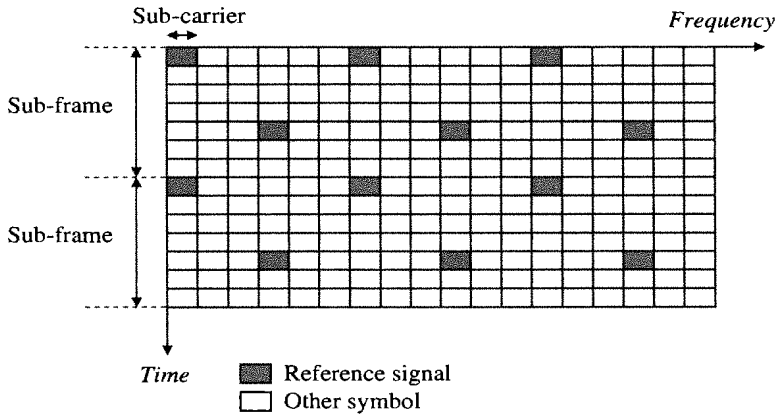


Figure 5. Multiplexing of downlink reference symbols in downlink

[2] A reference signal basically corresponds to the pilot channel of WCDMA

domain compared to the reference symbols of the first OFDM symbol. It was reported that by multiplexing reference signals into two OFDM symbols within a sub-frame, low-to-high mobility environments up to, e.g., 350 km/h can be supported without additional reference signals in the time domain.

4.1.2 Orthogonal reference signals

In E-UTRA, it should be possible to provide orthogonal reference signals between cells of the same Node B as well as between different transmit antennas of the same cell. Orthogonal reference signals between transmit antennas within the same cell is e.g. needed to support downlink transmit diversity and MIMO transmission.

(1) Orthogonal reference signals for different transmission antennas

Orthogonal reference signals for different transmit antennas of the same cell/beam is established by means of FDM, possibly in combination with TDM. Thus, reference-signal multiplexing with different antenna-specific frequency (or time) shifts is used for each antenna. The main reason for relying on FDM/TDM-based orthogonality between transmit antennas of the same cell/beam is that it provides more accurate orthogonality compared to CDM-based orthogonality since no inter-code interference occurs in a frequency-selective fading channel. A high level of orthogonal accuracy is necessary to separate composite streams from different antennas in MIMO multiplexing and MIMO diversity schemes.

(2) Orthogonal reference signals for different cells in the same Node B

CDM-based reference-signal orthogonality is used between different cells/beams belonging to the same Node B in order to suppress the mutual interference particularly near the cell boundary. The merit of CDM-based orthogonality, compared to FDM-based orthogonality, between cells of the same Node B is a better tracking ability for the channel estimation, particularly UEs far from sector borders, since the density of the CDM-based orthogonal reference symbols in the frequency domain is higher than in case of FDM-based orthogonality.

Figure 6 shows the principle of the intra-Node B orthogonal reference signal employing the combination of a Node B-specific scrambling code and cell-specific orthogonal sequence in the same Node B. As shown in **Figure 6**, we employ the same scrambled code among all cells belonging to the same Node B unlike in the WCDMA scrambled code assignment. Furthermore, a cell-specific orthogonal sequence is applied in order to distinguish cells (typically three or six) within the same Node B. Therefore, the resultant cell-specific scrambled code for the reference signal, $p_{n,m}$ (n is the cell belonging to the same Node B and $m$is the index for the reference symbols), is generated through the combination, i.e., multiplication, of a Node B-specific scrambled code and cell-specific orthogonal sequence represented as

$$p_{n,m} = c_m \cdot s_{n,m \bmod SF}. \tag{2}$$

In this equation, c_m denotes the Node B-specific scrambled code, and $s_{n,m}$ is the orthogonal sequence with the spreading factor of SF employed in the n-th cell.

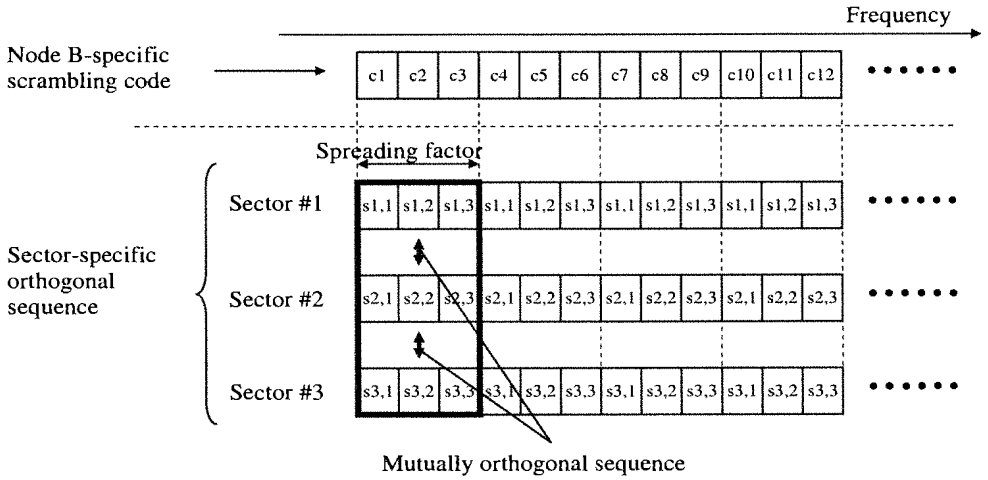


Figure 6. Principle of intra-Node B orthogonal reference signal structure

The cell-specific orthogonal sequence is generated by a Walsh-Hadamard sequence or phase rotation sequence. Here, we assume a cell-specific orthogonal sequence generated by phase rotation as indicated in the following equation assuming Nsectors ($SF = N$) in the same Node B.

$$(3) \qquad s_{n,m} = \exp\left(j\frac{2n\pi}{N}m\right).$$

Thus, in the three-cell configuration at each Node B, the phase rotation of 0, $2\pi/3$, and $4\pi/3$ is added to Sectored beams 1, 2, and 3, respectively. Using the orthogonal reference signal in **Figure 6**, intra-Node B orthogonality in the channel estimate is achieved by despreading CDM based reference symbols in the frequency or time domain. Note that the channel estimate at each sub-carrier is directly used without despreading for the UE without intra-Node B macro-diversity.

4.2 Broadcast Channel (BCH)

The broadcast channel (BCH) is used to broadcast system and cell-specific control information over the entire cell area. The broadcast control information includes information related to connection setup, cell selection, and re-selection, etc..

4.2.1 Broadcast Control Information

Broadcast control information can be categorized into cell-specific information, Node B-specific information, and system-specific information. Furthermore, another level of categorization is primary information, which is necessary to be immediately available to UE after cell search and initial acquisition, and non-primary information. **Table 2** lists different kinds of broadcast control information together with the categorization according to above.

Table 2. Broad cast Control Information

System control information elements	Classification (Area scope)	Primary or not
SFN (System Frame Number)	Node B specific or cell specific	Primary
PLMN (Public Land Mobile Network) identity	Node B specific or cell specific	Primary
Overall transmission bandwidth	Node B specific	Primary
Number of transmit antennas	Node B specific or cell specific	Primary
Scheduling and update information index (value tag) of system control information	Cell specific	Primary
NAS (Non Access Stratum) system information	Node B specific	Non-primary
UE (User Equipment) timers and counters	Node B specific	Non-primary
Cell selection and re-selection parameters	Node B specific or cell specific	Non-primary
Common physical channel configuration	Node B specific or cell specific	Non-primary
UL interference	Cell specific	Non-primary
Dynamic persistence level	Cell specific	Non-primary
Measurement control information	Cell specific	Non-primary
Time of day	PLMN specific	Non-primary
UE positioning related information	Cell specific	Non-primary
Stored RB (Radio Bearer) configuration	PLMN specific	Non-primary
PLMN Ids of neighboring cells	Cell specific	Non-primary

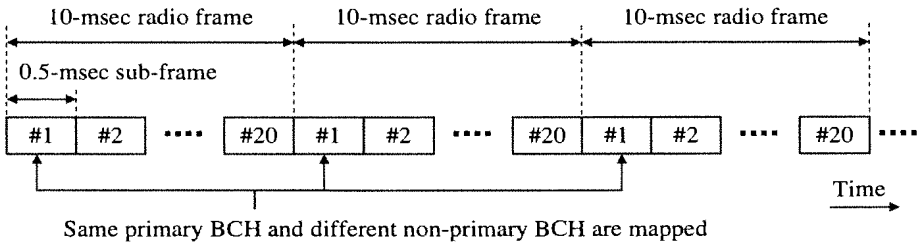
4.2.2 *Multiplexing of BCH*

(1) Primary broadcast information

The primary broadcast information is transmitted using the BCH with a predetermined radio resource, which is known to all UEs. The BCH is multiplexed into one or a few sub-frames during one radio frame.

The BCH is transmitted from the center part of the overall cell transmission band as shown in **Figure 7**, regardless of the overall cell transmission bandwidth, similar to the case of the synchronization channel (SCH), see below. Accordingly, no change in the carrier frequency is necessary after establishing the initial acquisition. In terms of the BCH transmission bandwidth, a wide transmission bandwidth such as 5 MHz can achieve superior link performance compared to e.g. a 1.25-MHz transmission bandwidth due to a larger frequency-diversity effect. On the other hand, a 1.25-MHz transmission bandwidth for the BCH has advantages in that the UE can decode the BCH of the target cell to perform handover without a change in the carrier frequency when the BCH is transmitted from the central part of the 20-MHz transmission bandwidth of the neighboring cell where the UE capability for the minimum reception bandwidth is 10 MHz (note that the assumption is that the UE capability for the minimum reception bandwidth is slightly extended).

(a) Time domain



(b) Frequency domain

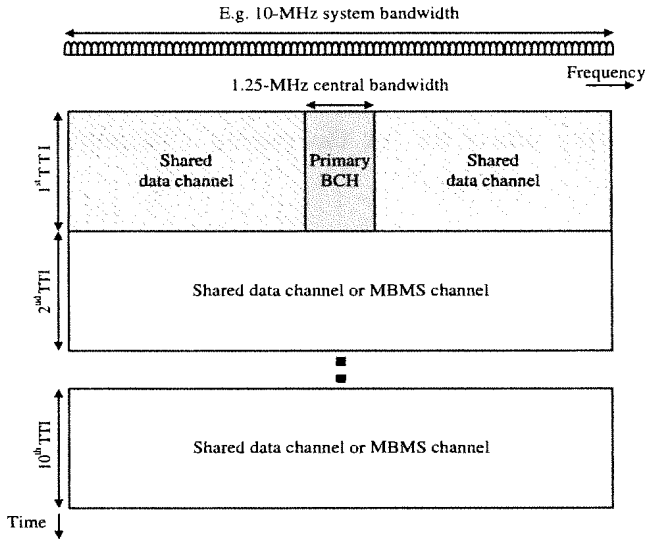


Figure 7. BCH Multiplexing

A constant 1.25-MHz transmission bandwidth for the BCH is also beneficial in order to achieve simple cell search since the UE does not need to detect the BCH bandwidth prior to decoding it.

(2) **Non-primary broadcast information**
Non-primary broadcast information is transmitted employing a scheduled-based shared data channel. A set of UE is informed of the RB assignment for non-primary broadcast information using the primary broadcast information in the BCH.

4.3 Paging Indicator and Paging Channel (PCH)

The paging channel (PCH) is used for network-initiated connection setup. Efficient reception of the PCH is necessary to obtain a high power saving effect.

4.3.1 *Control Information in Paging indicator and PCH*

A paging indicator (PI) is used before receiving the PCH similar to WCDMA. The number of bits for the PI information is much less than that for the PCH. Thus, the time duration of the PI is much shorter than that for the PCH. Therefore, by using the PI, a much higher gain for power saving at a set of UE using intermittent reception is obtained compared to the case with direct PCH reception without the PI. PI information contains the following.

- Group ID: The group ID indicates the ID of the user group who are to receive the subsequent PCH.
- Mapping information: This information indicates the location of the RBs where the PCH to be decoded is multiplexed.

The PCH conveys the following information employing a scheduled-based shared data channel.

- User ID: The user ID indicates the ID of the user who is paged from the Node B.
- Cause ID: The cause ID indicates the cause for paging such as the traffic service type.

The flow of the decoding procedure for the paging information is given in **Figure 8**.

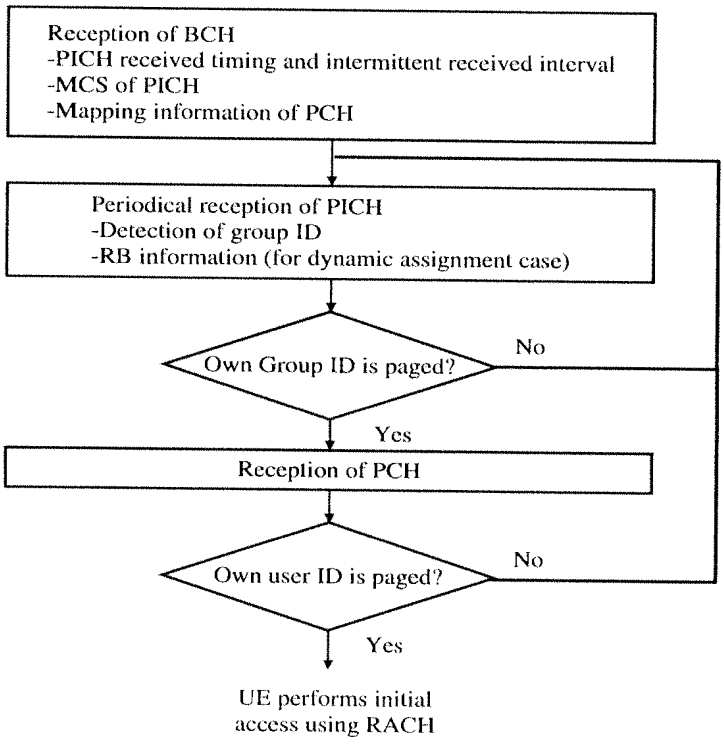


Figure 8. Flow of decoding procedure for paging information

4.3.2 *Multiplexing of PI information and PCH*

Figure 9 illustrates an example of the multiplexing of PI information and the PCH. The PI information is conveyed using the downlink L1/L2 control channel. In the figure, the PI information is multiplexed into the same OFDM symbol duration as the L1/L2 control channel using distributed transmission. Note that different cell-specific control information in the same Node B is sent on the L1/L2 control channel, whereas the cell-common PI information in the same Node B is transmitted, and coordinated transmission is applied to the PI information. By using separate coding between Cat. 1 information (control information related to scheduling (resource assignment)) and Cat. 2/3 information (control information related demodulation and decoding), transmission of the Cat. 2/3 information can be omitted to avoid an unnecessary increase in the overhead. This configuration also allows application of the synchronous PI information and PCH transmission schemes employing coordinated transmission among cells within the same Node B.

The PI information is transmitted from the system-dependent pre-assigned transmission frequency band. For example, in the figure assuming a 20-MHz system bandwidth, two 10-MHz frequency blocks of the L1/L2 control channel are defined, but only the central 5-MHz band is used as the pre-assigned transmission band for the PI information.

The PCH is transmitted within the pre-assigned transmission band similar to the case of the PI information. In the example in **Figure 9**, the system allocated bandwidth and system-dependent pre-assigned transmission band for the PCH are

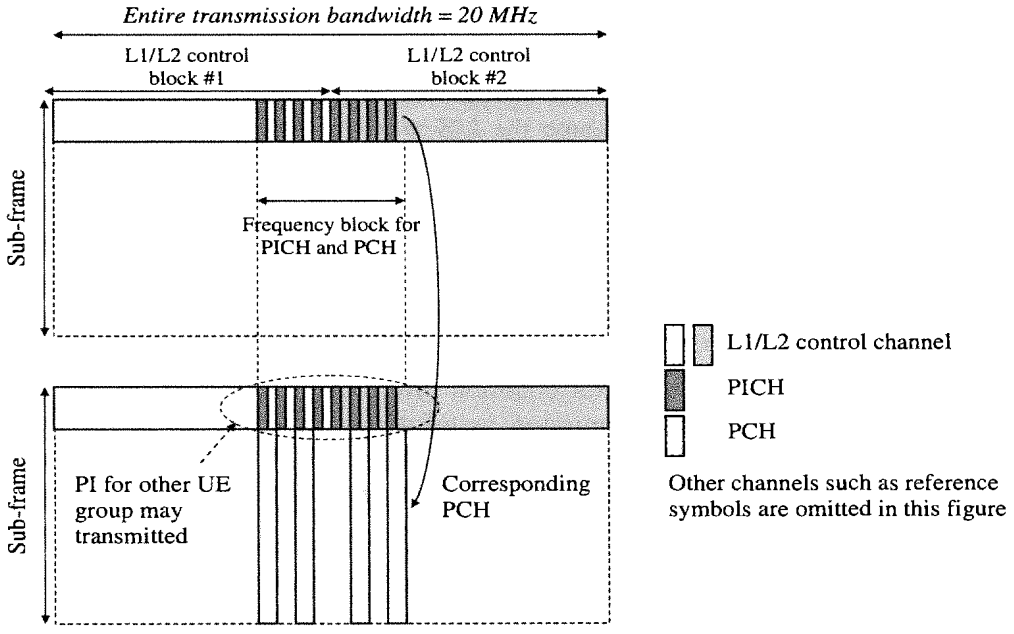


Figure 9. Multiplexing of PI information and PCH

20 and 5 MHz, respectively. Sets of UE are notified of the pre-assigned transmission band at each cell site using the broadcast information. It should be noted that assigning the central part of the system bandwidth as the pre-assigned transmission band for the PCH can be beneficial in simplifying the cell search procedure for the neighboring cells with the same carrier frequency, since the change in the center frequency at the UE can be avoided. By transmitting the PICH in advance using a pre-decided duration before the PCH, the decoding processing of the PCH can be simplified (see **Figure 9**).

4.3.3 Resource assignment for PCH

There are two possibilities for RB assignment for the PCH within the pre-assigned frequency block: Semi-static assignment and dynamic assignment. When semi-static assignment is used, the RB positions for the PCH are fixed. The number of assigned RBs may be changed according to the amount of paging information. In this case, the UE is informed of the number of assigned RBs for the PCH using the information regarding the number of RBs. The assigned RBs within the pre-decided transmission band are pre-decided according to the number of assigned RBs. Therefore, the UE can know the positions of the RBs for the PCH by decoding only the RB index information. In order to achieve coordinated synchronous transmission within the same Node B, the position of the RBs for the PCH must be common to all sectors within the same Node B. Meanwhile, when dynamic assignment is used, the assigned RB position can be dynamically changed according to the frequency domain channel dependent scheduling results on the shared data channel. Typically, by prioritizing the frequency domain channel dependent scheduling of the shared data channel, the PCH is transmitted using the remaining RBs. This brings about increased channel dependent scheduling gain for the shared data channel. However, the number of control signaling bits for the PI information will be increased compared to the case with semi-static assignment since the UE must be informed of the detailed RB positions of the PCH by using the PI. Similar to the semi-static assignment, to achieve coordinated transmission among sectors within the same Node B, the position of the RBs for the PCH must be common to all sectors within the same Node B.

4.3.4 Synchronous transmission and soft-combining reception

Since the PI and PCH convey sector-common information from all sectors in the same Node B, synchronous transmission associated with soft-combining among cells within the same Node B was proposed to achieve high quality transmission of the PI and PCH. **Figure 10** shows synchronous transmission employing delay diversity among cells in the same Node B, i.e., sectors, and soft-combining reception. As shown in **Figure 10**, the same paging information or PCH is transmitted among cells in the same Node B using coordinated delay diversity so that the time delays of the paths of all cells in the same Node B are aligned within the CP. Then, since soft-combining within the CP is used at the UE, high

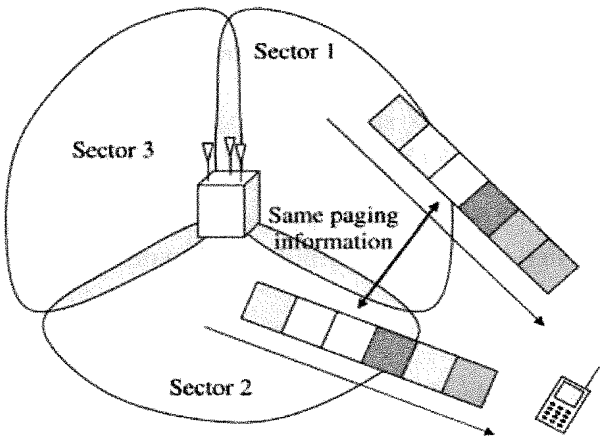


Figure 10. Principle of simultaneous transmission and soft-combining reception

quality reception is achieved for UEs located near the cell boundary. This coordinated transmission and soft-combining can be applied regardless of the usage of repetition (spreading) for the PCH. In synchronous transmission with soft-combining, two reference signal structures are considered: Cell-common reference signals in the same Node B and cell-specific orthogonal reference signals in the same Node B. It was reported that the cell-common reference signals in the same Node B achieved better packet error rate performance than the cell-specific orthogonal reference signals in the same Node B, even though an additional cell-specific orthogonal reference signal is necessary for demodulation of the L1/L2 control channel within the same sub-frame. This is because when cell-specific orthogonal reference signals in the same Node B are used, the influence of the background noise is greater than that with cell-common reference signals, since the received signal is demodulated independently at each cell and then soft-combined.

4.4 Downlink L1/L2 Control Channel

4.4.1 Control signaling bits in L1/L2 control channel

The following L1/L2 control signaling bits are transmitted using the downlink L1/L2 control channel.

- Downlink scheduling information for the downlink shared data channel
  - UE identity: Identification of the assigned UE
  - RB assignment information: Location of the assigned RBs
  - MIMO related information: Employed MIMO mode (MIMO multiplexing or MIMO diversity, etc.) and the number of data streams (note that a portion of the information may be transmitted as downlink demodulation-related information)
- Control information for demodulation of the downlink shared data channel
  - MCS information

- Control information for decoding of the downlink shared data channel
  - Hybrid ARQ related information: hybrid ARQ process number and redundancy version including new data indicator
- Uplink scheduling information for the downlink shared data channel
  - UE identity and RB assignment information: Similar to downlink-related information
- Control information for demodulation of the uplink shared data channel
  - MCS information and MIMO related information: Similar to downlink-related information
- ACK/NACK bit in response to uplink transmission
- Other information
  - Transmission timing control bits for adaptive transmission timing alignment in the uplink
  - Transmission power control (TPC) command for uplink transmission
  - PI information (this information can be categorized into downlink scheduling information)

The UE first detects the scheduling-related information, and the demodulation and decoding-related information are subsequently detected. It should be noted that the number of control signaling bits for demodulation and decoding of the shared data channel may change according to the MIMO configuration when the per antenna rate control (PARC) is applied. However, since the MIMO configuration is sent as a part of the scheduling-related information in advance, the number of bits for demodulation and decoding of the shared data channel can be identified before the UE decodes these bits.

4.4.2 *Multiplexing of L1/L2 control channel*

As shown **Figure 11**, there are two candidates for multiplexing of the L1/L2 control channel with other physical channels: Time domain multiplexing (TDM) and frequency domain multiplexing (FDM). Here, we compare TDM and FDM

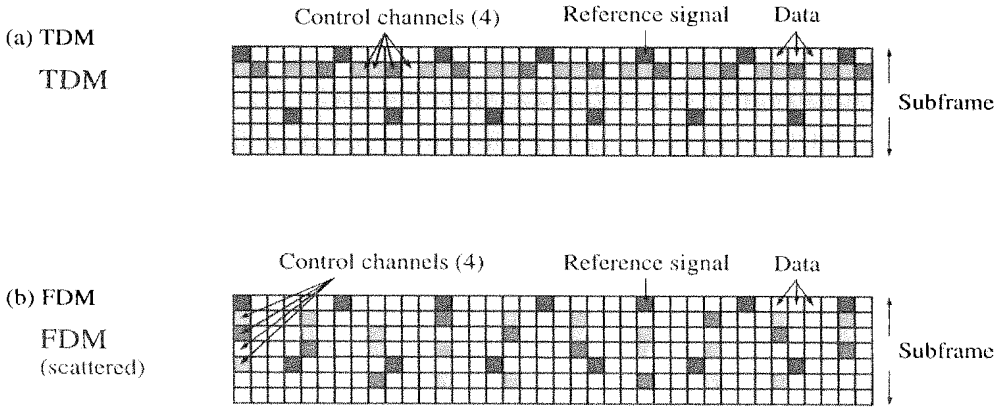
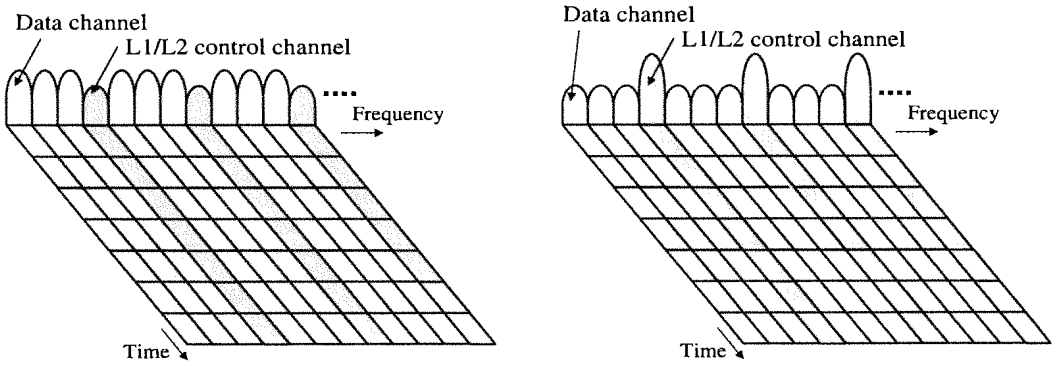


Figure 11. TDM and FDM Multiplexing of downlink L1/L2 control channel

multiplexing from the viewpoints of the possibility of power savings using the micro-sleep mode, processing delay, and a method for increasing the coverage. From the viewpoint of power saving TDM is potentially more advantageous than FDM, due to the possibility for micro-sleep. In addition, compared to FDM, TDM can somewhat reduce the processing delay due to the reception and demodulation time for the L1/L2 control channel. However, FDM can allow for power balancing between coded data symbols, reference symbols, and the L1/L2 control channel, which may improve coverage, see **Figure 12**. In this case, for UEs near the cell edge, more power can be allocated to the L1/L2 control information symbols by reducing the transmission power of the data symbols at the cost of decreased throughput. However, in the TDM structure, the total transmission power for the L1/L2 control channel can be increased to increase the coverage using the following methods. The first is using a long TTI at the cost of increasing the control delay. By repeating the same L1/L2 control information over multiple sub-frames, the received power of the L1/L2 control channel is increased. The second is to use a low coding rate including a large repetition factor within one sub-frame by reducing the number of coded data symbols in the shared data channel. A low coding rate including a large repetition factor in in case of TDM is fundamentally the same as power balancing in case of FDM although the lower coding rate method in TDM needs additional signaling to inform UE of the transport format of the L1/L2 control channel. It should be noted though that power balancing in case of FDM may require signaling of the transmission power ratio between the reference signal and the shared data channel in case of 16QAM or 64QAM modulation. Alternatively, blind estimation can be applied as is used for HSDPA.

It should also be mentioned that a lower coding rate for the L1/L2 control channel requires a change in the transport format of the shared data channel since the number of symbols available to the shared data channel is changed according to the coding rate of the L1/L2 control channel. This brings about some degree of



(a) Small cell environment (b) Large cell environment

Figure 12. Power balancing in FDM multiplexing

complexity at the UE receiver. However, the number of symbols available to the shared data channel is also changed according to the number of scheduled sets of UE since the number of symbols for the L1/L2 control channel is dependent on the number of scheduled sets of UE both for TDM and FDM. Therefore, the control of the transport format for the shared data channel according to the configuration of the L1/L2 control channel is required for both TDM and FDM.

4.4.3 Channel coding scheme for L1/L2 control channel

The coding schemes, i.e., joint or separate coding, in the downlink L1/L2 control channel listed below have a major impact on the design of the downlink L1/L2 control channel structure.

- Joint or separate coding of downlink transmission-related Cat. 1 information (control information related to scheduling (resource assignment))
- Joint or separate coding between downlink transmission-related Cat. 1 information and Cat. 2 and 3 information (control information related demodulation and decoding) within the same UE.
- Joint or separate coding between downlink transmission-related control information and uplink transmission-related information

In general, joint coding is advantageous from the viewpoints of the number of control signaling bits and the channel coding gain. Separate coding is advantageous from the viewpoint of the effect of link adaptation such as transmission power control (TPC) and the adaptive modulation and coding channel rate (AMC), the effect of beam-forming or pre-coding, and frequency diversity via channel dependent scheduling. Here, we focus on joint or separate coding for the downlink L1/L2 control channel for downlink transmission related information. **Figure 13** shows the possible channel coding schemes for L1/L2 control

Option	Cat. 1 information for multiple users	Cat. 1 and Cat. 2/3 information	
1	Joint	Joint	Cat. 1 and 2/3 for multiple sets of UE
2	Joint	Separate	Cat. 1 for multiple sets of UE; Cat. 2/3 for UE 1; Cat. 2/3 for UE 2; Cat. 2/3 for UE 3
3	Separate	Joint	Cat. 1 and 2/3 for UE 1; Cat. 1 and 2/3 for UE 2; Cat. 1 and 2/3 for UE 3
4	Separate	Separate	Cat. 1 for UE 1; Cat. 2/3 for UE 1; Cat. 1 for UE 2; Cat. 2/3 for UE 2; Cat. 1 for UE 3; Cat. 2/3 for UE 3

Figure 13. Channel coding scheme for L1/L2 control information

information. In principle, the following tradeoffs exist between the joint and separate coding schemes for downlink transmission-related control information.

- **Total number of control signaling bits and overhead associated with channel coding**

The joint coding scheme can reduce the overall number of control signaling bits for multiplexed sets of UE. Moreover, the size of the overhead such as the cyclic redundancy check (CRC) code associated with each coding block can be decreased in the joint coding scheme rather than the separate coding scheme.

- **Channel coding gain**

The joint coding scheme can provide a higher channel coding gain than the separate coding scheme, since the number of information bits accommodated within one coding block becomes larger.

- **Reception quality using link adaptation**

The separate coding scheme has a high affinity to UE-dependent link adaptation such as TPC and AMC for the L1/L2 control channel. We proposed a CQI-based TPC and consider applying the TPC to the L1/L2 control channel to mitigate the fluctuation in the received level due to instantaneous fading. The application of AMC to the L1/L2 control channel was also proposed. Thus, the required average received signal energy per bit-to-noise power spectrum density ratio (E_b/N_0) of the L1/L2 control channel in a multipath fading channel can be decreased by employing the separate coding scheme rather than the joint coding scheme due to the user-dependent precise link adaptation. In the joint coding scheme, the required transmission power may be significantly increased, since TPC compensates for the worst CQI among sets of UE to which the shared L1/L2 control information should be correctly decoded.

- **Effect of channel dependent scheduling gain**

The separate coding scheme has a high affinity to UE-dependent channel dependent scheduling since the control signaling bits can be transmitted from the assigned RBs.

It is shown that the combination of separate coding of the downlink transmission-related Cat. 1 information and separate coding between downlink transmission-related Cat. 1 information and Cat. 2 and 3 information require fewer radio resources than joint coding since the difference in the impact of the accuracy of link adaptation is much greater than that in the total number of control signaling bits and channel coding gain.

4.5 MBMS

MBMS transmissions are performed in the following two ways: Multi-cell transmissions and single-cell transmissions. Moreover, in the case of multi-cell transmission, tight inter-cell (Node B) synchronization, in the order of substantially less than the CP duration, can be optionally applied to enable UEs to simultaneously receive MBMS transmissions from multiple cell sites, so called SFN or Single Frequency

Network reception. To support multi-cell reception also in case of large cells with substantial propagation times, a long CP with the length of 16.67 μsec can be used in case of MBMS transmission.

4.5.1 Multiplexing of MBMS traffic

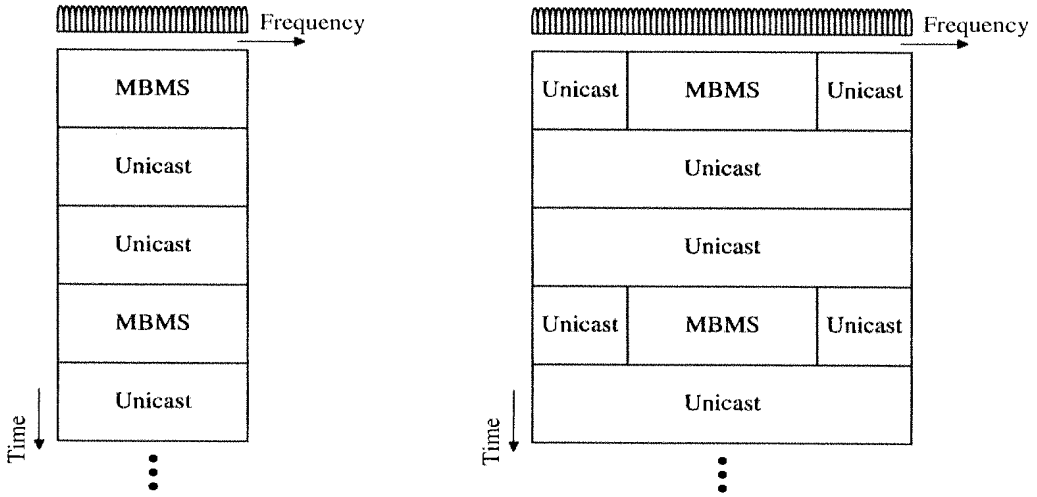
MBMS transmissions can be carried out on a separate carrier, with only MBMS transmission. Alternatively, MBMS transmission and unicast data traffic can share the same carrier.

In a system where Unicast and MBMS traffic are multiplexed into the same transmission band, TDM and/or FDM multiplexing are used. With TDM multiplexing, the MBMS traffic is transmitted in specific sub-frames using the same transmission band as the Unicast traffic. Moreover, TDM multiplexing of different MBMS streams is preferred in order to minimize the reception time of a specific MBMS stream. This enables lower power consumption for MBMS capable UE as shown in **Figure 14**.

Additional FDM multiplexing between MBMS traffic and unicast traffic is also supported and is especially required in case of an overall cell transmission bandwidths larger than the mandatory UE reception bandwidth capability.

4.5.2 Reference signal for MBMS

A reference signal for channel estimation of the MBMS channel is necessary in the MBMS sub-frame. In this case, channel gains are estimated using multiple reference signals with different time delays from multiple Node Bs providing MBMS service. Focusing on only MBMS traffic provisioning, it is sufficient to accommodate the



(a) Narrow over-all transmission bandwidth

(b) Wide over-all transmission bandwidth

Figure 14. Multiplexing of MBMS traffic

shared data channel providing MBMS traffic and cell-common scrambled reference signal in an MBMS sub-frame. However, the downlink L1/L2 control information such as the scheduling grant and ACK/NACK bit in hybrid ARQ is necessary for uplink data transmission. Therefore, the cell-specific L1/L2 control channel and cell-specific scrambled reference signal for decoding control signaling bits and channel-quality measurement must be multiplexed in the MBMS sub-frame. Thus, comprehensive designs of cell-common scrambled and cell-specific scrambled reference signals are required in the MBMS sub-frame. The following two candidates are considered for reference signal structures associated with the scrambled code for the MBMS sub-frame.

- **Cell-common scrambled reference signals associated with additional cell-specific scrambled reference signals**

In this structure, a cell-common scrambled code is multiplied to the reference signals, which are used for channel estimation of MBMS traffic symbols. Moreover, the additional cell-specific scrambled reference signals are necessary for cell-specific channel-quality measurement and for channel estimation of the L1/L2 control channel. It should be noted that different cell-common scrambled codes are used for different MBMS streams.

- **Cell-specific scrambled reference signals associated with the same cell-specific scrambled modulation between reference signals and data**

The cell-specific scrambled reference signal for channel estimation of MBMS traffic was proposed. In this method, when applying the same scrambling modulation in the frequency domain to the data symbols in the same MBMS sub-frame, the cell-specific scrambled reference signal is used for channel estimation of the MBMS traffic symbols without detecting the scrambling code information in each cell. The cell-specific scrambled reference signals are simultaneously used for cell-specific channel-quality measurement and channel estimation for the L1/L2 control channel. Thus, although the cell-specific scrambled reference signal can be used for channel estimation of MBMS traffic as well as L1/L2 control information, the interpolation of channel gains in the frequency and time domains cannot be applied since the set of UE does not know the scramble code assigned to each cell. Therefore, the reference signal with the same scrambled modulation as the original reference signal must be repeated to improve the channel estimation accuracy.

The cell-common and cell-specific scrambled reference signals were compared from the viewpoint of the achievable PER performance of the MBMS traffic symbols. It was reported that almost the same PER was achieved between the cell-common scrambled reference signal including the addition of the overhead for a cell-specific reference signal for the uplink L1/L2 control channel and the cell-specific scrambled reference signal including repetition of the reference signal, although the former exhibited slight superiority to the latter under the high mobility conditions due to the interpolation of channel gains both in the time and frequency domains. Accordingly, the cell-common scrambled reference signal is considered to be the current working assumption for reference signals in the MBMS sub-frame.

4.6 Shared Data Channel

4.6.1 Localized and Distributed Transmissions

In OFDM-based radio access, the granularity in the frequency domain is much narrower than that of DS-CDMA based 3G systems. Thus, frequency domain in addition to time domain (hereafter simply frequency domain) channel-dependent scheduling was proposed and its effectiveness in increasing the user throughput was investigated in several papers. In case of frequency-domain channel-dependent scheduling, the entire wideband signal is divided into resource blocks (RB) of continuous sub-carriers, (i.e. localized resource blocks). By dynamically assigning each RB to a UE with instantaneously good channel conditions at the corresponding frequency band, the user and cell throughput can be increased. This is also often referred to as multi-user diversity.

In a high mobility case, however, the control loop of channel-dependent scheduling cannot track the instantaneous fading variation and, consequently, the multi-user diversity effect can not be utilized to the same extent as in case of low mobility. In this case, discontinuous transmission in the frequency domain with a comb-shaped spectrum is more appropriate in order to, instead, achieve high-quality reception using frequency diversity over the entire transmission band. Thus discontinuous transmission is necessary to achieve high throughput and affinity to simultaneous localized transmission in the same sub-frame. The distributed OFDMA transmission is roughly categorized into sub-carrier-level transmission and RB-level transmission as shown in **Figure 15(a)** and **15(b)**, respectively. Sub-carrier-level distributed transmission provides a large frequency diversity gain due to the mapping of the transport channel to the physical channel at the sub-carrier level. Sub-carrier-level distributed transmission is achieved by puncturing bits of the localized transmission within the same RB. Therefore, the punctured-bit information for distributed transmission in addition to the RB information is necessary to demodulate the localized-transmission-UE. This brings about an increase in the number of control signaling bits for simultaneous transmitting sets of UE employing localized transmission. Moreover, the bandwidths or the transport block size of coexisting localized transmissions are changed according to the number of simultaneously assigned sub-carrier-level distributed transmissions.

Meanwhile, in the RB-level distributed transmission, the sets of UE employing localized transmission do not need information pertaining to the resource allocation of the sets of UE employing distributed transmission and vice versa. RB-level distributed transmission achieves simple radio resource assignment using the same RB unit as in localized transmission in a unified manner, although there is a slight sacrifice of the achievable frequency diversity effect. Thus, the RB-level distributed transmission seems more practical than the sub-carrier-level transmission from the viewpoint of simple radio resource assignment and the control signaling format. For low data-rate traffic such as VoIP, however, RB-level distributed transmission cannot obtain a sufficient frequency diversity effect because only one

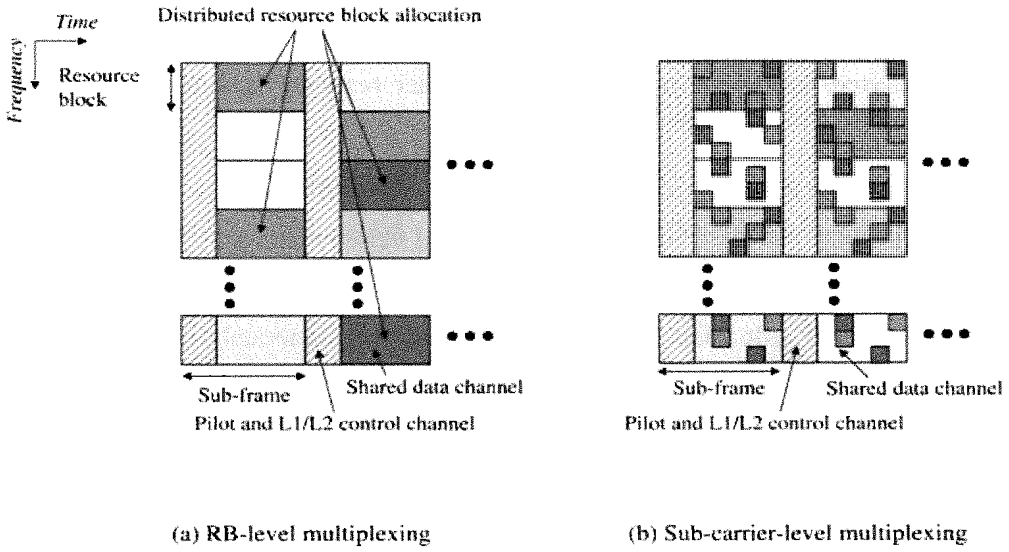


Figure 15. Sub-carrier-level and RB-level distributed OFDMA transmissions

RB size is sufficient to accommodate the payload size of such low-rate traffic. Therefore, block-wise RB-level distributed OFDMA transmissions with N_D-block divisions were proposed in order to obtain the frequency diversity effect even for low-rate traffic (here N_D indicates the number of VRBs within one PRB). In the block-wise RB-level distributed transmission, one or a few RBs are further divided into a few blocks each. The divided blocks with the size of $1/N_D$ of one RB are multiplexed to generate one RB that comprises N_D original RBs. In the block-wise RB-level distributed transmission, A RB that is assigned to distributed transmission, is segmented into N_D units (the RB is called a VRB. The N_D units of N_D sets of UE using distributed transmission are multiplexed into the one PRB. Therefore, in particular for small size traffic, which requires only one or a few PRBs in the original BR-level distributed transmission, we can increase the number of PRBs into the one distributed transmission that is multiplexed by employing the proposed N_D-block division. The N_D virtual distributed transmissions are multiplexed into the one PRB and virtual granularity in the frequency domain of resource assignment for the distributed transmission is identical to that for localized transmission. Furthermore, we do not allow multiplexing of distributed and localized transmissions in the same PRB. Meanwhile, in the sub-carrier-level distributed transmission, distributed transmission is multiplexed into the same PRB of the localized transmission by puncturing. Therefore, unlike sub-carrier-level distributed transmission, we can assign radio resources both to the distributed and localized transmissions in a unified manner in the RB-level distributed transmission. Moreover, in the scheme, the localized transmission channel can be decoded independently of the distributed transmission without applying control signaling on the resource assignment of distributed transmission, and vice versa. Meanwhile,

the puncture pattern information of the distributed transmission is necessary for localized transmission to decode the own channel. Therefore, the block-wise RB-level distributed transmission can achieve simpler resource assignment than sub-carrier-level distributed transmission.

4.6.2 Frequency domain channel-dependent scheduling

The Node B scheduler (for Unicast transmission) dynamically controls which time and frequency domain resources are allocated to a certain UE at a given sub-frame. Downlink control signaling informs UEs what resources and respective transmission formats have been allocated. The scheduler can instantaneously choose the best multiplexing strategy from the available methods, e.g. localized or distributed transmissions in the frequency domain. The flexibility in selecting RBs and multiplexing sets of UE will influence the available scheduling performance. Scheduling is tightly integrated with link adaptation and hybrid ARQ. The decision of which user transmissions to multiplex within a given sub-frame may for example be based on

- QoS parameters and measurements
- Payloads buffered in the Node-B ready for scheduling
- Pending retransmissions
- CQI reports from the sets of UE
- UE capabilities
- UE sleep cycles and measurement gaps/periods
- System parameters such as bandwidth and interference level/patterns

The UE is able to measure and report to the Node B the channel quality of one RB or a group of RBs, in the form of the CQI or Channel Quality Indicator. The achievable performance depends on the trade-off relation between the uplink signaling overhead and gains by frequency and time domain channel-dependent scheduling, and link adaptation taking varying channel-conditions and type of scheduling into account. Therefore, the granularity of the CQI reporting in the time and frequency domain is adjustable in terms of sub-frame units and RB units, and set on a per UE or per UE-group basis. CQI feedback from the UE, which indicates the downlink channel quality, can be used at Node B at least for the following purposes:

- Time/frequency selective scheduling
- Selection of modulation and coding scheme
- Interference management
- Transmission power control for physical channels, e.g., L1/L2-control signaling channels.

In a low mobility environment, when the round trip delay of frequency and time domain channel-dependent scheduling can track the instantaneous fading variation, high gain is achieved. However, in high mobility for a UE the gain in the channel-dependent scheduling is not obtained. In this situation, frequency hopping is beneficial to achieve high quality reception by randomizing the fluctuation of the received signal level in the frequency and time domains, in addition to distributed transmission.

4.6.3 Adaptive modulation and coding (AMC)

Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the shared data channel. Link adaptation uses either localized (for frequency selectivity) or distributed (for frequency diversity) transmission modes. The selection of localized or distributed transmission may be based on the service type, UE speed, packet size, or other factors. In the following discussion, we assume that one channel-coded block (stream) is transmitted from one user using multiple RBs. Note that in the case of localized transmission, the RB is defined as the minimum transmission bandwidth. The support of multiple channel-coded streams may also be necessary for segmenting large IP packets, etc.

In localized OFDMA transmission, three link adaptation methods are considered.

- RB-dependent adaptive modulation and RB-common channel coding rate method
- RB-common adaptive modulation and channel coding rate method
- RB-dependent adaptive modulation and channel coding rate method

In the RB-dependent adaptive modulation and channel coding rate method, the reliability of one coded bit differs among different RBs when the channel coding rate is changed according to the CQI within one coded block. Accordingly, the achievable channel coding gain is reduced compared to the other two methods. It was reported that the gain in the achievable throughput using the RB-dependent adaptive modulation from the RB-common modulation is small such as approximately 3%. This is because interleaving over multiple RBs assigned to one set of UE works well, and even the common modulation scheme is not optimum at each RB. Therefore, the same coding and modulation is applied to all groups of RBs belonging to the same L2 PDU scheduled to one user within one TTI and within a single stream. This applies to both localized and distributed transmission. **Figure 16** shows a block diagram for the RB-common modulation method. The operation of the method is as follows.

- CRC bits are attached at every L2 PDU and channel encoding is performed. The coding rate is common to all RBs.
- Channel interleaving is performed after hybrid ARQ transmission operation such as coding rate control.
- The interleaved coded block is segmented into multiple RBs.
- preading, e.g., repetition, may be performed as part of the channel coding or as part of the data modulation.
- A common modulation scheme is assigned to all assigned RBs regardless of the CQI information reported for the respective RBs. The modulation scheme and coding rate are decided from the average CQI information for all RBs assigned to the same sub-frame.
- Scrambling may be employed after adaptive modulation.

Note that when multiple RBs are assigned, they are not required to be adjacent. Clearly, the number of control signaling bits in RB-common modulation is reduced compared to that for RB-dependent modulation. Furthermore, in the case of multiple

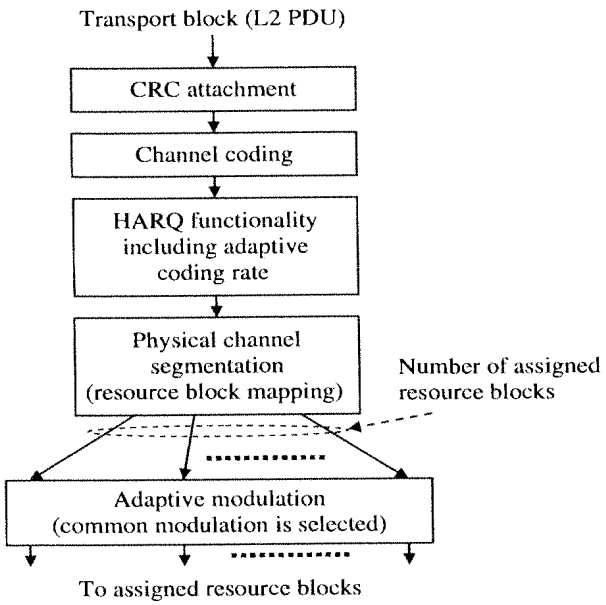


Figure 16. Resource block-common adaptive modulation and resource block-common channel coding rate scheme (for localized and distributed transmission modes)

channel-coded streams, the schemes in **Figure 16** may be separately applied to several different groups of RBs.

4.6.4 Hybrid ARQ

E-UTRA Hybrid ARQ is based on so called Incremental Redundancy, with Chase combining being a special case. Furthermore, an N-channel Stop-and-Wait Hybrid-ARQ protocol is used.

Hybrid ARQ is categorized into synchronous and asynchronous processing.

- Synchronous hybrid ARQ: The (re)transmissions for a certain hybrid ARQ process are restricted to occur at know sub-frame timings. Thus, explicit signaling of the hybrid ARQ process number is not necessary, since the process number is derived from e.g., the sub-frame number.
- Asynchronous hybrid ARQ: The (re) transmissions for a certain hybrid ARQ process can occur at any sub-frame. Therefore, explicit signaling for the hybrid ARQ process number is necessary.

The various forms of hybrid ARQ can be further classified as adaptive and non-adaptive schemes from the viewpoint of transmission attributes, e.g., RB allocation, modulation scheme, transport block size, and duration of retransmission. Each scheme has the following control channel requirements.

- Adaptive hybrid ARQ: Transmitter may change some or all of the transmission attributes used in each retransmission from those of the initial transmission due to, e.g., a change in the propagation channel conditions. Therefore, the associated

control information is to be transmitted together with the retransmitted RB(s) such as the modulation scheme, RB application, and duration of transmission.
- Non-adaptive hybrid ARQ: The changes in the transmission attributes for retransmissions are known to both the transmitter and receiver at the timing of the initial transmission. Therefore, the associated control information does not need to be retransmitted.

Assuming these categorizations, the HS-DSCH in WCDMA uses the adaptive, asynchronous hybrid ARQ scheme, while E-DCH in WCDMA uses the non-adaptive, synchronous hybrid ARQ scheme. Furthermore, the asynchronous, adaptive ARQ is the current working assumption in the E-UTRA downlink, similar to HD-DSCH. Therefore, Node B transmits the process number to a target UE associated with the UE ID, which is conveyed by modulation of CRC bits.

4.7 SCH and Cell Search Procedure

4.7.1 Cell search in OFDM based radio access

In the Evolved UTRA, a set of UE must acquire the best cell with the minimum path loss between the cell and the target UE. The cell acquisition process is called cell search. Similar to WCDMA, one-cell frequency reuse is the baseline in the Evolved UTRA, although the interference coordination using partial fractional frequency reuse is under discussion. In the cell search procedure, the UE acquires time and frequency synchronization with a cell and detects the Cell ID of that cell. The cell search procedure is categorized into the initial cell search and a neighboring cell search for handover. In this section, we mainly focus on the initial cell search. The assumptions for the cell search process in the Evolved UTRA are given below.
- The Evolved UTRA and UTRAN employ the 3G spectrum including additional spectra. This is also true in WCDMA. However, in addition, the GSM spectrum such as the 900-MHz frequency band is considered, which has a narrower frequency spectrum than 5 MHz. Therefore, the UE must search multiple frequency spectra in the initial cell search process.
- Similar to WCDMA, a set of UE must acquire a carrier frequency to connect to the target cell, which is on the frequency raster separated by every 200 kHz (or possibly a multiple of 200 kHz).
- Support of multiple transmission bandwidths from 1.25 to 20 MHz was decided. Meanwhile, a set of UE does not have any knowledge regarding the transmission bandwidth of the target cell. Thus, the UE must find the transmission bandwidth of the target cell from the candidates from 1.25 to 20 MHz.
- OFDM-based radio access was adopted in the downlink. Therefore, the SCH structure and cell search procedure, which is appropriate to OFDM, are necessary.

Cell search in the Evolved UTRA is performed employing two physical channels transmitted in the downlink, the SCH and BCH. Additional usage of a reference signal was proposed to detect, e.g., the cell ID. The primary purpose of the SCH is to acquire the carrier frequency and received timing, i.e., at least the SCH symbol timing of the downlink signal in the target cell. The primary purpose of the BCH

is to broadcast a certain set of cell and/or system-specific information similar to the current UTRA BCH transport channel. In addition to the SCH symbol timing and carrier frequency information, the UE must acquire at least the following cell-specific information.

- The overall transmission bandwidth of the cell
- Cell ID
- Radio frame timing information when this is not directly given by the SCH timing, i.e., if the SCH is transmitted more than once every radio frame
- Information regarding the antenna configuration of the cell (number of transmitter antennas)
- CP length information regarding the sub-frame in which the SCH and/or BCH are transmitted

Each set of information is detected by using the SCH, reference symbols, or the BCH.

4.7.2 SCH structure

The SCH in the downlink is necessary to detect the sub-frame timing, frame timing, cell-ID, etc. There are two different options for SCH structures: Hierarchical SCH and non-hierarchical SCH.

(1) Hierarchical SCH

The hierarchical SCH comprises a primary SCH (P-SCH) and secondary SCH (S-SCH) similar to the SCHs in WCDMA. The P-SCH has the same sequence, which is common to all cells. The S-SCH has a cell-specific, i.e., Node B-specific, sequence. The hierarchical SCH is suitable for cross-correlation based SCH-symbol timing detection (SCH-replica based detection). The SCH symbol timing of the target cell is detected by taking the correlation between the received signal and cell-common P-SCH replica in the time domain. It is required that the P-SCH code have a good auto-correlation property in the time domain.

In order to reduce the level of computational complexity inherent to the cross-correlation based detection, a layered (hierarchical) code structure in the time domain, which is adopted for the SCH in WCDMA, is beneficial. The P-SCH can be used as a reference to detect the S-SCH in the frequency domain after the SCH symbol timing detection. The S-SCH is used to detect the cell ID group, radio frame timing, and other control information conveyed by the S-SCH. For the S-SCH, many codes should be defined in order to carry many control information bits, and it is desirable that the detection of the S-SCH code be simple.

(2) Non-Hierarchical SCH

In non-hierarchical SCH, the SCH is mapped every N (N is greater than one) sub-carriers in the frequency domain within the same OFDM symbol duration. In this case, the same signal waveform is repeated N times within one OFDM symbol duration. Therefore, by detecting the auto-correlation of the repeated signal waveforms, the SCH symbol timing is estimated. The application of the Generalized Chirp Like (GCL) sequence to the non-hierarchical SCH was proposed. In

the non-hierarchical SCH, auto-correlation detection for all possible GCL sequence candidates can be simply implemented by performing one discrete Fourier transform (DFT). The auto-correlation based detection using a non-hierarchical SCH enables a lower level of computational complexity than the cross-correlation based detection using a hierarchical SCH. In contrast, it was reported that the SCH symbol timing detection probability by auto-correlation based detection becomes worse than that for cross-correlation based detection particularly under low received SINR conditions. This is because the influence of the background noise and interference is greater in auto-correlation based detection than in cross-correlation based detection.

The 3GPP agreed to employ the hierarchical SCH in which the cell search time performance is prioritized especially for handover cell search, which is conducted under very low SINR conditions.

4.7.3 Multiplexing of SCH

(1) SCH Transmission Bandwidth

The SCH structure is based on the constant bandwidth of 1.25 MHz regardless of the overall transmission bandwidth of the cell, at least for the initial cell search as shown in **Figure 17**. This is a result of the simple channel structure and simple acquisition operation being prioritized because the SCH is the first channel that a set of UE acquires without information about the transmission bandwidth.

(2) Multiplexing in Time domain

A small number of SCH symbols per radio frame is desirable in order to reduce the overhead. Furthermore, from the viewpoint of the timing detection performance against the background noise and interference, the signal energy of the SCH should be concentrated on a small number of OFDM symbols. Meanwhile, time diversity

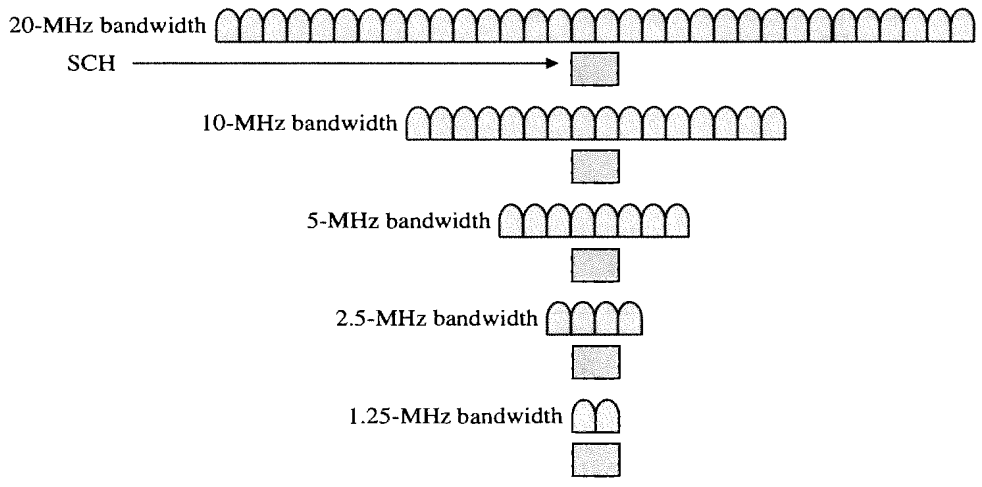


Figure 17. SCH transmission bandwidth

employing multiple SCH symbols is very effective in achieving fast cell search by improving the detection probability of the SCH particularly in a high mobility environment. As a result, it was decided that the SCH and BCH should be transmitted one or multiple times every 10-msec radio frame. The optimum number of SCHs per radio frame is to be specified from the cell search time performance including inter-radio access technology (RAT) measurement for various mobility conditions, and the impact on the TDD mode.

Next, we focus on the multiplexing of the SCH symbol in the sub-frame duration. The use of two types of CPs, short and long, was adopted mainly for Unicast and the MBMS. Assuming this condition, the SCH symbol mapping at the last OFDM symbol within a sub-frame was proposed as shown in **Figure 18**. In the SCH symbol mapping, the transmission timing of the SCH signal becomes identical regardless of the CP length. As a result, a set of UE can detect all SCH symbols for cell search without identifying the CP length of the SCH symbol.

(3) Multiplexing in frequency domain

As shown in **Figure 17**, the SCH is transmitted from the central part of the given spectrum regardless of the overall transmission bandwidth of a cell. Furthermore, the center frequency of the center sub-carrier of the SCH, i.e., over the entire transmission bandwidth of each cell site, is designed to satisfy the 200-kHz raster condition regardless of the entire transmission bandwidth of the cell site. By employing SCH multiplexing, a set of UE can detect the SCH on the 200-kHz raster and carrier frequency simultaneously irrespective of the total transmission bandwidth of the target cell. The system information and cell-unique information in the BCH is also transmitted from the central part of the total transmission bandwidth. Note that the current working assumption for the UE capability for the minimum reception bandwidth is 10 MHz. Thus, the SCH multiplexing in **Figure 17** was decided when the total transmission bandwidth of a cell site is 10 MHz or narrower. Three options for SCH multiplexing in the frequency domain were proposed when the total transmission bandwidth is 20 MHz.

Using the SCH multiplexing in the frequency domain, a set of UE first detects the central part of the spectrum of the best cell. Then, the UE moves to the

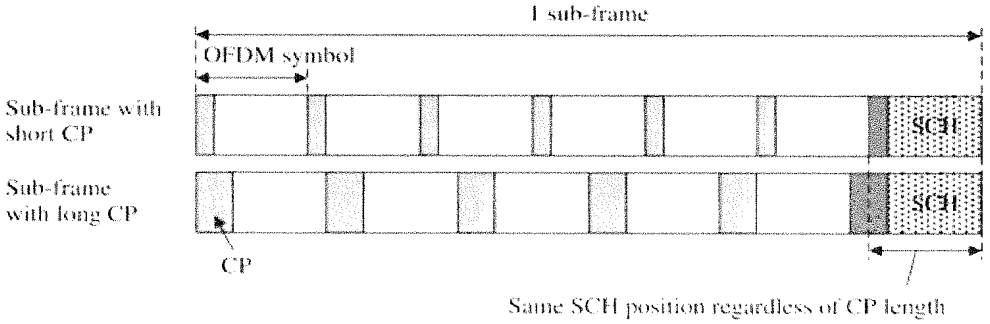


Figure 18. SCH symbol mapping

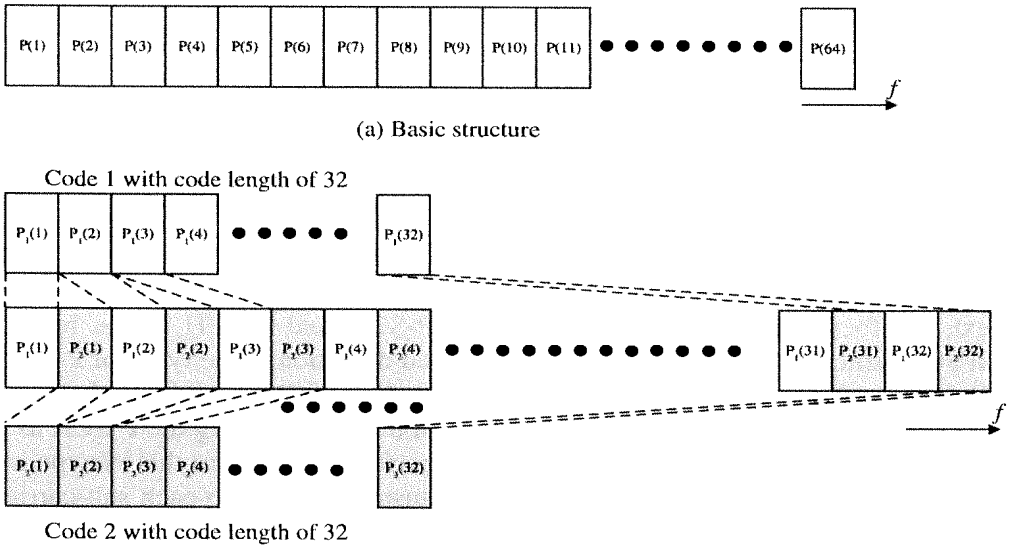
transmission bandwidth for actual communications. This transmission bandwidth for communications is assigned through the BCH from the Node B after the initial cell search. In the SCH multiplexing, the sub-carrier spacing does not have to satisfy the integer relationship with the 200-kHz frequency raster. Furthermore, we can avoid inefficient transmissions of the BCH signaling from any fractional transmission bandwidth. Since the transmission bandwidth for actual communications is assigned by the BCH from the cell site, each cell site can manage the transmission bandwidth assignment of the UE. As a result, unbalanced utilization of the spectrum of each cell site can be avoided.

Next, we focus on the multiplexing of the P-SCH and S-SCH in the hierarchical SCH structure. In the cross-correlation based detection, three types of P-SCH and S-SCH multiplexing methods are considered: FDM, CDM, and TDM. In the S-SCH correlation detection, coherent detection of the S-SCH using the P-SCH as a reference can improve the detection probability performance. From this viewpoint, FDM or CDM is desirable since the P-SCH is transmitted close to each sub-carrier of the S-SCH both in the time domain and in the frequency domain. Meanwhile, TDM is more advantageous than FDM in that the P-SCH does not suffer from interference from the S-SCH at the SCH timing detection in the time domain. Moreover, TDM can generate a larger number of S-SCH sequences compared to FDM since all the sub-carriers within a 1.25-MHz bandwidth can be used for the S-SCH transmission. Considering the advantages and disadvantages of the respective multiplexing methods between the P-SCH and S-SCH, TDM based multiplexing was decided as the working assumption in the 3GPP specification.

The number of codes for the S-SCH depends on the code length. Assuming the SCH transmission bandwidth of 1.25 MHz, the number of S-SCH codes per SCH symbol becomes less than approximately 70 because the maximum number of sub-carriers allocated to the 1.25-MHz SCH is 75. If the S-SCH code directly identifies the cell ID as proposed, the number of S-SCH codes is too small when assuming a 1.25-MHz transmission bandwidth. To solve this problem, M (typically two)-code interleaved mapping of the (S)-SCH using FDM within one OFDM symbol was proposed as shown in **Figure 19**. The resultant number of codes becomes $(N_{sym}/M)^M$ (N_{sym} indicates the number of S-SCH sub-carriers). For instance, when the code length is $N_{sym} = 64$, the number of total codes could be 1024 when $M = 2$, which is much larger than that when $M = 1$. By using the interleaved mapping of M codes, the frequency diversity effect is gained for the respective codes. In the auto-correlation based detection, coherent detection cannot be applied to detect the SCH. Thus, a SCH code sequence is assigned to the differential phase of the contiguous SCH sub-carriers in the auto-correlation based method whereas, we can assign it to the absolute phase of the S-SCH sub-carriers in the SCH-replica based method.

(4) Cell search procedure

In the method described, the cell ID (cell-specific scrambling code) is directly identified only by the SCH without using the reference signal. To enable flexible cell ID assignment, many cell IDs such as 512 for WCDMA, are



(a) Basic structure

(b) M-code interleaved mapping ($M=2$)

Figure 19. Proposed (S-)SCH mapping in frequency domain (example of basic code length of 16)

necessary. However, the number of cell IDs generated is limited by the SCH sequence length. Moreover, according to the increase in the number of cell IDs defined in the system, the cell search time becomes longer. The grouping of cell IDs was proposed, which is similar to WCDMA. The overall cell search procedure including the possible cell ID grouping is as follows as indicated in **Figure 20**.

- **SCH symbol timing detection**

First, the SCH symbol timing is detected following the detection of the OFDM symbol timing (FFT window timing). In the hierarchical SCH structure, the SCH symbol timing is detected from the correlation between the received signal and the SCH replica in the time domain. The repeated signal waveform arising from the decimation of the SCH sub-carrier in the frequency domain is detected in the auto-correlation based detection with the non-hierarchical SCH structure. Simultaneously, the carrier frequency of the target cell, which is on the 200-kHz frequency raster defined in the 3G system, is detected. The detection and compensation of the frequency drift can also be performed in this step.

- **Cell ID or Cell ID group index detection**

From the SCH symbol timing detected, the S-SCH or direct SCH sequence in the frequency domain is detected in the hierarchical or non-hierarchical SCH structure. The SCH sequence indicates the cell ID or cell ID group index when the grouping of cell IDs is used similarly to that in WCDMA. In addition to the cell ID or cell ID group index, the following information can be conveyed by the SCH sequence:

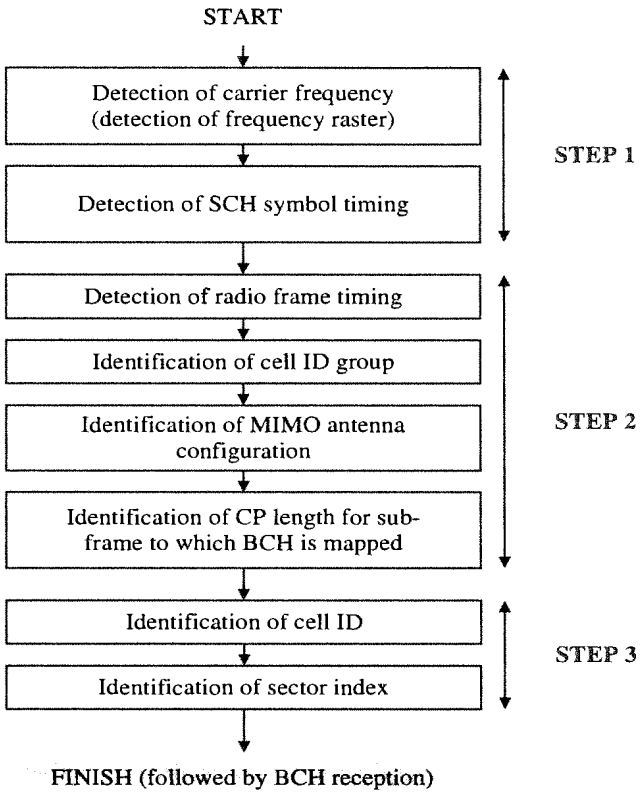


Figure 20. Flow of initial cell search procedure in Evolved UTRA

radio frame timing, MIMO antenna configuration, and CP length of the sub-frame with primary BCH, etc.

When the cell ID grouping is applied, the cell ID belonging to the group detected by SCH sequence in frequency domain and the sector index are identified. The detection of the cell ID is performed by taking the correlation between the received signal after FFT and the reference signal symbol replica. Even without cell ID grouping, the use of reference signal is beneficial for detecting sector index and for verification of cell ID.

5. UPLINK PHYSICAL CHANNEL

Uplink physical channels are categorized into the contention-based channel and scheduled based channel. Furthermore, the random access channel (RACH) is included in the contention-based channel. The reference signal, L1/L2 control channel, and shared data channel basically belong to the scheduled channel. In this section, we explain the structures and features of the E-UTRA uplink physical-channel structure related to

- Reference signals
- Random Access Channel (RACH)
- L1/L2 Control Channel
- Shared Data Channel

5.1 Uplink Reference Signal

Two uplink reference signals are defined in the E-UTRA uplink for two purposes.

- Demodulation reference signal: Used for channel estimation for uplink coherent demodulation/detection at a Node B
- Sounding reference signal: Used for channel-quality measurements for uplink frequency- and/or time-domain channel-dependent scheduling, link adaptation, etc.

The uplink demodulation reference signal, sounding reference signal, and data/control symbols are TDM-multiplexed using different LBs as show in **Figure 21**.

The transmission bandwidth of the demodulation reference signal is equal to the transmission bandwidth of the shared data channel or L1/L2 control channel. The demodulation reference signals are mapped onto the 4th and 11th LBs within 1-msec TTI (see also Fig. 4). Since only localized FDMA is used for the uplink shared data channel, the demodulation reference signals from different UEs are basically orthogonally multiplexed using localized FDMA within a TTI. However, when MIMO is used in the uplink (both in single-user and multiuser MIMO), orthogonal reference signals are also employed between multiple transmit antennas in the code domain as described in Section 4.1.1.

The bandwidth of the sounding reference signal is basically set wide to achieve frequency-domain channel dependent scheduling. However, if the UE at the cell edge transmits a wideband sounding reference signal, the CQI measurement error

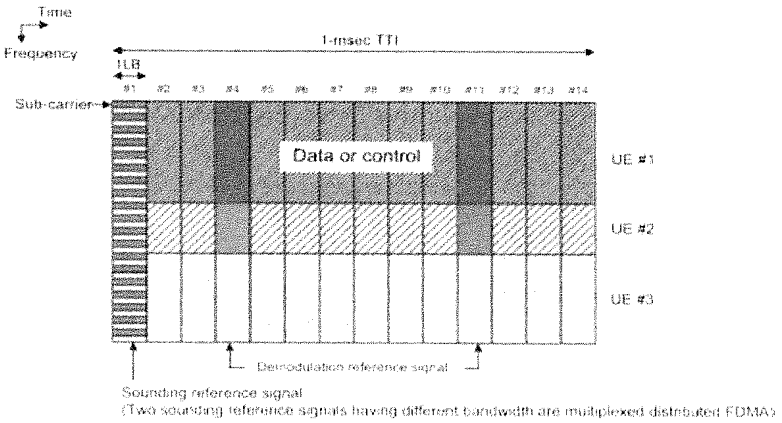


Figure 21. Orthogonal uplink reference signal structure

is increased due to the decreased received signal power density and the inter-cell interference caused by the sounding reference signal is increased. Thus, it is necessary to support multiple sounding reference signals with different transmission bandwidths.

Since the uplink transmissions are time-aligned within a CP, orthogonal sounding reference signals occupying the same LB and the same frequency block can be generated to accommodate different UEs within the same Node B in the uplink using either CDMA with the same spectrum or FDMA using a different spectrum as explained in the following section.

5.1.1 Orthogonal reference signals in code domain

In the uplink, synchronization of the inter-UE timing within a sample-duration is not maintained at the Node B input. Thus, if a random sequence is used for the reference-signal sequence, the reference signals will suffer from multi-access interference (MAI) and MPI. Therefore, a sequence with a good auto-correlation property is necessary such as the CAZAC sequence. However, the number of sequences is small when the CAZAC sequence is used as the reference signal sequence because the scrambled code cannot be used in conjunction with the CAZAC sequence. The number of available CAZAC sequences is limited according to the length of the CAZAC sequence, i.e., proportional to the sequence length. For instance, the number of Zadoff-Chu sequences is the number of integers relatively prime to the sequence length "N." Thus, assuming N is a prime number, the number of sequences becomes $(N-1)$ at maximum. Note that in a cellular system with one-cell frequency reuse, a sufficient number of reference signal sequences, i.e., at least the same number of sequences as cell IDs in WCDMA such as 512, is necessary to achieve flexible reference signal sequence assignment. By employing a cyclic shift based CAZAC code generation method, multiple CAZAC sequences are generated by cyclic shift of the original CAZAC sequence as shown in **Figure 22**. The cyclic shift based CAZAC sequences provide a good cross-correlation property to mitigate mutual interference within the duration of the cyclic shift value. The Zadoff-Chu sequence with the code length of N (here we assume N is an odd number), $a_u(k)$, is represented as

$$(4) \qquad a_u(k) = \exp\left(\frac{-j2\pi u}{N} \cdot \frac{k(k+1)}{2}\right), k = 0, 1, \ldots, \tilde{N}1.,$$

where u denotes the sequence index, which is a prime relation to the N value. When N is a prime number, the number of available sequences is (N-1). When cyclic shift is applied, the number of orthogonal CAZAC sequences becomes $L = \lfloor N/\Delta \rfloor$ for the sequence length of N. The resultant CAZAC sequence with cyclic shift, $a_{u,l}(k)$, is given in the next equation using the cyclic shift index l (l = 0, 1, ..., $\tilde{L}1$).

$$(5) \qquad a_{u,l}(k) = a_u\{(k + l \cdot \Delta) \bmod N\}, l = 0, 1, \ldots, \tilde{L}1.$$

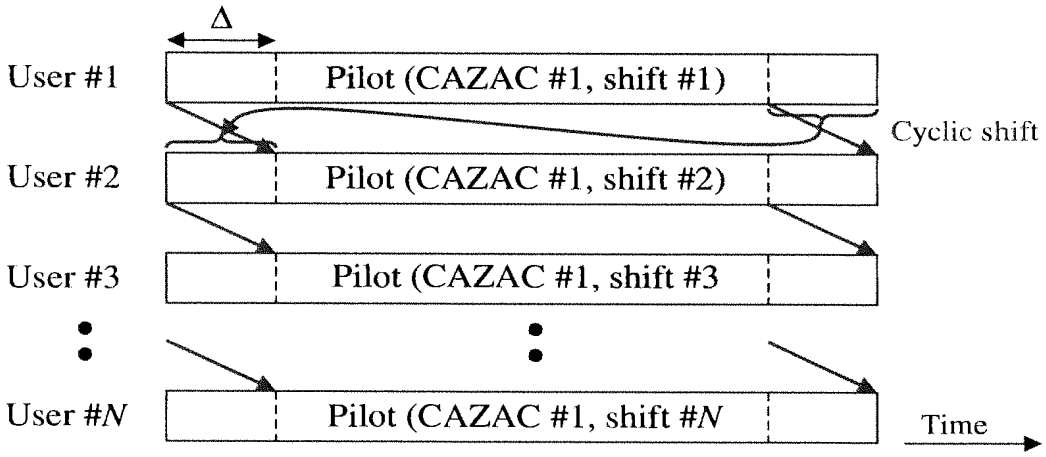


Figure 22. Cyclic shifted CAZAC sequence generation

The cyclic shift value, Δ, to achieve an orthogonal sequence is decided from the total received timing errors among simultaneously receiving sets of UE. Moreover, the total number of received timing errors arises from the timing errors of the maximum delayed paths and transmission timing errors, which synchronize the received timings of the downlink reference signals. Accordingly, by using the cyclic shift based CAZAC sequences, the orthogonality among sets of UE in the same transmission bandwidth is achieved. The cyclic shift based CAZAC sequences from the one original CAZAC sequence is used with priority. Thus, when all cyclic shift based CAZAC sequences from the one original sequence are used up, the cyclic shift based CAZAC sequences from the second sequence are employed.

5.1.2 Orthogonal reference signals in frequency domain

It is difficult to achieve orthogonality using CDMA among simultaneous sets of UE with different transmission bandwidths. Thus, FDMA is employed for multiplexing reference signals particularly with different transmission bandwidths. Employing distributed transmission provides channel gain over the assigned transmission bandwidth. Therefore, distributed transmission is used for multiplexing multiple reference signals using FDMA.

Furthermore, the orthogonal reference signal with the combination of CDMA and FDMA was proposed as shown in **Figure 21**. When distributed FDMA transmission is used, the sequence length of the reference signal becomes short in the time domain. Thus, in the method, the multiplexing using distributed FDMA transmission is restricted only to sets of UE with different transmission bandwidths. Instead, CDMA using the cyclic shifted CAZAC sequences are used for multiplexing sets of UE with the same transmission bandwidth. Thus, by combining FDM and CDM multiplexing, orthogonality among sets of UE with different and identical transmission bandwidths is flexibly achieved.

5.2 RACH

The RACH is used for the initial physical-channel set-upincluding resource request for channel-dependent scheduling in the uplink. A simple channel configuration is required for the RACH to achieve fast acquisition. The random access procedure is classified into two categories: Non-synchronized random access and synchronized random access.

5.2.1 Non-synchronized random access

(1) Purposes of non-synchronized random access

The non-synchronized random access is used when the UE is not time synchronized with simultaneously accessing UEs. The random-access procedure is based on the transmission of a random-access burst. The purposes of non-synchronized RACH are as follows.

- Received timing measurement for time alignment so that the UE transmission timing is adjusted within the CP duration. Note that in the Evolved UTRA uplink, the orthogonality among simultaneous accessing users in the frequency domain is maintained as long as the received timings are aligned within the CP duration.
- Request for UE ID that is given by the Node-B
- Uplink resource request for sending an L2/L3 message such as the Radio Resource Control (RRC) message, Non-Access Stratum (NAS) message, or detailed scheduling request information

(2) Resource assignment for non-synchronized RACH

Figure 23 shows the resource assignment for the non-synchronized RACH. The non-synchronized RACH is transmitted as a contention-based channel in the time/frequency resource, assigned by the Radio Resource Management (RRM) configuration. Prior to attempting non-synchronized random access, the UE shall synchronize with the downlink transmission. Thus, the transmission timing of the non-synchronized RACH can be determined based on the received timing of the downlink signal such as the downlink reference signal. The appropriate transmission power of the non-synchronized RACH can be determined through open-loop transmission power control so that distance-dependent path loss and shadowing variation are compensated. It is possible to vary the random access burst transmit power between successive bursts using power ramping with a configurable step size including a zero step size for both FDD and TDD or per-burst open loop power determination for the TDD case only. Frequency hopping at each RACH attempt is beneficial to improve the RACH detection.

(3) Structure of non-synchronized RACH

The non-synchronized RACH transmission consists of only a preamble, which achieves accurate detection of the RACH attempts including RACH receive timing. The required control signaling is implicitly carried by the preamble signature sequence. A preamble sequence having a good auto-correlation property such as

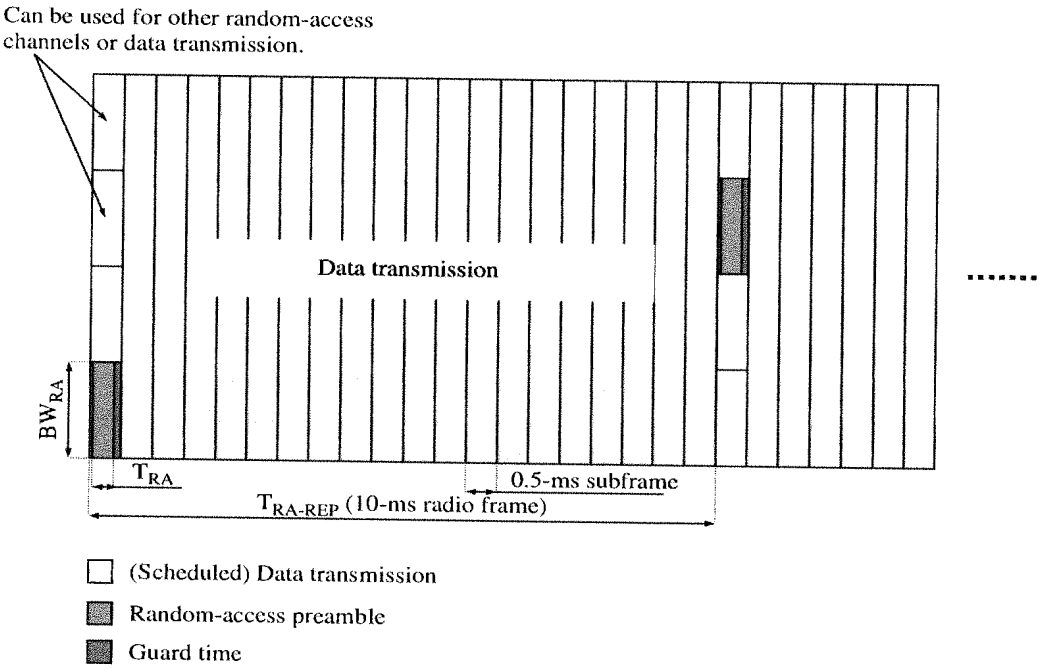


Figure 23. Resource assignment for non-synchronized RACH

a CAZAC sequence is used to achieve good detection probability. A small non-synchronized RACH control message is desirable to achieve a high detection probability and for a short delay of the physical channel setup. It was decided that the number of available information bits for the non-synchronized RACH is limited to four to six bits from the viewpoint of sufficient coverage provisioning.

An efficient transmission method for the required control signaling bits is necessary using the limited accommodated bit size. Thus, the grouping of the purposes for the non-synchronized RACH was proposed to achieve efficient required control signaling bits. **Table 3** shows the grouping of the purposes associated with the respective purposes. In the grouping scheme, purposes such as initial access, RRC re-establishment, and handover failure are grouped into the same purpose group. Moreover, uplink data transmission, uplink synchronization for downlink data reception, and inter-Node B handover are each assigned to a separate group. Thus, according to the grouping scheme, we need only a two-bit group index for the random access purpose in addition to a random ID for the non-synchronized RACH. Furthermore, for the purposes of initial access, RRC re-establishment, and handover failure, the UE requests the Node B to acquire the cell-specific UE ID, i.e., the Cell specific-Radio Network Temporary Identifier (C-RNTI). Meanwhile, for the purposes of the uplink data transmission, the uplink synchronization for downlink data transmission, and completion of handover, the UE can use the C-RNTI, which has been assigned from the connected Node B.

Table 3. Purposes of Non-synchronised RACH and Its Grouping

Purpose	UE has UE ID (C-RNTI)?	Contents of message part	Purpose group index
Initial access	No	L3 message (basically large message size)	#1
RRC re-establishment HO failure			
UL data transmission	Yes	UL scheduling request	#2
UL synchronization for DL data transmission		None	#3
HO complete		HO complete	#4

Therefore, from the group index of the random access purpose, the Node B can identify the need for the C-RNTI feedback and size of the message to be conveyed using the shared channel.

(4) Procedure of non-synchronized RACH

Figure 24 shows the procedure using the non-synchronized RACH with the proposed two-bit group index of the random access purpose. The non-synchronized random access is processed in one-step as follows.

- UE transmits the non-synchronized RACH.
  - The preamble sequence is selected according to the Random ID selected by the UE randomly. Otherwise, a random ID can be selected according to the rough CQI value or UE power headroom using a one-to-one corresponding manner.
  - The purpose group index is also indicated by the selected preamble sequence.
- Node B sends a response to the non-synchronized RACH via the downlink.

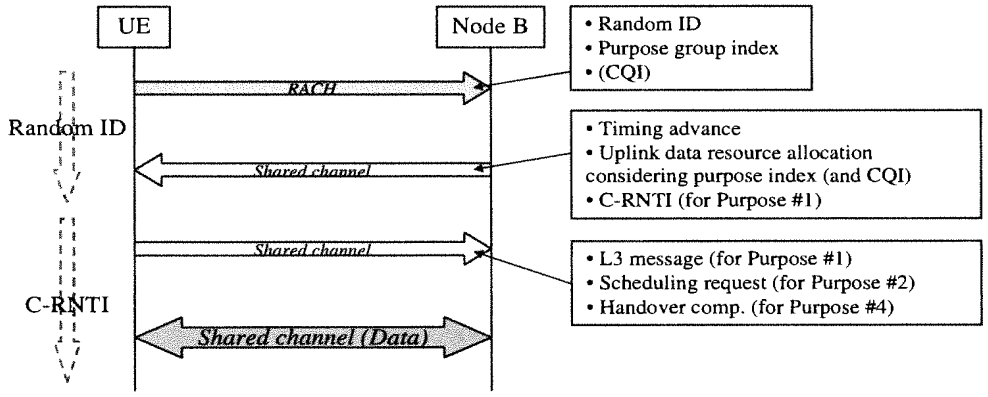


Figure 24. Non-synchronized random access procedure using RACH that transmits random ID and purpose group index

  - Timing adjustment is determined by the received timing of the non-synchronized RACH.
  - Uplink shared radio resources are allocated to the UE. The amount of the shared radio resources is determined by the expected message size that is indicated by the purpose group index and CQI value if available.
  - If the received purpose group index is #1, the Node B allocates new C-RNTI to the UE.
- The UE sends the control message information using the allocated uplink shared radio resources.
  - C-RNTI can be used to manage this shared channel transmission in the same way as that in the normal shared data channel transmission.
  - When the entire message is not transmitted using the initially assigned radio resources, additional shared radio resources are allocated by the Node B based on more accurate CQI.
  - hybrid ARQ can be applied.
- After finishing the RACH message transmission, actual data transmission starts.

5.2.2 Synchronized random access

Synchronized random access is used by the UE to request resources for uplink data transmission during the interval in which received timing alignment is maintained. One of the objectives of the synchronized random access procedure is to reduce the overall latency. Synchronized random access and data transmission are also time and/or frequency multiplexed.

Figure 25 shows the scheduling request in the active state. When the uplink scheduling grant is transmitted in the downlink L1/L2 control channel, the uplink shared data channel is transmitted from a set of UE using the assigned RB. Meanwhile, in the discontinuous reception (DRX) mode without uplink timing synchronization, the non-synchronized RACH is transmitted to establish uplink timing synchronization followed by a scheduling request procedure. Synchronous random access is employed in the active mode, during which the uplink timing synchronization is maintained; however, the uplink scheduling grant to assign RBs for the shared data channel is not transmitted over, e.g., several-hundred-milliseconds to several seconds.

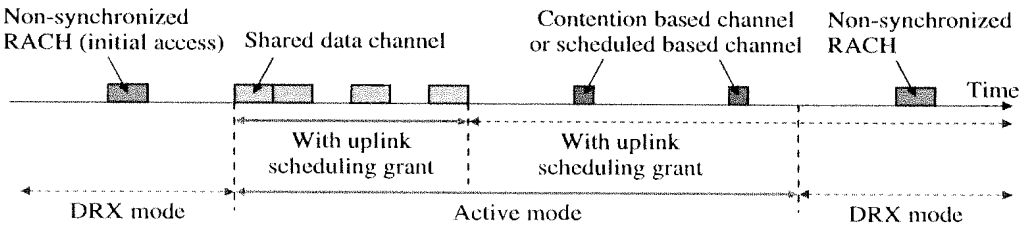


Figure 25. Scheduling request in active state

Therefore, during the active mode without shard data transmission, the following two functions are necessary.

- Transmission of scheduling requests
- Synchronization timing update, i.e., tracking of timing synchronization

The contention-based or scheduled based physical channels are considered to achieve these functions.

- Contention-based channels

In the contention-based mode, the synchronized random access channel is used for both purposes. In the case, the synchronized RACH for timing synchronization is transmitted asynchronously among sets of UE with a short delay. Establishing timing synchronization is not always guaranteed due to misdetection by contention with other channels.

- Schedule-based channels

In the scheduled-based mode, reference signal or CQI signal is used for synchronization timing update, and the L1/L2 control channel is used for scheduling requests instead in the schedule-based mode. Timing synchronization is accurately maintained without contention with other physical channels whereas, the physical channel for timing synchronization must be transmitted at the pre-assigned frequency and time resource, which leads to a delay longer than that for a contention based channel.

5.3 Uplink L1/L2 Control Channel

L1/L2 control signaling is essential to channel-dependent scheduling, link adaptation, and hybrid ARQ, etc. In the E-UTRA uplink, efficient and high-quality transmission of L1/L2 control signaling must be established while maintaining the low-PAPR feature of the single-carrier transmission in order to achieve a wide coverage area. Similar to the downlink, the transmission bandwidth capability of the UE should be taken into account in the design of the L1/L2 control signaling channel.

5.3.1 Uplink L1/L2 Control Information

The control signaling information conveyed by the L1/L2 control channel is as follows.

- Data-associated signaling, which is transmitted with uplink data transmission
  - Transport format (MCS information) of an uplink data channel, if the UE determines the transport format (if it is decided by Node B, this information is not necessary)
  - Hybrid ARQ related information of an uplink data channel, e.g., redundancy version and new data indicator
- Data-non-associated signaling, which can be transmitted regardless of the uplink data transmission states
  - ACK/NACK in response to downlink data transmission

- Downlink CQI for the purpose of downlink scheduling and link adaptation

In addition to the two types of data-non-associated signaling, scheduling request for uplink data transmissions can be transmitted by the L1/L2 control channel in the active mode.

5.3.2 Multiplexing of L1/L2 control channel

(1) TDM-based low-PAPR transmission of L1/L2 control information

There are three multiplexing combinations for the uplink reference signal, data, and L1/L2 control signaling within a sub-frame for a single set of UE.

- Multiplexing of the reference signal, data, and data-associated L1/L2 control signaling
- Multiplexing of the reference signal, data, data-associated, and data-non-associated L1/L2 control signaling
- Multiplexing of the reference signal and data-non-associated L1/L2 control signal in the data-associated control channel

It is necessary to multiplex the L1/L2 control signaling channel and shared data channel for the same UE within the same sub-frame. If the L1/L2 control signaling channel is multiplexed into the shared data channel using FDM (multicarrier) or CDM (multicode), the PAPR is increased. Therefore, as shown in **Figure 26**, TDM-based multiplexing of the L1/L2 control signaling channel into other physical channels was approved. The low PAPR property can be maintained by implementing one IFFT that takes advantage of the TDM-based feature.

(2) Multiplexing of L1/L2 control signaling

As was specified, E-UTRA supports multiple transmission bandwidths from 1.25 to 20 MHz. Accordingly, the L1/L2 control information must be transmitted in a unified manner to all types of UE that have different capabilities pertaining to the minimum maximum-transmission bandwidth. Therefore, similar to the downlink, we propose a block-wise transmission scheme for the L1/L2 control channel as shown in **Figure 27** that has the following features. The allocated system bandwidth of each cell is segmented into one or several frequency blocks.

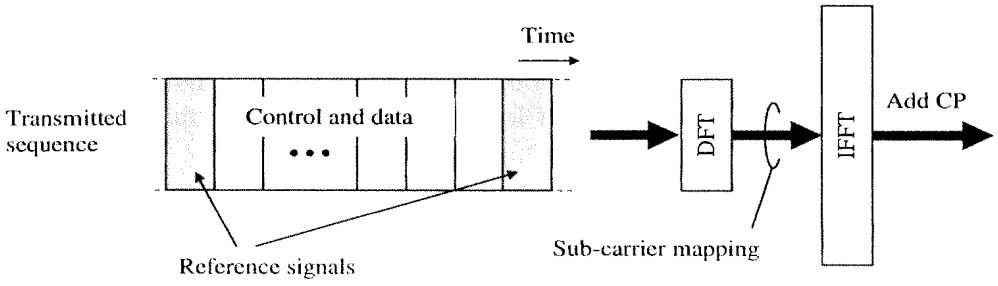


Figure 26. Transmission principle of TDM-based multiplexing

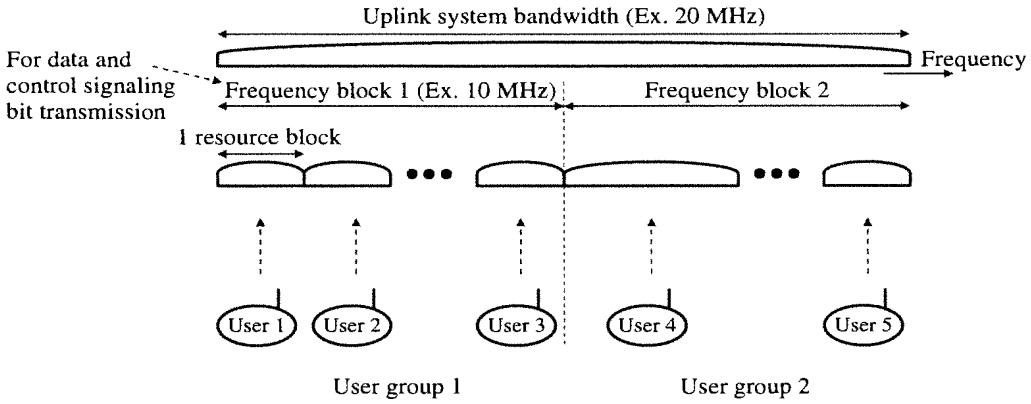


Figure 27. Example of block-wise transmission for L1/L2 control channel

- The pre-determined transmission bandwidth of the L1/L2 control channel should be equal to or less than the minimum maximum-transmission bandwidth in the UE capability.
- To each set of UE, at least one of the frequency blocks is assigned by Node B. The UE with a high capability uses multiple consecutive frequency blocks. Within the assigned frequency block, the UE transmits the L1/L2 control information, the reference signals for scheduling and demodulation, and the data channel transmission using one or multiple RBs within the pre-assigned frequency block.
- Frequency block assignment for each set of UE can be changed adaptively or by using a pre-determined manner. The purpose for changing the frequency block assignment is to average the traffic load of each frequency block and to avoid fatal transmission error due to, for example, severe frequency selective interference from other cells.

There are two methods to multiplex the data-non-associate L1/L2 control signaling bits from the UE without uplink shared data channel transmission: TDM within a sub-frame or FDM. In the TDM case, data-non-associated L1/L2 control information such as ACK/NACK and CQI signals are multiplexed into one block duration by TDM in a sub-frame, in which different assigned sets of UE transmit the shared data channel. In the same sub-frame, the reference signal of the data-non-associated UE is multiplexed with those of other sets of UE in the same block duration by distributed FDMA or CDMA. However, when TDM multiplexing within a sub-frame is used in the limited resource allocation to L1/L2 control signaling bits, the achievable coverage is decreased for a set of UE located at the cell boundary. Meanwhile, when the data-non-associated control signaling bits for sets of UE that transmit only the L1/L2 control signaling is multiplexed exclusively in a semi-statically assigned time-frequency region, i.e., FDM, wide coverage is provided, since the whole sub-frame duration is used for ACK/NACK and CQI transmission. However, the delay will be increased due to a long transmission interval since assigning an exclusive time-frequency region for the ACK/NACK and CQI to every sub-frame will severely degrade the signaling overhead in the uplink.

Therefore, to address the disadvantages of the above mentioned multiplexing methods, the multiplexing of ACK/NACK and CQI signals using separated multiple narrowband exclusive time-frequency regions with frequency hopping was proposed as indicated in **Figures 28**. In this figure, multiple narrowband time-frequency regions exclusively used for the data-non-associated L1/L2 control information such as ACK/NACK and CQI transmission are prepared at each sub-frame. Between the separated multiple time-frequency regions, frequency hopping is used to achieve frequency diversity (intra-sub-frame or inter-sub-frame frequency hopping). By using the narrowband exclusive time-frequency regions for ACK/NACK and CQI transmission, the overhead of the time-frequency resources for the ACK/NACK and CQI is reduced. The ACK/NACKs and CQIs of different sets of UE are multiplexed using the frequency/time/code domain or a hybrid of them within the assigned time-frequency region. The number of time-frequency regions for ACK/NACK and CQI transmission and the bandwidth of that at each sub-frame can be re-configurable according to the number of ACK/NACK and CQI signals.

5.3.3 Link adaptation for the L1/L2 control channel

At least the distance-dependent path loss and shadowing variation must be mitigated in the uplink in order to guarantee a high-quality PER. In scheduling-based packet access, the time-frequency resources are assigned to different sets of UE every sub-frame. The inter-Node B interference varies with a wide dynamic range every sub-frame, since the location of an interfering set of UE changes. Therefore, the effect of fast link adaptation, which compensates for the instantaneous fading variation, is unclear.

TPC based on CQI measurement (CQI-based TPC) was proposed. The transmission power is controlled based on the CQI measurement results, which are originally required for AMC and channel-dependent scheduling for the uplink data channel. The required transmission power (or required transmission power relative to the reference signal/data channel) is directly calculated based on the CQI value

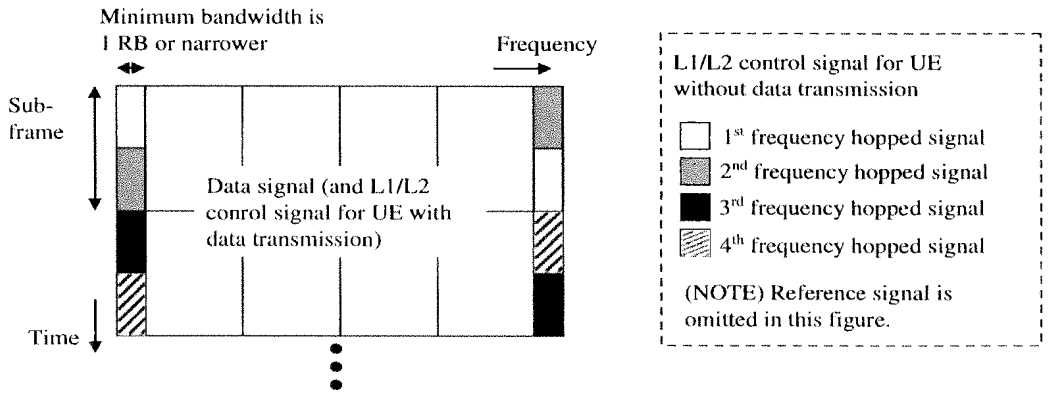


Figure 28. ACK/NACK and CQI multiplexing method using separated multiple narrowband exclusive time-frequency regions with frequency hopping

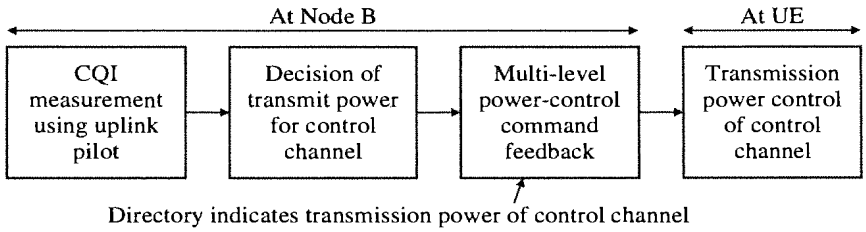


Figure 29. General description of fast transmission power control using multi-step power-control commands based on the CQI value for uplink

and fed back to the UE using multi-step power-control commands as shown in **Figure 29**. Therefore, CQI-based TPC does not need the history of its own transmission power. For the uplink data-associated control signaling channel, the MCS information for the uplink data channel is utilized as the power-control command. Therefore, no additional feedback command is required in the downlink. For the uplink data-non-associated control signaling channel such as ACK/NACK of the downlink shared data channel, the CQI of the downlink, and uplink scheduling request, multi-step power-control commands are fed back to the UE.

Furthermore, when the uplink L1/L2 control channel is transmitted with the data channel, in addition to the CQI-based TPC, a rough and slow adaptive modulation and coding rate including the repetition factor (AMC) can be applied. In this case, the relationship between the MCS used for the L1/L2 control channel and the data channel should be fixed. The use of AMC especially to control the coding rate and repetition factor in addition to the CQI-based TPC alleviates the limitation to the maximum transmission power of the UE, extends the coverage area, and improves the radio resource efficiency.

5.4 Shared Data Channel

5.4.1 Localized and Distributed Transmissions

In general, according to the increase in the transmission bandwidth, the channel quality is improved owing to the increasing frequency diversity. In the uplink, nevertheless, we must consider the restricted transmission power of a set of UE due to the battery usage. When the transmission bandwidth is excessively increased for the data rate, the received power spectrum density is reduced. Accordingly, the channel quality becomes worse since the increasing channel estimation error exceeds the improvement in the frequency diversity effect.

Next, we consider the orthogonal multiplexing of simultaneously accessing sets of UE in the frequency domain. Unlike in the downlink, the orthogonality using the distributed FDMA transmission is not perfectly achieved due to the residual synchronization and frequency offset error particularly for a narrow comb, i.e., sub-carrier, bandwidth. From the aforementioned two factors, the localized FDMA transmission

is considered for the shared data channel employing the adaptive transmission bandwidth according to the offered data rate.

5.4.2 *Channel-dependent scheduling*

In the uplink shared data channel, a certain frequency resource in a certain sub-frame, i.e., RU, is dynamically assigned to the target UE for uplink data transmission by the Node B scheduler. Downlink control signaling informs the set(s) of UE of what resources and the respective transmission formats that have been allocated. The selection of the sets of UE that are multiplexed within a given sub-frame is based on the following criteria.

- QoS parameters and measurements
- Payloads buffered in the UE ready for transmission
- Pending retransmissions
- Uplink channel quality measurements
- UE capabilities
- System parameters such as bandwidth and interference level/patterns

Among these, channel-dependent scheduling using the uplink CQI is effective in increasing the user and cell throughput associated with the combined usage with AMC including 16QAM modulation. Moreover, frequency domain channel-dependent scheduling is beneficial in improving the user and cell throughput performance levels in the uplink using SC-FDMA radio access as well as in the downlink OFDM radio access. To achieve frequency domain channel-dependent scheduling, a reference signal (pilot channel) with a wider transmission bandwidth than that for the shared data channel is necessary for CQI measurement before transmitting the shared data channel. However, with the limited maximum transmission power of a set of UE, an excessively wide transmission bandwidth for a reference signal for CQI measurement brings about increased CQI measurement error, and degrades the gain in the frequency domain channel-dependent scheduling for a set of UE located near the cell boundary.

Therefore, an adaptive transmission bandwidth of a reference signal for CQI measurement according to the path loss between a set of UE and a Node B was proposed. In the adaptive transmission bandwidth scheme, the UE, which is in a transmission-power-limited situation near the cell boundary, transmits a narrow-bandwidth reference signal to reduce the CQI measurement errors. Thus, the achievable throughput is improved since the improvement in channel-dependent scheduling by improving the CQI measurement accuracy exceeds the loss in frequency diversity effect. However, reference signals with different transmission bandwidths for CQI measurement are multiplexed using distributed FDMA. Moreover, a reference signal for demodulation, i.e., channel estimation for a shared data channel is multiplexed simultaneously within the same short block duration. Therefore, according to an increase in the number of reference signals multiplexed simultaneously using the distributed FDMA transmission, the sequence length of the reference signals becomes short. Accordingly, the number of reference signal sequences generated is decreased. Therefore, to avoid the decrease in the number

of reference signal sequences, group-wise frequency resource allocation of the reference signals for CQI measurement was proposed associated with an adaptive transmission bandwidth in the frequency domain channel-dependent scheduling. **Figure 30** shows the group-wised frequency allocation assuming two transmission bandwidths for reference signals for CQI measurement when frequency domain channel-dependent scheduling is applied. The transmission bandwidth of a reference signal for CQI measurement is assigned by a Node B according to the path loss between a set of UE and the Node B. A set of UE with a low path loss uses a reference signal for CQI measurement with a wide transmission bandwidth such as 5 MHz, whereas a set of UE with a high path loss, i.e., located near the cell boundary, employs a narrow transmission bandwidth such as 1.25 MHz for CQI measurement. Different reference signals with different transmission bandwidths for CQI measurement are multiplexed into different frequency bands using localized FDMA transmission, i.e., by group-wised resource allocation in the frequency domain. Therefore, a reference signal for demodulation is multiplexed with only one reference signal for CQI measurement to minimize the reduction in the number of reference signal sequences accommodated by distributed FDMA. Reference signals for CQI measurement with the same transmission bandwidth are multiplexed using CDMA employing the cyclic-shifted sequences originating from the same CAZAC sequence within the same short block.

Similar to the downlink, the gain of the frequency and time domain channel-dependent scheduling is reduced in a high mobility environment, since the feedback loop in the channel-dependent scheduling cannot track the instantaneous channel variation. In such a situation, frequency hopping is beneficial in randomizing the fluctuations in the received signal level. Frequency hopping can mitigate the fluctuation in the interference to the surrounding cells compared to the channel-dependent scheduling.

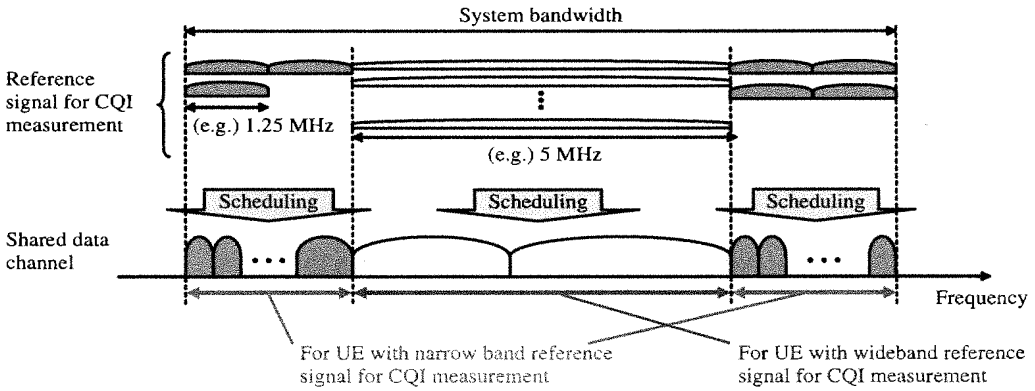


Figure 30. Group-wise frequency resource allocation of reference signals for frequency domain channel-dependent scheduling

5.4.3 Link adaptation

Link adaptation for the shared data channel is necessary in order to guarantee the required minimum transmission performance of each set of UE such as the user data rate, packet error rate, and latency, while maximizing the system throughput. Three types of link adaptation are performed according to the channel conditions, the UE capability such as the maximum transmission power and the maximum transmission bandwidth, and the required QoS such as the data rate, latency, and packet error rate. The three link adaptation methods are an adaptive transmission bandwidth, adaptive transmission power control (TPC), and adaptive modulation and channel coding (AMC). The transmission bandwidth is decided mainly from the data rate requirement. Slow TPC may be used so that the distance-dependent path loss and shadowing variation are compensated. Moreover, the transmission power of a set of UE is also controlled to suppress the interference to neighboring cells particularly when the UE is located near the cell boundary. Then, the optimum MCS is selected from the CQI information reported every TTI so that the required packet error rate is satisfied against the instantaneous multipath fading channel.

5.4.4 Hybrid ARQ

Incremental Redundancy is used as hybrid ARQ as well as in the downlink. Chase Combining is a special case of Incremental Redundancy and is thus implicitly supported as well. The N-channel Stop-and-Wait protocol is used for uplink hybrid ARQ similar to the downlink. Furthermore, the synchronous, non-adaptive ARQ is the current working assumption in the uplink. The retransmitted packet is transmitted from the sub-frame with the pre-decided delay from the initial transmitted packet. Therefore, the UE does not have to report the UE ID and process number to the Node B because the packet retransmission from the target UE is known to the Node B.

6. MIMO CHANNEL TRANSMISSION (MIMO MULTIPLEXING/DIVERSITY)

The MIMO channel transmissions such as MIMO multiplexing and MIMO diversity are considered in the E-UTRA. In particular, OFDM based radio access in the downlink has affinity to MIMO channel transmissions due to the robustness against time dispersion.

6.1 High level principles of MIMO channel transmissions

(1) Downlink

The baseline antenna configuration for MIMO channel transmissions in the downlink is two transmission antennas at the cell site and two reception antennas at the UE. Higher-order MIMO channel transmissions are also supported with the maximum antenna configurations of 4×4.

(2) Uplink
The baseline of the UE transmission is single-antenna transmission. Moreover, the baseline antenna configuration for single-user MIMO in the uplink is two transmission antennas at a set of UE and two reception antennas at the cell site.

6.2 MIMO multiplexing

(1) Downlink
In the Unicast mode, the following techniques are under discussion and are to be decided.

- **Single-user and Multi-user MIMO**

Both single-user and multi-user MIMO are supported in the downlink (note that multi-user MIMO is also called spatial division multiple access (SDMA)). In the single-user MIMO, Spatial division multiplexing (SDM) of multiple modulation symbol streams is solely assigned to a single set of UE using the same time and frequency (code) domain resources. Meanwhile, the modulation symbol streams are simultaneously assigned to different sets of UE using SDMA. The application of single-user or multi-user MIMO to a set of UE is determined by Node B in either a dynamic or semi-static manner.

- **Number of code words**

Multiple code words that use the same time and frequency domain resources and are independently channel-encoded are considered, in which CRC is attached to each code word. A single code word is included as a special case. The maximum number of code words per RB transmitted from the Node B is 1, 2, or 4. The maximum number of code words that can be received at a set of UE is fixed depending only on the UE capability. The number of code words per set of UE is restricted to, e.g., 2, from the viewpoint of the control signaling overhead.

- **Link adaptation**

Link adaptation is applied independently for each code word when multiple code words are transmitted to a set of UE with the control interval of 0.5 msec to a few milliseconds.

- **Pre-coding**

Multi-user MIMO is supported only with pre-coding. In pre-coding, the antenna domain MIMO signal processing is converted into the beam domain processing. Feedback information from a set of UE is necessary, which indicates the equivalent channel gain from each transmission antenna. Both codebook based and non-codebook based pre-coding are considered. In the codebook based scheme, the pre-coding vector(s) is selected from codebook(s) to reduce the control signaling overhead associated with the minimum size of the codebook. Regardless of the codebook usage, the feedback signaling should be minimized. The updating interval of the pre-coding vector is sufficiently short so that it can track the instantaneous channel variation such as 0.5 msec or longer. Since the pre-coding vector is updated

to track the instantaneous channel variation, the achievable performance gain, i.e., the generated beam associated with each set of UE, is degraded when the feedback of the channel gain from a set of UE cannot track the channel variation in a high mobility environment. Therefore, pre-coding is suitable for local areas with a relatively short ISD and with heavy traffic in the coverage area.

Adaptive beam forming with a narrow antenna separation is considered as an alternative method of pre-coding to achieve SDMA. Adaptive beam forming generates a directive narrow beam toward the direction of each UE. The feedback of the channel gain from a set of UE is not necessary, since it tracks only the direction of the UE (note that the direction of the UE is estimated from the direction of arrival of the received signal in the uplink). Therefore, adaptive beam forming is appropriate to increase the coverage area for large cells, which support low-to-high mobility sets of UE.

Rank adaptation

Rank adaptation is supported, in which an antenna subset of MIMO layers is selected according to the channel condition of each set of UE. When the rank is one, transmit diversity is used. The number of code words transmitted to a set of UE is controlled through rank adaptation when the UE supports multiple code words.

Antenna selection is also considered, in which only the number of transmission antennas is selected according to the channel conditions of the UE using the same MIMO scheme.

The MIMO channel transmission for MBMS is also discussed in the downlink. In an MBMS channel, transmitting a feedback signal from multiplexed sets of UE is not feasible. Thus, the potential candidate for MIMO channel transmission is an open loop scheme. In terms of transmit diversity, it seems that the additional diversity gain is small, since the large frequency diversity gains is already obtained due to delayed signals from multiple cell sites by soft-combining reception at a set of UE.

(2) Uplink

Both single-user and multi-user MIMO is supported in the uplink. A specific example of SDMA in the uplink is 2-by-2 multi-user MIMO, where two sets of UE transmit an uplink signal on a single antenna and share the same time and frequency domain resource allocation. There the sets of UE employ orthogonal reference signals for a Node B to separate respective streams from two sets of UE.

6.3 Transmit diversity

(1) Downlink

Transmit diversity is considered mainly for application to the control channels. In particular, open loop transmit diversity is considered for the downlink control channels. Various numbers of transmission antennas at a cell site must be supported. Similarly, various types of UE with different capability antenna configurations are supported. Thus, a unified transmit diversity scheme for the control channels is necessary regardless of the antenna configuration at the cell site and regardless

of the UE capability from the viewpoint of simplicity. The following open loop transmit diversity schemes are considered for the cell-specific control channels.

- Block-code based transmit diversity (STBC, SFBC)
- Time (or frequency) switched transmit diversity
- Cyclic delay diversity (CDD)
- Pre-coded transmission using selected pre-coding vector(s) including selection transmit diversity

(2) Uplink

In the uplink, the complexity of the UE transmitter is considered together with the achievable transmit diversity gain. The UE transmitter configuration with one RF chain, i.e., transmitter circuitry, and two antennas is considered as promising candidates for uplink transmit diversity. In the configuration, selection diversity with either open loop control or closed loop control is applied. The final adoption and scheme are decided from the substantial gain considering the performance loss such as insertion loss of the RF switch.

7. INTER-CELL INTERFERENCE MITIGATION

The improvements in frequency efficiency and user throughput near the cell boundary are very important requirements in the E-UTRA. Therefore, to achieve this, the following three techniques are discussed to mitigate inter-cell interference.

- Inter-cell-interference randomization
- Inter-cell-interference cancellation
- Inter-cell-interference co-ordination/avoidance

In addition to the above, the use of an adaptive beam-forming antenna transmitter/receiver at the cell site is a general method that can be considered as a means to mitigate inter-cell-interference.

In terms of inter-cell-interference randomization, the cell-specific scrambled code is applied to reference signals and other physical channels with repetition coding. The inter-cell-interference is suppressed in line with the processing gain.

In the inter-cell-interference cancellation, the following two methods are considered. First is spatial suppression based on, e.g., the MMSE criterion employing multiple antennas. Second is based on the detection and subtraction of inter-cell interference. In inter-cell-interference cancellation, the suppression gain, which is beyond what can be achieved by just taking advantage of the processing gain in inter-cell-interference randomization, is obtained.

In inter-cell-interference coordination, resource allocation is restricted through coordination between cells. The coordination of resource allocation at each cell is achieved by the configuration for the common channels and by scheduling for the scheduled based channel such as the shared data channel. The inter-cell-interference coordination restricts the time and frequency resources that are available to the resource manager or the transmission power that can be applied at a certain time and the frequency resources. The restrictions on the allocation of resources or transmission power will provide the possibility for improvement in the received

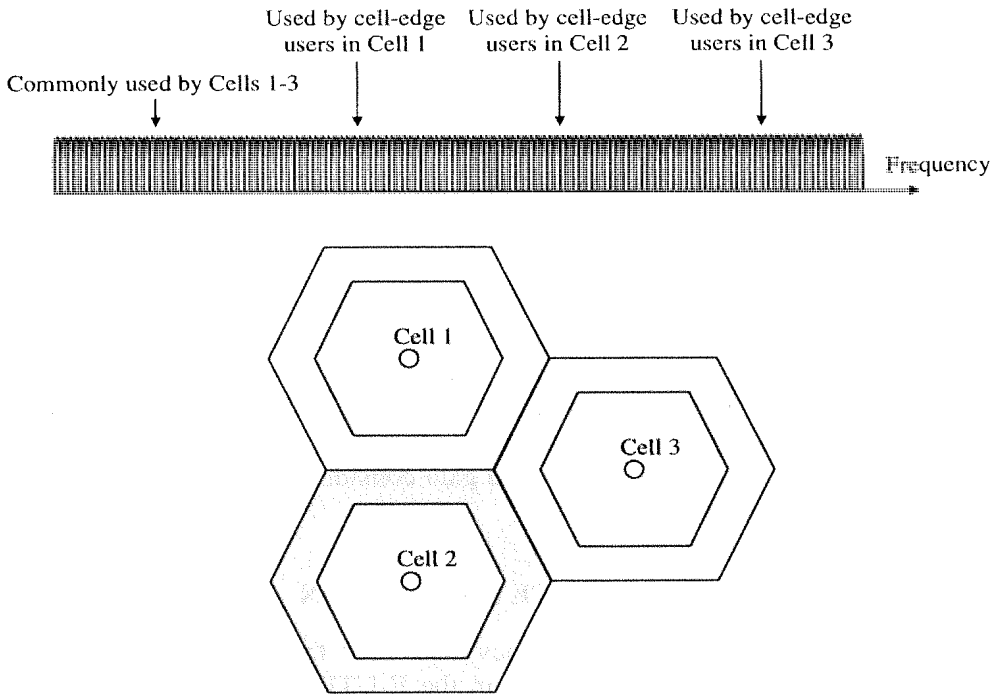


Figure 31. Principle of inter-cell-interference coordination

SINR and the achievable user throughput at the cell edge based on the corresponding time and frequency resources in a neighboring cell. **Figure 31** illustrates an example of the coordination of inter-cell-interference. As shown in the figure, one-cell frequency reuse is used in the central part near the cell site of each cell where the influence of other-cell interference is slight. Meanwhile, fractional frequency reuse is introduced in regions near the cell edge to avoid the influence of other-cell interference.

The coordination between cells is mainly achieved by a scheduler at each cell site independently, not by additional tight inter-Node B communication and/or additional UE measurements and reporting. In this case, certain inter-communications between different Node Bs will be required in order to set and reconfigure the scheduler restrictions. Two cases are considered: Static and semi-static interference coordination. The reconfiguration of the restrictions is performed on a time scale corresponding to days or seconds in the static or semi-static inter-ference coordination cases, respectively.

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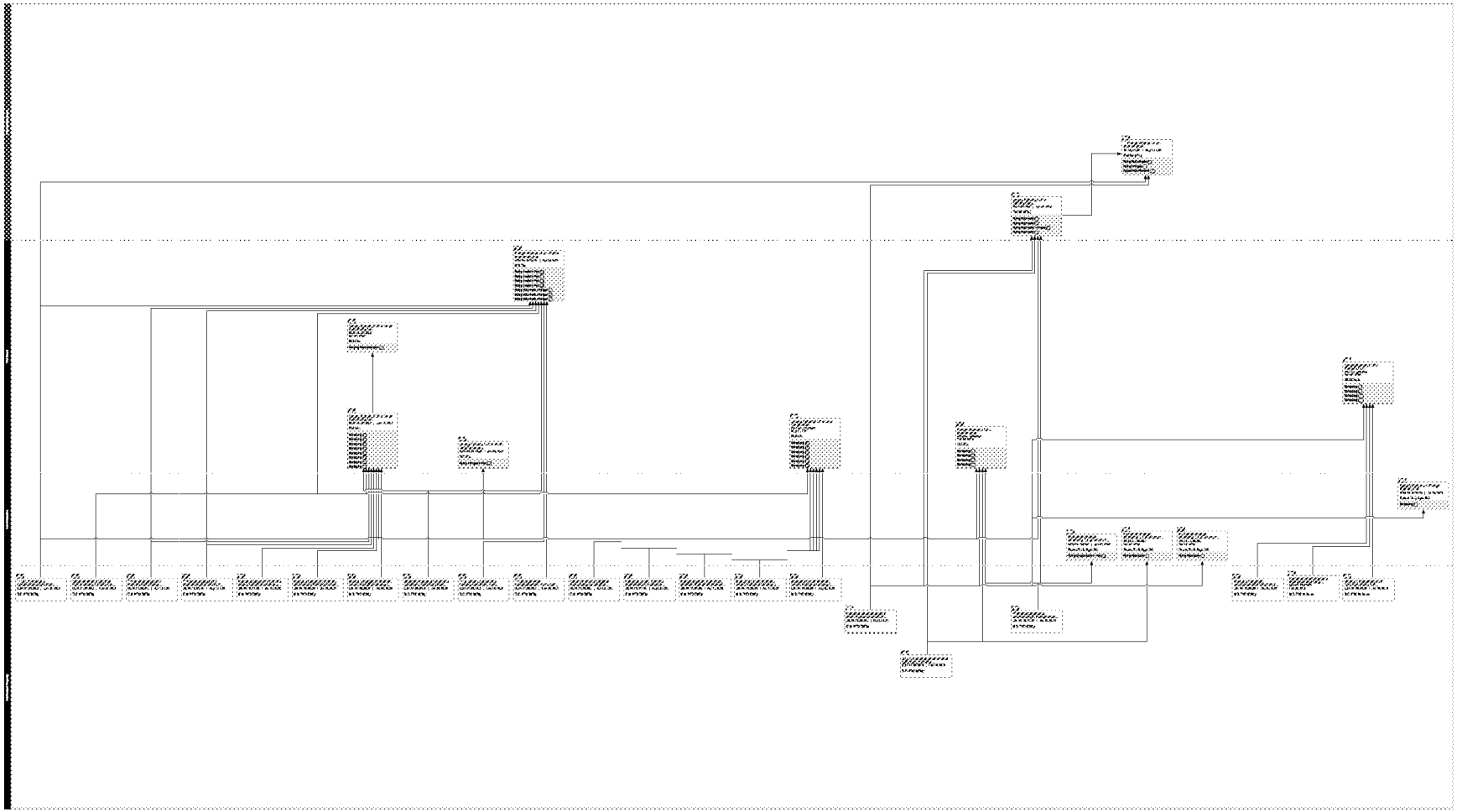
Search Notes

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Litigation: Cases Found

Status	Docket	Description
Closed	6:13cv1950	Omega Patents, Llc V. Calamp Corp.
Open	IPR2023-00504	Geotab USA, Inc. et al. Vs. Omega Patents, LLC
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1. ELASTIC LAMINATED FABRIC MATERIAL AND METHOD OF MAKING SAME Del. Of Pat.
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3. VEHICLE SECURITY SYSTEM FOR A VEHICLE HAVING A DATA COMMUNICATIONS BUS AND RELATED METHODS Del. Of Pat.
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US PAT 6346876 , U.S. PTO Utility , Feb. 12, 2002

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AND Ruled Not Invalid by

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Appeal After Remand

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Ruled Patentable by

26. EX PARTE OMEGA PATENTS, L.L.C. PATENT OWNER AND APPELLANT
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Construed by

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2011 WL 13176638 , M.D.Fla. , May 31, 2011

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US PAT 7305293 , U.S. PTO Utility , Dec. 04, 2007

Construed by

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US PAT 7671727 , U.S. PTO Utility , Mar. 02, 2010

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2015 WL 10568791 , M.D.Fla. , Feb. 20, 2015

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AND Ruled Not Invalid, Infringed by

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Appeal After Remand

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AND Ruled Not Invalid by

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Appeal After Remand

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Construed by

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Report and Recommendation Adopted by

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News

1. Omega Patents Wraps up One Case and Launches Another

National Law Review | Mar 11, 2013 | 490

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http://www.google.com/patents/US7671727?pg=PA1amp;dq=7,671,727amp;hl=enamp;sa=Xamp;ei=GpM3UeC2LcPfrAGm9IH4Awamp;ved=0CDYQ6AEwAA#v=onepageamp;qamp;f=false [8]:
http://www.google.com/patents/**US8032278**?pg=PA1amp;dq=8,032,278amp;hl=enamp;sa=Xamp;ei...

☐ US8032278B2 - Vehicle tracking unit with downloadable codes and associated methods

Original

Bibliographic information & Images

Publication number and date
US8032278B2
2011-10-04
Granted

Application number and date
US11773272 (/api/control?client=&query=AN:("US11773272")&autosearch=true)
2007-07-03

Priority number and date
US11773272 (/api/control?client=&query=PRN:("US11773272")&autosearch=true)
2007-07-03

Ultimate owner
Voxx International (/api/control?client=&query=uo:("Voxx%20International")&autosearch=true)

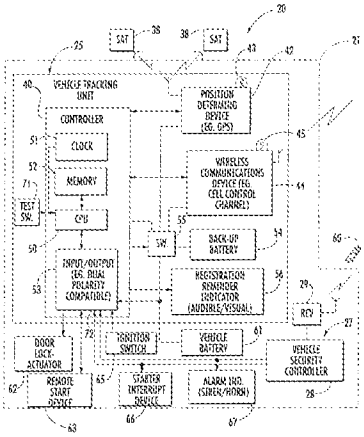
Original assignee
Kenneth E. Flick (/api/control?client=&query=pa:("Kenneth%20E.%20Flick")&autosearch=true)

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Legal representative
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1/14 Clipped image



Abstract

A multi-vehicle compatible tracking unit is for a vehicle including a vehicle data bus extending throughout the vehicle. The vehicle tracking unit may include a vehicle position determining device, a wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles. A downloading interface may be included for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller.

Original

Claims

1. A multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle, the multi-vehicle compatible tracking unit comprising: a vehicle position determining device; a wireless communications device; a multi-vehicle compatible controller for cooperating with said vehicle position determining device and said wireless communications device to send vehicle position information; said multi-vehicle compatible controller to be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles; and a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by said multi-vehicle compatible controller.

2. The multi-vehicle compatible tracking unit according to claim 1 wherein said downloading interface comprises a wired signal downloading interface.

3. The multi-vehicle compatible tracking unit according to claim 2 wherein said wired signal downloading interface comprises a connector for temporary connection to a downloading device.

4. The multi-vehicle compatible tracking unit according to claim 1 wherein said downloading interface comprises a wireless signal downloading interface.

5. The multi-vehicle compatible tracking unit according to claim 4 wherein said wireless signal downloading interface comprises a wireless receiver for temporary connection to a downloading device.

6. The multi-vehicle compatible tracking unit according to claim 1 wherein the corresponding at least one vehicle code is for reading from the at least one vehicle device.

7. The multi-vehicle compatible tracking unit according to claim 1 wherein the corresponding at least one vehicle code is for writing to the at least one vehicle device.

8. The multi-vehicle compatible tracking unit according to claim 1 wherein said downloading interface is also for permitting downloading of at least one programming instruction for said multi-vehicle compatible controller.

9. The multi-vehicle compatible tracking unit according to claim 1 further comprising a remote transmitter; and wherein said multi-vehicle compatible controller also performs at least one vehicle remote control function responsive to said remote transmitter.

10. The multi-vehicle compatible tracking unit according to claim 9 wherein the at least one vehicle remote control function comprises at least one of a vehicle security function, a remote keyless entry function, and a remote engine starting function.

11. The multi-vehicle compatible tracking unit according to claim 1 wherein said wireless position determining device comprises a Global Positioning System (GPS) receiver.

12. The multi-vehicle compatible tracking unit according to claim 1 further comprising a housing containing said vehicle position determining device, said wireless communications device, said multi-vehicle compatible controller, and said downloading interface.

13. A multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle, the multi-vehicle compatible vehicle tracking unit comprising: a vehicle position determining device; a wireless communications device; a multi-vehicle compatible controller for cooperating with said vehicle position determining device and said wireless communications device to send vehicle position information; said multi-vehicle compatible controller to be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles; and a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by said multi-vehicle compatible controller; said downloading interface comprising a connector for temporary connection to a downloading device.

14. The multi-vehicle compatible tracking unit according to claim 13 wherein the corresponding at least one vehicle code is for reading from the at least one vehicle device.

15. The multi-vehicle compatible tracking unit according to claim 13 wherein the corresponding at least one vehicle code is for writing to the at least one vehicle device.

16. The multi-vehicle compatible tracking unit according to claim 13 wherein said downloading interface is also for permitting downloading of at least one programming instruction for said multi-vehicle compatible controller.

17. The multi-vehicle compatible tracking unit according to claim 13 further comprising a remote transmitter; and wherein said multi-vehicle compatible controller also performs at least one vehicle remote control function responsive to said remote transmitter.

18. A multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle, the multi-vehicle compatible vehicle tracking unit comprising: a vehicle position determining device; a wireless communications device; a multi-vehicle compatible controller for cooperating with said vehicle position determining device and said wireless communications device to send vehicle position information; said multi-vehicle compatible controller to be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles; and a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by said multi-vehicle compatible controller; said downloading interface comprising a wireless receiver for temporary connection to a downloading device.

19. The multi-vehicle compatible tracking unit according to claim 18 wherein the corresponding at least one vehicle code is for reading from the at least one vehicle device.

20. The multi-vehicle compatible tracking unit according to claim 18 wherein the corresponding at least one vehicle code is for writing to the at least one vehicle device.

21. The multi-vehicle compatible tracking unit according to claim 18 wherein said downloading interface is also for permitting downloading of at least one programming instruction for said multi-vehicle compatible controller.

22. The multi-vehicle compatible tracking unit according to claim 18 further comprising a remote transmitter; and wherein said multi-vehicle compatible controller also performs at least one vehicle remote control function responsive to said remote transmitter.

Original

Families

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This section contains all family relations of this particular document. For more information about the different families, refer to the User Manual (Glossary/Families).

Extended (74) Priority date/claims	Complete (2) Priority date/claims	Main (2) Priority date/claims	Domestic (2) Priority date/claims	Publication number	Application number	Title	Status

2001-05-17 US09859673 US09859727 US09859728 US09859729 US09859733 US09859971 US09859972 US09859973 US10105487 US10105513 US10105654 US10105667 US10105676 US10105702 US10105751 US10105778 US10105825 US10105845 US10105852 US10105856 US10105858 US10105860 US10105892 US10105980 US10244361 US10325223 US10383496 US11075498 US11076259 US11076261 US11076309 US11076331 US11076570 US11077401 US11773272 US11844703 US14504987 US14505062 US60205178 US60222777 US60236890 US60246436 US60246463 US60251552 US60252125 US60258005 US60264811	2014-10-02 US09859727 US10105856 US14504987 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2014-10-02 US09859727 US10105856 US14504987 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2014-10-02	☐	USRE047354E	US14504987	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	Granted
	2014-10-02 US09859727 US10105856 US11077401 US14505062 US60205178 US60222777 US60236890 US60246436 US60251552 US60252125 US60258005 US60264811	2014-10-02 US09859727 US10105856 US11077401 US14505062 US60205178 US60222777 US60236890 US60246436 US60251552 US60252125 US60258005 US60264811	2014-10-02	☐	USRE047225E	US14505062	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	Granted
	2007-08-24 US09859972 US10383496 US11076259 US11844703 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2007-08-24 US09859972 US10383496 US11076259 US11844703 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2007-08-24	☐	US7671727B2	US11844703	Speed exceeded notification device for vehicle having a data bus and associated methods	Ceased
				☐	US20080030316A1	US11844703	SPEED EXCEEDED NOTIFICATION DEVICE FOR VEHICLE HAVING A DATA BUS AND ASSOCIATED...	Ceased
	2007-07-03 US09859972 US10383496 US11076259 US11773272 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2007-07-03 US09859972 US10383496 US11076259 US11773272 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2007-07-03	☐	US8032278B2	US11773272	Vehicle tracking unit with downloadable codes and associated methods	Granted
				☐	US20070279283A1	US11773272	VEHICLE TRACKING UNIT WITH DOWNLOADABLE CODES AND ASSOCIATED METHODS	Granted
	2005-03-10 US09859727 US10105856 US11077401 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-10 US09859727 US10105856 US11077401 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-10	☐	US7015830B2	US11077401	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	Granted
				☐	US20050190080A1	US11077401	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	Granted

2005-03-09 US09859972 US10383496 US11076331 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-09 US09859972 US10383496 US11076331 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-09	☐	US7305293B2	US11076331	Vehicle tracker including input/output features and related methods	Granted
			☐	US20050156718A1	US11076331	Vehicle tracker including input/output features and related methods	Granted
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2005-03-09 US09859972 US10383496 US11076259 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-09 US09859972 US10383496 US11076259 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2005-03-09	☐	US7720597B2	US11076259	Vehicle tracker including input/output features and related methods	Granted
			☐	US20050156716A1	US11076259	Vehicle tracker including input/output features and related methods	Granted
2003-03-07 US09859972 US10383496 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2003-03-07 US09859972 US10383496 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2003-03-07	☐	US7149623B2	US10383496	Vehicle tracker including input/output features and related methods	Granted
			☐	US20030154027A1	US10383496	Vehicle tracker including input/output features and related methods	Granted
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			☐	US20040201520A1	US10325223	Vehicle tracker with user notifications and associated methods	Ceased
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			☐	US20030018429A1	US10244361	Vehicle tracker with user registration reminder and related methods	Ceased
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2002-03-25 US09859727 US10105845 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105845 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6765499B2	US10105845	Vehicle tracker unit providing variable frequency transmission and related methods	Granted
			☐	US20020158778A1	US10105845	Vehicle tracker unit providing variable frequency transmission and related methods	Granted

2002-03-25 US09859727 US10105487 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105487 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6741187B2	US10105487	Vehicle tracker providing vehicle alarm alert features and related methods	Granted
			☐	US20020101365A1	US10105487	Vehicle tracker providing vehicle alarm alert features and related methods	Granted
2002-03-25 US09859727 US10105513 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105513 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6703946B2	US10105513	Vehicle tracking unit having a self diagnostic mode and related methods	Granted
			☐	US20020173887A1	US10105513	Vehicle tracking unit having a self diagnostic mode and related methods	Granted
2002-03-25 US09859727 US10105856 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105856 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6924750B2	US10105856	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	Granted
			☐	US20020163449A1	US10105856	Vehicle tracking unit for controling operable vehicle devices using a vehicle data bus and related methods	Granted
2002-03-25 US09859727 US10105654 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105654 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6798355B2	US10105654	Vehicle tracker including security device monitoring bypass feature and related methods	Granted
			☐	US20020156577A1	US10105654	Vehicle tracker including security device monitoring bypass feature and related methods	Granted
2002-03-25 US09859727 US10105980 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105980 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6844827B2	US10105980	Vehicle tracker including a connector for an upgrade device and related methods	Ceased
			☐	US20020105444A1	US10105980	Vehicle tracker including a connector for an upgrade device and related methods	Ceased
2002-03-25 US09859727 US10105751 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105751 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6784809B2	US10105751	Vehicle tracker including override feature and related methods	Ceased
			☐	US20020154034A1	US10105751	Vehicle tracker including override feature and related methods	Ceased

2002-03-25 US09859727 US10105825 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105825 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6771188B2	US10105825	Vehicle control system for controlling a vehicle function including a vehicle tracking unit and related...	Granted
			☐	US20020154036A1	US10105825	Vehicle control system for controlling a vehicle function including a vehicle tracking unit and related...	Granted
2002-03-25 US09859727 US10105860 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105860 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6765500B2	US10105860	Vehicle tracker including missed call feature and related methods	Ceased
			☐	US20020163450A1	US10105860	Vehicle tracker including missed call feature and related methods	Ceased
2002-03-25 US09859727 US10105852 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105852 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6803861B2	US10105852	Vehicle tracking unit with fault condition diagnosis and related methods	Granted
			☐	US20020105442A1	US10105852	Vehicle tracking unit with fault condition diagnosis and related methods	Granted
2002-03-25 US09859727 US10105858 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105858 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6819269B2	US10105858	Vehicle tracker including battery monitoring feature and related methods	Ceased
			☐	US20020105443A1	US10105858	Vehicle tracker including battery monitoring feature and related methods	Ceased
2002-03-25 US09859727 US10105702 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105702 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6744384B2	US10105702	Vehicle tracker having switchable polarity output terminals and related methods	Ceased
			☐	US20020154033A1	US10105702	Vehicle tracker having switchable polarity output terminals and related methods	Ceased
2002-03-25 US09859727 US10105676 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105676 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6737989B2	US10105676	Vehicle tracker including variable frequency transmission and related methods	Granted
			☐	US20020158777A1	US10105676	Vehicle tracker including variable frequency transmission and related methods	Granted

2002-03-25 US09859727 US10105667 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105667 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6693563B2	US10105667	Vehicle tracking unit providing theft alert notifications and related methods	Ceased
			☐	US20020190873A1	US10105667	Vehicle tracking unit providing theft alert notifications and related methods	Ceased
2002-03-25 US09859727 US10105892 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25 US09859727 US10105892 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2002-03-25	☐	US6816089B2	US10105892	Vehicle tracker having find alert features and related methods	Granted
			☐	US20020101366A1	US10105892	Vehicle tracker having find alert features and related methods	Granted
2001-05-17 US09859973 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859973 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US7031835B2	US09859973	Vehicle tracker cooperating with a starter interrupt and related methods	Ceased
			☐	US20020013660A1	US09859973	Vehicle tracker cooperating with a starter interrupt and related methods	Ceased
2001-05-17 US09859727 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859727 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6512465B2	US09859727	Vehicle tracker including stationary time determination and associated methods	Granted
			☐	US20020014978A1	US09859727	Vehicle tracker including stationary time determination and associated methods	Granted
2001-05-17 US09859971 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859971 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6507786B2	US09859971	Vehicle tracker with user registration reminder and related methods	Ceased
			☐	US20020016672A1	US09859971	Vehicle tracker with user registration reminder and related methods	Ceased
2001-05-17 US09859728 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859728 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6512466B2	US09859728	Vehicle tracker with power saving features and related methods	Ceased
			☐	US20020008644A1	US09859728	Vehicle tracker with power saving features and related methods	Ceased

2001-05-17 US09859733 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859733 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6509868B2	US09859733	Vehicle tracker with user notifications and associated methods	Granted
			☐	US20020021242A1	US09859733	Vehicle tracker with user notifications and associated methods	Granted
2001-05-17 US09859972 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859972 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6606561B2	US09859972	Vehicle tracker including input/output features and related methods	Ceased
			☐	US20020016673A1	US09859972	Vehicle tracker including input/output features and related methods	Ceased
2001-05-17 US09859729 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859729 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6809659B2	US09859729	Vehicle tracker with test features and related methods	Ceased
			☐	US20020008645A1	US09859729	Vehicle tracker with test features and related methods	Ceased
2001-05-17 US09859673 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17 US09859673 US60205178 US60222777 US60236890 US60246463 US60251552 US60252125 US60258005 US60264811	2001-05-17	☐	US6522267B2	US09859673	Vehicle tracker conserving codes and related methods	Ceased
			☐	US20020014977A1	US09859673	Vehicle tracker conserving codes and related methods	Ceased

Description

RELATED APPLICATIONS

[0001] The present application is a continuation-in-part of U.S. patent application Ser. No. 11/076,259 filed Mar. 9, 2005 now U.S. Pat. No. 7,720,597, which is a continuation of U.S. patent application Ser. No. 10/383,496 filed Mar. 7, 2003 now U.S. Pat. No. 7,149,623, which is a continuation of U.S. patent application Ser. No. 09/859,972 filed on May 17, 2001 now U.S. Pat. No. 6,606,561 which, in turn, was based upon provisional patent application Ser. Nos. 60/264,811 filed on Jan. 29, 2001; 60/258,005, filed Dec. 22, 2000; 60/251,552, filed Dec. 6, 2000; 60/252,125, filed Nov. 20, 2000; 60/236,890, filed Sep. 29, 2000; 60/246,463, filed Nov. 7, 2000; 60/222,777, filed Aug. 3, 2000; and 60/205,178, filed May 17, 2000, the entire contents of each of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to the field of vehicle devices, and, more particularly, to a tracking system for vehicles, and related methods.

BACKGROUND OF THE INVENTION

[0003] Motor vehicles, such as passenger cars, trucks, busses, fleet vehicles, etc. are widely used and knowing the locations of such vehicles is often desired. For example, should a vehicle be stolen, it would be beneficial to know the vehicle's location so that authorities could be promptly and accurately directed to retrieve the vehicle. Indeed, the tracking system could plot the getaway path of the thief.

[0004] For a company with hired drivers, it may be desirable to know the driver's whereabouts during the course of the day. Similarly, a rental car agency or other fleet operator, for example, may wish to know the whereabouts of its fleet of vehicles.

[0005] It may also be desirable to track the location of a vehicle as it is used throughout the course of a normal day. For parents of younger or older drivers, for example, knowledge of the vehicle's location may provide some assurance that the driver is at designated locations and following a prescribed route.

[0006] A number of patents disclose various systems and approaches to tracking vehicles. For example, U.S. Pat. No. 5,223,844 discloses a tracking system including a control center and a mobile unit installed in the vehicle. The mobile unit may send security warnings to the command center via a wireless transceiver. Position information for the vehicle is determined using a GPS receiver at the vehicle.

[0007] U.S. Pat. No. 5,515,043 discloses a similar system which may send one or more preprogrammed telephone messages to a user when away from the vehicle. The user may remotely access location information or cause certain commands to be carried out by entering a personal identification number (PIN).

[0008] The widespread availability and use of the Internet has prompted a number of vehicle tracking systems to also make use of the Internet. For example, TelEvoke, Inc. proposed such a system in combination with Clifford Electronics. The system was to provide notification, control and tracking services via the telephone or the Internet. Users could be notified via phone, e-mail, or pager of events such as a car alarm being triggered. Users could control the vehicle remote devices via phone, web, or PDA such as unlocking car doors. Additionally, users could track TelEvoke-enabled vehicles on the Internet or via the telephone. An Internet map could be viewed by the user showing the actual and prior vehicle locations. TelEvoke offered its services via a centralized fully automated Network Operations Center. To reduce the communications costs, it was proposed to use the control channel of the cellular telephone network.

[0009] There are, of course, a number of vehicles which come from the manufacturer with some form of security system already installed. In addition, a number of vehicles are also equipped with aftermarket security systems. Many conventional vehicle tracking units may not be readily installed in vehicles, particularly those vehicles already including a vehicle security system. In addition, complexity of installation may significantly increase the system costs.

[0010] A number of patents disclose various security and control systems that address data bus interoperability. For example, U.S. Pat. No. 5,719,551, assigned to Omega Patents, LLC, the assignee of the present invention, discloses a vehicle security system for a vehicle including a data bus connecting a plurality of vehicle devices. A signal enabling circuit enables the alarm controller to operate using a set of desired signals selected from a plurality of possible sets for different vehicles. U.S. Pat. No. 6,011,460, assigned to Omega Patents, LLC, discloses a similar system where the set of desired signals from the plurality of different sets of signals for different vehicles is obtained, such as by connection and communication with a downloading device. Additionally, U.S. Pat. No. 6,756,885, also assigned to Omega Patents, LLC, discloses a multi-vehicle control system whereby a multi-vehicle compatible controller stores a set of device codes for a given vehicle device for a plurality of different vehicles. Device codes are read from the data communications bus, and a match between a read device code and the stored device codes is determined to provide compatibility with different vehicles.

[0011] Unfortunately, such advanced techniques for dealing with multiple device codes for a vehicle having a data communications bus have not yet been developed for vehicle tracking units.

SUMMARY OF THE INVENTION

[0012] In view of the foregoing background, it is therefore an object of the present invention to provide a multi-vehicle compatible tracking unit which may be used to control operable vehicle devices, and/or read information therefrom via the vehicle data communications bus and related methods.

[0013] This and other objects, features, and advantages in accordance with the present invention are provided by a multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle. The multi-vehicle compatible tracking unit may include a vehicle position determining device, a wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for communication thereover with at least one vehicle device. The at least one vehicle device may use at least one corresponding vehicle device code from among a plurality thereof for different vehicles. The tracking unit may also include a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller. Accordingly, the multi-vehicle compatible tracking unit may be used to control operable vehicle devices, and/or read information therefrom via the vehicle data communications bus.

[0014] The downloading interface may comprise either a wired or wireless signal downloading interface. The wired signal downloading interface may comprise a connector for temporary connection to a downloading device, for example. The wireless signal downloading interface may include a wireless receiver for temporary connection to a downloading device. The wireless signal downloading interface may also be in the form of a connection to the wireless communications device used for sending position information. The downloading interface may also be for permitting downloading of at least one programming instruction for the multi-vehicle compatible controller, in some embodiments.

[0015] The corresponding at least one vehicle code may be for reading from the at least one vehicle device, and/or for writing to the at least one vehicle device. Further, the multi-vehicle compatible tracking unit may comprise a remote transmitter. At least one vehicle remote control function responsive to the remote transmitter may be performed by the multi-vehicle compatible controller. For example, the at least one vehicle remote control function may include at least one of a vehicle security function, a remote keyless entry function, and a remote engine starting function. Also, the wireless position determining device may comprise a Global Positioning System (GPS) receiver. A tracking unit may also include a common housing for its various components.

[0016] A method aspect is for using a multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle. The multi-vehicle compatible tracking unit may include a vehicle position determining device, a wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for connection thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality of thereof for different vehicles. The method may include downloading the enabling data related to at least one corresponding vehicle device code for use by the multi-vehicle compatible controller via a downloading interface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a simplified block diagram of a vehicle tracking system in accordance with the present invention.

[0018] FIG. 2 is a more detailed block diagram of the vehicle tracking unit as shown in FIG. 1.

[0019] FIG. 3 is a more detailed block diagram of the monitoring station as shown in FIG. 1.

[0020] FIG. 4 is a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating a vehicle stolen alert.

[0021] FIGS. 5A-5C are a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating a vehicle alarm sounding alert.

[0022] FIG. 6 is a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating a vehicle speeding alert.

[0023] FIG. 7 is a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating an unauthorized transmitter learned alert.

[0024] FIG. 8 is a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating a low battery alert.

[0025] FIG. 9 is a flowchart for operation of the vehicle tracking system as shown in FIG. 1 illustrating a GPS or cellular unit failure alert.

[0026] FIG. 10 is a simplified block diagram of a multi-vehicle compatible tracking unit in accordance with the invention.

[0027] FIG. 11 is a more detailed block diagram of an embodiment of the downloading interface as shown in FIG. 10.

[0028] FIG. 12 is a more detailed block diagram of another embodiment of a downloading interface as shown in FIG. 10.

[0029] FIG. 13 is a more detailed block diagram of yet another embodiment of the downloading interface as shown in FIG. 10.

[0030] FIG. 14 is a flowchart showing a method in accordance with the invention.

[0031] FIG. 15 is a flowchart showing another embodiment of a method in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0032] The present invention will now be described more fully hereinafter with reference to the accompanying drawings in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime notation and multiple prime notation are used to indicate similar elements in alternate embodiments.

[0033] Referring to FIGS. 1-3, the vehicle tracking system **20** in accordance with the invention is now initially described. The vehicle system **20** illustratively includes a vehicle tracking unit **25** to be mounted in the vehicle **21** and a monitoring station **30** which is remote from the vehicle and which is typically in a fixed location. In the illustrated embodiment, the vehicle tracking unit **25** interfaces with various vehicle devices, such as may include security sensors, door locks, etc. as will be appreciated by those skilled in the art.

[0034] The vehicle tracking unit **25** is also illustratively connected to a separate vehicle security system **27** as may already be installed in the vehicle **21**, from the factory or installed as an aftermarket product. Those of skill in the art will appreciate that in some embodiments of the vehicle tracking system **20** a separate vehicle security system **27** may not be needed, and/or various features thereof can be readily incorporated in the vehicle tracking unit **25**.

[0035] The monitoring station **30** may typically service a number of subscribers **31**. As shown perhaps best in FIG. 3, the monitoring station **30** may include a user interface, such as the schematically illustrated telephone network interface **33** and the internet interface **34** which are schematically coupled to a telephone **35**, and a computer **36**, respectively. Of course in other embodiments, other interfaces may be used and only one of the illustrated interfaces may be needed. Those of skill in the art will also recognize that messages may be sent to a subscriber or user via preprogrammed voice messages, e-mail messages, facsimile messages, pager alerts, etc. In addition commands or instructions from the subscriber can also be input to the monitoring station **30** via the telephone network interface **33** and/or the internet interface **34**, from the subscribers telephone **35** or computer **36**.

[0036] The monitoring station **30** is illustratively connected to a cellular telephone tower **32** which, in turn, may communicate with the vehicle tracking unit **25** in some embodiments. Of course, in other embodiments other communications approaches are also contemplated, such as, for example, including satellite communications.

[0037] The monitoring station **30** may typically include the necessary modems, and other communications electronics, and computers for its functions which are described in greater detail below. The configuration of such components and their details will be readily apparent to those skilled in the art. Accordingly, no further discussion of these details is needed.

[0038] Referring now more specifically to FIG. 2, additional details of the vehicle tracking unit **25** and devices at the vehicle are now further described. The vehicle tracking unit **25** illustratively includes a controller **40**, a vehicle position determining device **42**, and a wireless communications device **44** connected together. The vehicle position determining device **42** may be provided by a GPS receiver, for example. The GPS receiver typically operates by receiving multiple signals from spaced apart satellites **38** as will be appreciated by those skilled in the art.

[0039] In other embodiments, the vehicle position determining device **42** may be provided based upon communications with the cellular telephone network, or based upon other satellite transmissions, for example. As a particular example, time of arrival techniques are available based upon multiple reception paths to determine position via the cellular telephone network as will be appreciated by those skilled in the art. The vehicle position determining device **42** also illustratively includes an indicator **43** associated therewith, such as for indicating an operating mode, or proper operation of the device as will be addressed in greater detail below.

[0040] The wireless communications device **44** may be provided by a cellular telephone transceiver configured to operate on a control channel of the cellular network. Such a control channel may provide nearly universal coverage for the tracking system **20** as will be appreciated by those skilled in the art. In addition, the control channel may offer relatively inexpensive communications between the monitoring station **30** and the vehicle tracking unit **25** as will be appreciated by those skilled in the art. The wireless communications device **44** also illustratively includes an optional status indicator **45** with a similar function as the indicator **43** for the vehicle position determining device.

[0041] The wireless communications device **44** in other embodiments, may transmit in the voiceband of the cellular network. Alternately, the wireless communications device may communicate over other networks, such as over satellite, or via wireless internet services, as will be appreciated by those skilled in the art.

[0042] The controller **40** illustratively includes a central processing unit (CPU) **50** or other logic circuitry which is connected to a clock signal generator **51** and a memory **52**. In other embodiments, the memory **52** may be an embedded memory in the CPU **50**. The controller **40** also includes schematically illustrated input/output circuitry **53** to interface with various vehicle devices. In particular the input/output circuitry **53** may provide dual polarity compatibility for one or more inputs or outputs as will be described in greater detail below. One or more of the terminals of the input/output circuitry **53** may also provide both input and output functions as will also be described in greater detail below. This may significantly simplify and accelerate installation of the vehicle tracking unit **25** in the vehicle **21**.

[0043] Also illustratively shown as part of the vehicle tracking unit **25** are a back-up battery **54**, and switch **55** connected thereto for selectively powering certain of the components based upon the controller **40**. Of course, the vehicle **21** also includes an electrical system including the vehicle battery **61**. Powering of the vehicle tracking unit **25** is described in greater detail below.

[0044] The vehicle **21** also includes a number of other components that may relate to vehicle tracking, security, and/or convenience features provided by the vehicle tracking system **20**. For example, the vehicle **21** may include one or more door lock actuators **62**, an optional remote starting device **63**, a starter interrupt device **66** and an alarm indicator **67**. For example, the alarm indicator may be provided by a vehicle horn or vehicle siren, and/or flashing of the lights.

[0045] The optional separate security system **27** illustratively includes a vehicle security controller **28** and a receiver **29** connected thereto. As is conventional, the vehicle security system **27** may be switched between armed and disarmed modes, for example, by one or more uniquely coded remote transmitters **60**. The vehicle security controller **28** may also be capable of learning a new uniquely coded remote transmitter **60** as will be

appreciated by those skilled in the art. The vehicle security controller **28** also illustratively is connected to the starter interrupt device **66** and the alarm indicator **67**.

[0046] For ease of explanation, a number of the features of the vehicle tracking system **20** are now described. The vehicle tracking system **20** includes a number of features that may simplify installation and maintenance. For example, as shown in FIG. 2, the vehicle tracking unit **25** may have a test switch **71** connected to the controller **40**.

[0047] In normal operation, the controller **40** may be called upon to operate at least one vehicle device. Of course, the controller **40** also cooperates with the wireless communications device **44** and the vehicle position determining device **42** to determine and send vehicle position information to the monitoring station **30**. Moreover, the controller **40** may be switchable to a test mode for test operation of the at least one vehicle device responsive to activation of the test switch **71**.

[0048] In some embodiments, the at least one vehicle device may be a plurality of vehicle devices that are tested by operation in sequence. For example, the at least one vehicle device may comprise at least one door lock actuator **62**. The at least one vehicle device may also comprise the starter interrupt device **66**, or the engine remote starter **63** if remote starting is an implemented feature. The at least one vehicle device which is tested, may also be the alarm indicator **67**. Accordingly, an installer, for example, can quickly check that the tracking unit has been properly installed.

[0049] To further provide for ready determination of proper operation of the vehicle tracking unit **25**, one or both of the position determining and wireless communications devices **42**, **44** may include associated indicators **43**, **45** as mentioned briefly above, and which provide an indication relating to proper operation. Each indicator **43**, **45** may indicate a mode of operation of the device, its proper operation, or a partial or complete failure of the device.

[0050] Another aspect of the invention is that the controller **40** may provide a selectable polarity for the at least one vehicle device based upon sensing thereof. Accordingly, a predetermined activation of the test switch **71** may cause the controller **40** to sense and select the proper polarity. Pressing the test switch **71** for a predetermined time or in a predetermined pattern may sense and set the polarity.

[0051] Another feature of the vehicle tracking unit **25** and vehicle tracking system **20** relates to conservation of the number of codes or messages that need to be sent to the vehicle tracking unit. In particular, the controller **40** may have a plurality of different controller states and respond differently to a same message from the monitoring station **30** at different times depending upon the controller state at a given time. Accordingly, a number of codes or messages used by the system can be conserved. Various messages are described in greater detail below.

[0052] A controller state may change based upon several different occurrences or events. For example the controller may change states in response to a change in at least one vehicle device, or based upon a message received by the wireless communications device **44** from the monitoring station **30**, and/or based upon elapsed time. The controller states, for example, may include an alert sent state based upon an alert message being sent from the wireless communications device **44**. Thereafter, receipt of a predetermined message by the wireless communications device **44** when the controller **40** is in the alert sent state may confirm receipt of the alert message by the monitoring station.

[0053] Receipt of the predetermined message by the wireless communications device **44** when the controller **40** is in another state different than the alert sent state may thus cause a different response by the controller. The alert sent state may comprise at least one of a vehicle stolen alert sent state, a vehicle alarm sounding alert sent state, a vehicle speeding alert sent state, an unauthorized remote transmitter alert sent state, a low vehicle battery alert sent state, and a device malfunction alert sent state. The various alert messages and confirmation thereof are described in greater detail below.

[0054] The code or message conservation aspects of the vehicle tracking system **20** also permit sending a sequence of codes or messages within a predetermined time to also cause a different response at the vehicle tracking unit **25**. In other words, the plurality of controller states may comprise a received first message state based upon a first message being received by the wireless communications device **44** from the monitoring station **30**. Receipt of a second message by the wireless communications device **44** when the controller **40** is in the received first message state, such as within a predetermined time window, for example, may thus cause a different response by the controller than does receipt of the second message when the controller is in another state than the received first message state.

[0055] The plurality of controller states may comprise a vehicle finder state sounding an audible signal via the alarm indicator **67** at the vehicle **21**. In this state the controller **40** would bypass sending a vehicle alarm sounding alert to the monitoring station **30**.

[0056] Another aspect of the vehicle tracking system **20** is the provision of certain power conservation and management techniques, such as to permit extended periods where the vehicle **21** is not in operation. During such extended periods, the vehicle battery **61** provides power to the vehicle tracking unit **25** as well as other vehicle devices. Accordingly, the voltage of the vehicle battery **61** drops over time. The vehicle tracking unit **25** may provide a significant drain on the vehicle battery **61** because of the power consumed by the wireless communications device **44** during transmission as will be appreciated by those skilled in the art.

[0057] The vehicle position determining device **42**, the wireless communications device **44** and the controller **40** may be considered as defining a power load of the vehicle tracking unit **25**. The controller **40** may operate the schematically illustrated power switch **55** to isolate the back-up battery **54** from the power load as a voltage of the vehicle battery **61** drops until reaching a threshold. After or below the threshold the controller **40** may cause the back-up battery **54** to selectively power only a first portion of the power load while a second portion of the power load remains powered by the vehicle battery.

[0058] For example, the wireless communications device **44** may have a higher operating voltage than the vehicle position determining device **42**. The first portion of the power load that is selectively powered despite the low vehicle battery voltage may thus be the wireless communications device **44**. In particular, the wireless communications device **44** may be powered for transmission. Accordingly, the back-up battery **54** can be saved for limited communication using the higher voltage wireless communications device **44**. This provides useful features even after an extended period during which the vehicle **21** is left unattended and the vehicle battery **61** gradually discharges.

[0059] To further conserve power, the controller **40** may reduce operation of the power load as vehicle battery voltage falls. Conversely, the controller **40** may restore operation of the power load based upon the voltage of the vehicle battery **61** rising again, such as upon being recharged.

[0060] Also relating to power consumption, the controller **40** further causes transmission of a low vehicle battery voltage alert to the monitoring station **30** based upon the voltage of the vehicle battery **61** falling below the threshold. The user or subscriber may cause the monitoring station **30** to issue a remote start command. The controller **40** may then generate a remote start output to the remote start device **63** to thereby start the engine and recharge the vehicle battery.

[0061] Another feature of the vehicle tracking system **20** is that the vehicle tracking unit **25** may be readily installed and connected to a vehicle **21**, such as in the illustrated embodiment where the vehicle includes a starter interrupt device **66** and a separate vehicle security controller **28**. More particularly, the controller **40** may switch between an armed mode and a disarmed mode based upon operation of the engine starter interrupt device **66**. The controller **40** when in the armed mode may cooperate with the wireless communications device **44** to send an alert message to the monitoring station **30** and including vehicle position information, for example, based upon the vehicle position determining device **42**. The controller **40** is also for selectively operating the engine starter interrupt device **66** to provide additional security features.

[0062] In one advantageous embodiment, the controller **40** preferably comprises a combination input and output terminal for connection to the engine starter interrupt device. This terminal is at the input/output circuitry **53** and is schematically illustrated by reference numeral **72**. The controller **40** may switch to the armed mode when in the disarmed mode and based upon the engine starter interrupt device **66** being operated to disable engine starting. Conversely, the controller **40** may switch to the disarmed mode based upon the engine starter interrupt device **66** being operated to enable engine starting. In other words, the vehicle tracking unit **25** can piggyback its arming and disarming off the existing vehicle security system **27**, for example.

[0063] The controller **40** may also selectively operate the engine starter interrupt device **66** based upon a command message from the monitoring station **30**. The controller **40** may selectively operate the engine starter interrupt device **66** based upon a command message from the monitoring station **30**. Alternately, or in addition thereto, the controller **40** may selectively operate the engine starter interrupt device **66** based upon the ignition switch **65**.

[0064] The following descriptive portions relate to various user or subscriber notifications and features provided by the vehicle tracking system **20**. Of course, the controller **40** preferably cooperates with the wireless communications device **44** to send an alert message. The monitoring station **30** may comprise a user interface, such as one or both of the telephone network or internet interfaces **33**, **34**, respectively (FIG. 3), for generating a sequence of alert message notifications based upon receiving the alert message sent from the vehicle tracking unit **25**. More particularly, the monitoring station interface permits canceling any remaining alert message notification based upon a cancellation command response from a user or subscriber having already received the alert message notification. The user may send the cancellation response via the telephone **35** or computer **36** (FIG. 3), for example. Thus, if the user may be reached at different telephone numbers or different users are desirably notified of the alert, this aspect of the vehicle tracking system **20** can make the notifications efficiently and without making unnecessary notifications.

[0065] The vehicle tracking system **20** may provide any of a number of very useful alerts, as discussed herein. For example, the alert message sent from the vehicle tracking unit may comprise at least one of a vehicle stolen alert message, and a vehicle alarm sounding alert message. The alert message may be one of a vehicle speeding alert message, and a vehicle acceleration alert message. In addition, the alert message may comprise an unauthorized remote transmitter alert message. Also, the alert message may be at least one of a low vehicle battery alert message, and a device malfunction alert message.

[0066] The speeding alert may be based upon exceeding a speed threshold for greater than a certain time, which may be user selectable. The acceleration alert may also be useful as such is also indicative of aggressive driving along with the speeding alert. The unauthorized remote transmitter alert increases overall security since a user will be notified if a would-be thief learns an unauthorized transmitter to operate the controller. These alerts are described in greater detail below.

[0067] The vehicle tracking system **20** may be implemented as a service to a subscriber. In other words, the subscriber pays a monthly fee for the service. Accordingly, it may be important to encourage a user to register. Similar subscriber or registrations systems in the past have suffered revenue losses since some users would wait to activate the system until the vehicle was stolen. In other words, the user would only subscribe or register and pay a single month's fee.

[0068] In accordance with this aspect of the vehicle tracking system **20** prompt user registration is encouraged. In particular, the vehicle tracking unit **25** may include the user registration reminder indicator **56** and the controller **40** may be switchable from an unregistered mode to a registered mode. In the registered mode, the controller **40** may cooperate with the wireless communications device **44** and the vehicle position determining device **42** to determine and send vehicle position information to the monitoring station **30**. In the unregistered mode, the controller **40** may activate the user registration reminder indicator **56** to encourage registration by the user.

[0069] The controller **40** may be switchable to the registered mode based upon an activation message from the monitoring station **30**. For example, when the registration payment has been received, the monitoring station can send one or more messages to the vehicle tracking unit **25** to stop activation of the registration reminder indicator **56**. The indicator **56** may be audible, visual or both. For example, the registration reminder indicator **56** could be a beeping sound generated by a small piezoelectric transducer every ten minutes or so when the ignition **65** is on.

[0070] In other words, the user registration reminder indicator **56** may provide a minor but irritating annoyance to the user to encourage registration. Upon successfully registering, the annoyance is abated. Accordingly, a relatively straightforward approach is provided to encourage user registration.

[0071] Along these lines, the controller **40** when in the unregistered mode may have reduced features compared to the registered mode. For example, the controller **40** when in the unregistered mode may be restricted or limited in sending messages with the wireless communications device **44**. Accordingly, usage of the wireless communications network may be reduced. Transmissions from the vehicle tracking unit **25** may also be beneficially suppressed during original installation, for example.

[0072] Returning again to features of the vehicle tracking unit **25** which facilitate installation, the controller **40** may send an alarm indication alert responsive to a continuous activation of the alarm indicator **67** for greater than a predetermined time. Alternately, or in addition thereto, the controller **40** may send an alarm indication alert responsive to a repetitive pattern of alarm indicator **67** activations. In other words, the controller may be configured to distinguish between normal operation of a vehicle horn by the driver, and activation of the horn by the security system **27**. As mentioned above, the controller **40** may also monitor signals of at least one of a first and second polarity. The controller **40** thus advantageously piggybacks off the alarm indication generated by the vehicle security system **27** to determine and send a vehicle alarm sounding alert to the monitoring station **30**.

[0073] In one variation, the controller **40** may monitor signals delivered directly to the vehicle alarm indicator by the vehicle security controller **28**. In another variation, the controller **40** monitors signals of voltage dips of the vehicle battery **61**. Circuitry is conventionally and readily available for both such functions, as will be readily appreciated by those skilled in the art.

[0074] The controller **40** may also include a dual polarity compatible output in the input/output circuitry **53** for a vehicle device, such as the vehicle alarm indicator **67**. The controller **40** may further monitor signals relating to activation of the vehicle alarm indicator **67** and send an alarm indication alert with position information from the vehicle position determining device and using the wireless communication device.

[0075] For the dual polarity output compatibility, the controller **40** may generate a first polarity output pulse followed by a second polarity output pulse. The controller **40** may also generate a repeating pattern of a first polarity output pulse followed by a second polarity output pulse on the dual polarity compatible output. In yet other embodiments, the controller **40** may sense an actual polarity of the device and thereafter use the actual polarity for the dual polarity compatible output.

[0076] Where the vehicle device is a vehicle horn, the controller **40** may typically be configured to generate a negative polarity output on the dual polarity compatible output. Conversely, wherein the vehicle device is a vehicle alarm indicator siren, the controller **40** may be configured to generate a positive polarity output on the dual polarity compatible output.

[0077] Another aspect of the vehicle tracking system **20** relates to conserving memory space and/or reducing transmission time over the communications network. In accordance with this advantageous feature, the controller **40** may determine the vehicle position information including a vehicle location and an associated stationary period for each occurrence of the vehicle remaining stationary for greater than a predetermined period. In one embodiment, the controller **40** may cooperate with the wireless transmission device **44** to send the vehicle position information to the monitoring station based upon each occurrence of the vehicle remaining stationary for greater than the predetermined period. In this embodiment, the monitoring station **30** may associate a time with each occurrence of the vehicle remaining stationary for greater than the predetermined period. In other words, the monitoring station **30** may time stamp the received information.

[0078] In another embodiment, the controller **40** cooperates with the wireless transmission device **44** to send the vehicle position information to the monitoring station **30** for a plurality of occurrences of the vehicle remaining stationary for greater than the predetermined period. In this embodiment, the controller **40** may associate a time with each occurrence of the vehicle remaining stationary for greater than the predetermined period. In other words, the controller time stamps the position and stationary period information.

[0079] As an example, the predetermined time which determines whether the vehicle **21** is stationary and the position should be determined, may be less than about three minutes. This time may filter out vehicle stops in normal traffic, but which will keep track of stops where the driver likely leaves the vehicle **21**. Accordingly, only the important information necessary to track the vehicle need be stored and/or transmitted thereby reducing the system costs. If the vehicle **21** is stationary overnight, for example, unnecessary position information need not be determined, stored, and/or transmitted to the monitoring station **30**.

[0080] The controller **40** may comprise the memory **52** for storing the vehicle position information therein. In one configuration, the controller **40** downloads the vehicle position information from the memory **52** to the monitoring station **30** based upon a predetermined schedule. In another configuration, the controller **40** downloads the vehicle position information from the memory **52** to the monitoring station **30** based upon a predetermined event. In yet another configuration, the controller **40** downloads the vehicle position information from the memory **52** to the monitoring station **30** based upon a predetermined percentage of memory usage.

[0081] Having now described certain general features and advantages of the vehicle tracking system **20**, this description now turns to additional specific details which are provided as examples. In particular, vehicle tracking system **20** preferably implements one or more of the following features:

- a. Detects the vehicle being stolen and transmits a signal to the monitoring station to contact up to 3 people, for example, predetermined by the user, of theft of the vehicle and then starts tracking the vehicle. The contact may be by one or more of the following: an e-mail message, a pager alert, a cellular telephone call, or other telephone call.
- b. Detects an optional vehicle security or alarm system activation and transmits a signal to the monitoring station to contact up to 3 predetermined people to inform them the vehicle's alarm is being activated.
- c. Detects an optional vehicle alarm system's remote PANIC activation and transmits a signal to the monitoring station to contact up to 3 predetermined people to inform them of the vehicle's PANIC being activated.
- d. Detects a vehicle being programmed to operate from an unauthorized remote transmitter, key transponder, other transponder, or other device that has a unique coding, and the vehicle unit transmits a signal to the monitoring station to contact up to 3 predetermined people to inform them of this occurrence. The system can also make available information relating to a number of such coded devices, or a change therein, or when a change occurred. A message can be sent to the user or the information can be available to the user on the website. The vehicle would be equipped with a security system as disclosed in U.S. Pat. No. 5,654,688, for example, which determines an unauthorized transmitter and provides an alert feature. This patent is incorporated herein in its entirety by reference.
- e. Detects the vehicle traveling over a predetermined speed, such as for a predetermined time, and transmits a signal to the monitoring station to send a message, such as an e-mail informing the user (and/or others) of this occurrence. Of course, the message could also be sent via a telephone call or page, should additional urgency be required. The vehicle's predetermined maximum speed limit and duration thereof can be selected by the user.
- f. Detects a low battery voltage such as for a predetermined time and transmits a signal to the monitoring station to contact up to 3 predetermined people to inform them of vehicle's low battery voltage. This is especially advantageous during winter so that the vehicle could be started, for example, to prevent a problem before it happens. The time setting is preferably selectable by the user.
- g. Detects the vehicle not moving for a predetermined time and transmits a signal to the monitoring station to send, for example, a nightly e-mail informing the user of all the vehicle's location and stationary time occurrences. The stationary time length is also selectable. This may be advantageous to encourage patrolling personnel not to remain for a long time in a same location.
- h. The vehicle unit preferably includes a back-up battery system making it more reliable.

[0090] The vehicle unit may be relatively inexpensive. In addition, the monitoring fee that includes sending up to 60 e-mails and making up to 6 phone calls per month, may also be relatively low. The relatively low monitoring fee is based, at least in part, on the current relatively low rates charged for use of the control channel of the cellular telephone network. It is also noted that access to the control channel provides coverage for almost the entire U.S., for example.

[0091] The user or subscriber also preferably has access to an Internet site that will display a map and silently contact the vehicle to acquire its current location, speed, direction of travel, and previous multiple locations with speeds, for example, the user's personal identification number (PIN) can be quickly activated by a telephone call. No additional installation may be required.

[0092] Certain annual pre-pay package arrangements may be available. For example, up to 10 access entries per month can be provided on a low monthly billing. Up to 30 access entries could be provided also for a relatively low monthly fee.

[0093] The present invention provides a number of other significant advantages including optional access from any phone or from any computer to access the monitoring station internet site. The user may control various vehicle functions remotely via the telephone or the internet site. The only charge may be for additional equipment and installation.

[0094] Additional features can also be included with the system and subscribed to by the user in accordance with the invention. For example, these include Hijack, Car Finding, Unlock Doors and Unauthorized Transmitter Alert Features. The equipment and installation is relatively inexpensive. For the hijack feature: from any phone or computer, the user may activate vehicle starter interrupt and sound the horn until the vehicle is retrieved (Command 4).

[0095] For the Car Finding feature: from any phone or computer, the user may activate the vehicle's horn, or siren and sound same for 30 seconds. This allows the user to find his vehicle in a crowded parking lot (Command 5).

[0096] For the Lock/Unlock vehicle doors feature: from any phone or computer a predetermined command (Command 7) activates unlocking of vehicle doors to retrieve keys, for example, that may have been accidentally locked inside the vehicle. Of course, the system can also be used to lock vehicle doors if this was forgotten (Command 6). The unauthorized transmitter alert feature is similarly selected as described above.

[0097] In addition, a remote vehicle start feature may also be provided, such as to start the vehicle's engine to heat or cool the vehicle prior to entry. The equipment and installation for remote starting may be relatively low. Some further details of a specific embodiment of the vehicle tracking unit **25** are provided below as relating to use of red and green LED indicators as may be coupled to the controller **40** and operated thereby. Also various representative wires, designated by color, are provided as an example embodiment.

[0098] The red LED verifies the GPS receiving signal. With a yellow wire having positive 12 volts, the red LED blinking indicates searching GPS location, constant indicates found location, and off indicates no GPS signal found. With the yellow wire not having positive 12 volts, if the red LED is off, the LED is not functioning.

[0099] The green LED verifies receiving the cell tower signal. With the yellow wire having positive 12 volts, blinking indicates the cell control channel signal is detected, constant indicates sending a micro burst signal (LED stays on 5 seconds after each transmission), and off indicates no cell tower signal received. With the yellow wire not having positive 12 volts, off indicates the green LED is not functioning.

[0100] An example of representative DIP switch feature selection is as follows. A first switch may be used for adding the orange wire for controlling arm/disarming of the system. When on, the orange wire controls arm/disarm as follows: to arm, the orange wire is grounded and the yellow wire does not have 12 volts positive. To disarm, the orange wire is not grounded. When the first switch is off, then only the yellow wire controls arm/disarm as follows: to arm, the yellow wire is without 12 volts positive, and 30 seconds after continued arm mode then the orange wire activates a constant 500 ma grounded output to operate an external starter interrupt relay until the system is disarmed. To disarm, the yellow wire is connected to 12 volts positive.

[0101] A main 5-pin plug may be provided on the vehicle unit and connected as follows:

- a. The Red Wire is connected to the 12 vdc power. An alert warning "E" is given if the system is armed and the battery voltage becomes lower than 11 volts for longer than ## minutes. This alert feature "E" will not operate again until the voltage is above 12 volts to re-set this feature.
- b. The black wire is connected to ground.
- c. The yellow wire is connected to the ignition 12 volts so that if the key is on, 12 volts is supplied thereto and if the key is off, the yellow wire is connected to ground. Further: if the system is in an armed mode and the Lat/Long changes, then Alert "A" is given. If the system is disarmed and within 2.5 seconds after the yellow wire receives 12 volts and the gray wire detects 3 or more positive pulses the system activates Alert "D". If the first DIP switch is in the off position then: if 12 volts is on yellow wire, the system is disarmed and the orange wire discontinues from the 500 ma ground, and if the yellow wire sees ground or neutral, then the system is armed and 30 seconds after the continued arm mode the orange wire activates a constant 500 ma grounded output to operate an external starter interrupt relay until the system is disarmed.
- d. The gray wire is for input and output, and can be connected to an alarm siren or horn positive terminal. In addition:
  - i. With the system armed and if the gray wire detects +12 v pulsing on/off or on constant for more than 10 seconds from an alarm siren or horn honking activation, then alert warning "T" alarm activation is given.
  - ii. With system disarmed and if the gray wire detects +12 v pulsing on/off or on constant for more than 10 seconds from an alarm siren or horn honking activation, then alert warning "C" panic activation is given.
  - iii. With system disarmed and if the Gray wire detects 3 or more 12 volt positive pulses within 2.5 seconds of yellow wire receiving +12 v and the gray wire by-pass not being activated, then alert warning "D" is given.
  - iv. The gray wire bypass operates as follows:
    - 1. After alert warning "B" bypass all future alert "B" signals until system is disarmed.
    - 2. After alert warning "C" bypass all future alert "C" signals until system is armed.
    - 3. After alert warning "D" bypass all future alert "D" signals until no 12 volt pulses are detected on the gray wire within 3 seconds of the yellow wire having 12 volts.
  - v. With the system armed or disarmed. The Output: Internal +12 v, 1 amp transistor with pulses 1 second on and 1 seconds off to activate siren or honk car horn or flashing light relay.
    - 1. Non-stop activation from (Command "4")
    - 2. 30-second activation from (Command "5")
  - vi. Turn off the above alert "A" from (Command "1").
- i. The orange wire is for the starter interrupt and arm/disarm system, and operates as follows:
  - i. If first DIP switch is in the:
    - 1. On position and: the orange wire has 12 volts or neutral, the system switches to the disarmed mode; the orange wire is grounded, then the system is switched to the armed mode; and the starter interrupt output will not automatically operate. It can only be activated from "Command 4"
    - 2. Off position and the orange wire does not effect the arming or disarming of the system; 30 seconds after system arms the orange wire will automatically activate constant 500 ma ground until the system is disarmed. And from "command #4". Connect to Starter interrupt relay output.
  - ii. Command 4 activates Orange wire to have 500 ma. negative until Command 1 is received.
  - iii. After alert warning "B" is activated the first time it is thereafter bypassed while the orange wire remains grounded. Alert warning "B" is re-set to operate again 3 seconds after orange wire becomes ungrounded.

[0123] The vehicle unit may also include a Door Lock Plug configured as follows, for example. A green wire provides a 250 ma, negative 1 second pulse for Lock Doors. (Command "6"). A red wire provides a constant 12 v output from the red power wire. A blue wire provides a 250 ma., negative 1 second pulse for Unlock Doors (Command "7"). A pink wire provides a 250 ma., negative 1 second pulse for remote Car Starter (Command "2").

[0124] An installation test button may also be provided to work as follows. Pressing the button activates the orange wire for 10-seconds (starter interrupt), with these circuits in sequence. First, it activates the gray wire for 1-second (siren/horn). After the first stops, it activates the green wire for 1 second to lock the doors. After the second stops, it activates the blue wire for 1 second to unlock the doors. After the third stops, it activates the pink wire for 1 second to activate an optional item.

[0125] Representative warning alerts are as follows:

- a. Alert Warning "A" (FIG. 4): Automatic activation of "Command 8" and the vehicle unit contacts monitoring station to instantly call 3 phone numbers with the message "Your vehicle is stolen please confirm then call 911 to advise police of website and your pin # so police can locate the vehicle". This is detected with the system armed and the GPS indicating movement. Bypasses all future alert warning "A" signals until the system is re-armed.
- b. Alert Warning "B" (FIGS. 5A-5C): the vehicle unit contacts the monitoring station to instantly call 3 phone numbers with the following message "Vehicle alarm activated please confirm". This is with the system armed and detecting gray wire having 12 volts pulsing or on constant for longer than 10-seconds. After alert warning "B" is activated the first time, it is thereafter bypassed while the orange wire remains grounded. Alert warning "B" is re-set to operate again 3 seconds after orange wire becomes ungrounded.

- c. Alert Warning "C" (FIG. 6): the vehicle unit contacts the monitoring station to instantly send e-mail message "vehicle was traveling faster than your preset amount of "###" and time limit of "##" seconds. Indicates the vehicle speed and location that the speeding started and how long speeding accrued" (Detected from GPS). This aspect is further understood with reference to the enclosed flowchart **84** of FIG. 6.
- d. Alert Warning "D" (FIG. 7): the vehicle unit contacts the monitoring station to instantly call 3 phone numbers with the message "Unauthorized remote transmitter was just programmed to operate your vehicle." This is with the system disarmed and the Gray wire detecting three or more 12 volt pulses within 2.5 seconds of the yellow wire having seen 12 volts positive. All future alerts "D" are bypassed until no 12 volt pulses are detected on the gray wire within 3 seconds of the yellow wire seeing 12 volts. This aspect is further understood with reference to the enclosed flowchart **85** of FIG. 7.
- e. Alert Warning "E" (FIG. 8): the vehicle unit contacts the monitoring station to instantly call 3 phone numbers with the message "Vehicle has low battery voltage and system has changed to low voltage mode". This is with the system armed and detecting the red wire with lower than 11 volts for ## minutes. All future alerts "E" are bypassed until, first, more than 13.5 volts are detected on the red wire and, second, after the yellow wire stops having positive voltage the red wire then must detect more than 12 volts.

[0131] The following are representative commands for use in the system:

[0132] Command 1: Reset all circuits and system remains asleep until the ignition key is turned on. Resets the triggered mode and unit is asleep to prevent power drain on vehicle battery.

[0133] Command 2: (Accessory activation) monitoring station Command to the system to activate Pink wire to pulse 250 ma negative for 1 second.

[0134] Command 3: (Vehicle Location) website to indicate present location and past events in memory.

[0135] Command 4: (Hijack or Stolen) monitoring station Command to vehicle system to activate:

- iv. Gray wire to pulse 1 sec on/1 sec off with 1 amp positive output and which continues until receive command # 1.
- v. Orange wire to have 500 ma ground and which continues until receive command # 1.

[0138] Command 5: (Car Find) monitoring station Command to system activating Gray wire for 30 seconds pulsing 1 sec on/1 sec off with 1 amp positive output.

[0139] Command 6: (Lock Doors) monitoring station Command to system activating Green wire to pulse 1 second with 250 ma negative.

[0140] Command 7: (Unlock Doors) monitoring station Command to system to activate Blue wire to pulse 1 second with 250 ma negative.

[0141] Command 8: (Start Constant Vehicle Tracking) sends previous 2 events in memory and then every 120 seconds get update of location information sent to the Web site.

[0142] The system is also operable in a battery saver mode which operates as follows:

- i. With the ignition key off, if the battery voltage drops below 11.5 volts for more than 5 seconds, the GPS verification wakes up to look:
- ii. Once instantly.
- iii. Once in 1 hour if at the same location.
- iv. Once in 6 hours if at the same location.
- v. Once in 12 hours if at the same location.
- vi. Once every 24 hours if at the same location.
- vii. Activate alert "E" when the battery saver mode is activated, and bypass sending all future Alert "E" until the battery voltage goes above 13 volts for 10 minutes to reset this feature.

[0150] Another aspect of the invention relates to automatic vehicle alert e-mails sent containing some or all of the previous system events. This sending can be triggered as follows:

- a. At a user selected predetermined time ## (01-24) of each day, or
- b. At a predetermined memory fill level, such as full or near full.

[0153] In addition, each system event may contain one or more of the following:

- a. Vehicle Location
- b. Vehicle total time at location
- c. Time of day
- d. Mph traveling
- e. Total time traveling above MPH
- f. Direction traveling
- g. Delta
- h. Special Alert messages, if any, including:
  - i. GPS signal not received for longer than 5 minutes.
  - ii) Traveling above ###MPH for ## minutes.
  - iii) Vehicle is stolen.
  - iv) Alarm activated.
  - v) Unauthorized remote transmitter alert.
  - vi) Battery saver mode activated
  - vii) Command 1: Reset all circuits and system remains asleep until the ignition key is turned on.
  - viii) Command 2: (Accessory activation)
  - ix) Command 3: (Vehicle Location was retrieved)
  - x) Command 4: (Hijack or Stolen mode activated)
  - xi) Command 5: (Car Find mode activated)
  - xii) Command 6: (Locked Doors)
  - xiii) Command 7: (Unlocked Doors)
  - xiv) Command 8: (Started 2-second incremental Vehicle Tracking)

[0176] Another feature of the invention relates to the selectable threshold conditions causing an event to be recorded into the memory of the vehicle unit. For example, this may include: while the yellow wire has 12 volts, record events every "??" default 15 minutes time if the GPS location has changed. If the GPS location is the same then only update stationary total time. If the GPS antenna is not receiving any signal then enter last known GPS location and with an indication that this was the last known GPS location before the GPS signal stopped, how long no GPS signal was received, and the GPS location in the on-hold file, when the vehicle is traveling above ### MPH for ##-minutes.

[0177] The monitoring station may also provide a number of automated phone calls as described above. These may include:

[0178] The user's vehicle has issued a stolen alert:

- ○ If vehicle is stolen, after receiving the phone message the user then calls 911 to advise police of the theft, and gives the police the website address and an identification number, such as the user's PIN, to allow the police to locate where your vehicle has been, where it is now and keep tracking it until the police can retrieve the vehicle.

[0180] If this is a false alert due to vehicle being towed away for service, for example, then the user may press "1" to put the vehicle in an off mode. Once the ignition key is turned on again the system will reset back to its normal operation mode.

[0181] The user's vehicle has issued an alarm activated for more than 10 seconds alert. The system will not respond to this alert again until ignition key is turned on again to reset this feature.

[0182] The vehicle battery voltage is low or has been disconnected. The tracking system is in low voltage mode. The system will not respond to this alert again until the battery voltage goes above 13 volts for 10 minutes to reset this feature.

[0183] The backup battery may be sized according to the GPS receiver and processing power draw. In addition, the battery may also be sized based upon estimated micro burst transmitting power draw. Such transmissions are typically at about 3 watts power to the antenna.

[0184] The system according to the invention including the vehicle unit and monitoring station provides a number of significant advantages and features. For example, the police may be directly contacted by the user when the vehicle is stolen. The user receives the telephone message from the monitoring station, and this is done without requiring the intervention of a manual security monitoring operator, such as an ADT operator, for example. In addition, once in the stolen mode, the vehicle unit will periodically continue to send out its location, so that the police may track the vehicle via the WEB, for example. This location sending feature may begin immediately, that is, without requiring the user to contact the vehicle to begin tracking. Having the vehicle contacting the monitoring station is considerably less expensive than other schemes where the vehicle is periodically polled via the cellular network, for example.

[0185] The system may also be interfaced to a breath alcohol sensor at the vehicle, for example, and this information recorded in memory. The information could be passed along to the monitoring station, which, in turn, could send out a notification message (e-mail or telephone) that the vehicle is being operated by a driver who may be impaired by alcohol. The vehicle's location could then be tracked to permit the police to detain the driver.

[0186] Another aspect of the unit is that it may be able to recognize the desirability to bypass certain security breach triggers or other events. For example, a car finding feature can be provided that will allow the user to sound the horn or siren when near the vehicle to help locate the vehicle, as in a crowded parking area. Without the bypass feature, the unit could recognize the horn or siren as a security breach and transmit such information to the monitoring center. In accordance with this aspect of the invention, the unit would recognize the car finding feature was activated and thereby bypass sending a security breach transmission, for example. Again, false alarms and unneeded usage and expense of the communications infrastructure would be avoided.

[0187] Yet another aspect of the invention relates to thwarting a would-be thief who attempts to disable the alarm by cutting the battery cable or power supplied to the system. The unit preferably includes a back-up battery. More particularly, upon being in an armed mode and sensing a breach of security, such as the hood opening, for example, the unit will send out a signal indicating the alarm or security breach and while the alarm is indicated, if the battery is disconnected then the unit will send out a message indicating the vehicle is stolen, and also providing the vehicle's current position. Accordingly, the would-be thief is not able to defeat the security system by quickly disrupting power to the unit during an alarm indication or security breach. Also, to prevent additional alerts, this message is prevented from being transmitted again until the user returns to the vehicle to disarm the system and/or turn on the ignition so that the unit sees a voltage above 13 volts, indicating the vehicle has started using the owner's ignition key. This aspect is further understood with reference to the enclosed flowchart **80** (FIG. 4).

[0188] Still another aspect of the invention relates to how the unit can discriminate between ordinary usage or honking of the horn as compared to a security system triggered alarm. Most vehicle security systems will provide a pattern of horn soundings as an alarm indication, and this can be determined and used to reduce false alarm transmissions from the unit. For example, the unit can look at the number of leading and trailing edges of the power pulse used to sound the horn. A single pressing of the horn switch by the user will cause two edges within a predetermined time, such as about 10 to 12 seconds. Accordingly, the unit can be configured to not send a security breach transmission to the control center based upon detecting two transitions. Since a number of vehicle security systems may have a continuous sounding of the horn within the predetermined time, the unit can send the transmission upon detecting only a single transition.

[0189] A number of other vehicle security systems provide a series of pulses or horn soundings within the predetermined time. Accordingly, the unit may also be configured to send a security breach transmission upon detecting greater than a predetermined number of transitions, such as greater than nine, for example. This number is also typically higher than a user would generate honking the horn several times within the predetermined time. In other terms, the number of transitions of the horn pulses can be counted, and if equal to one, or greater than nine, for example, the transmission is triggered, and otherwise the sounding of the horn is ignored. Also, to prevent additional alerts, this message is prevented from being transmitted again until the user returns to the vehicle to disarm the system and/or turn on the ignition so that the unit sees a voltage above 13 volts, indicating the vehicle has started using the owner's ignition key. This aspect is further understood with reference to the enclosed flowcharts **81**-**83** (FIGS. 5A-5C).

[0190] Yet another feature of the invention relates to a low vehicle battery alert. For example, the unit may monitor the battery voltage over a predetermined time such as ten minutes. The ten minute window prevents false tripping, for example, when the voltage dips during engine cranking. In particular, the voltage can be sensed and it can be determined whether it is greater than zero (e.g. greater than six volts) and less than a high value (e.g. eleven or twelve volts), and, if so, a low battery voltage transmission can be communicated to the monitoring station, and ultimately to the vehicle user when away from the vehicle. If the vehicle is being serviced and the battery is disconnected, this will cause the battery voltage to be equal to zero. Then, the low battery voltage transmission will not be communicated to the monitoring station. Also, to prevent additional alerts, this message is prevented from being transmitted again until the user returns to the vehicle to disarm the system and/or turn on the ignition so that the unit sees a voltage above 13 volts, indicating the vehicle has started using the owner's ignition key. Again, false triggerings are reduced. This aspect is further understood with reference to the enclosed flowchart **86** (FIG. 8).

[0191] Yet another advantageous feature of some embodiments of the invention relates to the ability to conserve electrical power. More particularly, when the vehicle is stopped and in the armed mode, the GPS receiver may be periodically operated to determine the vehicle position. If the vehicle position changes, this is indicative that the vehicle is being moved or stolen. For example, the GPS receiver may be operated to generate new vehicle position information every 29 seconds. These relatively quick successive position determinations or readings are generally termed hot start. These are relatively less complicated than a cold start position determination which takes longer, since the cold start position determination requires greater time to acquire and receive data from multiple satellites, as will be appreciated by those skilled in the art.

[0192] Unfortunately, this relatively high repeated usage of the GPS receiver may cause unnecessary battery drain, especially when the vehicle is left armed and unattended by the user for an extended period. Accordingly, the power conserving feature of the invention permits the GPS receiver to be turned off when the vehicle is in the armed mode, and the GPS receiver is turned on only when needed. For example, a vehicle sensor, such as a shock sensor, motion sensor, ignition sensor, door sensor, or other sensor, or combinations thereof could be used to start the GPS receiver. This sensor could also be used to trigger an alarm if desired; however it need not be so used in all embodiments. The GPS receiver, once turned on, could operate in the normal periodic fashion as described above, or for a fixed period of time. The GPS receiver could also be turned off again after some predetermined time if no further sensor signal is received, or if the position fails to change on subsequent position readings or determinations.

[0193] Yet another feature relates to permitting more colorful audible alert messages to be generated for the user. The user can, in some embodiments, access an internet site to type or enter the text for a message to be sent, such as to alert the user that his vehicle is being stolen. The audible message then communicated by a telephone call to the user is generated by a speech message synthesizer based upon the entered text. In accordance with this aspect of the invention, the user could type in phonetically spelled words or phrases, such as to create more colorful messages including slang terms, various accents, and/or to mimic various dialects, for example. The speech synthesizer would then generate the desired message customized for the user. Of course, the system could also permit the user to test or preview the pronunciation generated by the speech message synthesizer based on the entered text message prior to its adoption.

[0194] Another aspect relates to requesting GPS position information from a vehicle. If a command is sent downstream to the vehicle requesting that GPS information in turn be sent upstream from the vehicle, and the GPS information is not received within a predetermined time, such as about four minutes, then another command may be sent to the vehicle requesting the GPS information. This may keep repeating until GPS information is received, for a predetermined number of tries, or until a user instructs stopping of the requests. This helps to ensure and confirm the activation and reception of GPS tracking coordinates from the vehicle.

[0195] Yet another aspect relates to reducing a frequency with which GPS information is sent from the vehicle. More particularly, the unit may be configured to activate GPS information transmission upstream every 2 minutes. To reduce system usage expense and power consumption at the vehicle, this rate of transmission of GPS information could be progressively decreased over time. For example, in one embodiment, upon activation the GPS location signals could be sent every 2 minutes during the first hour, then once an hour for the next 23 hours, after which only one signal would be sent per day.

[0196] Turning now to the flowchart **87** of FIG. 9, still another aspect relates to warning the user of an inoperable or malfunctioning GPS or cellular telephone section. More particularly, if the GPS or cellular telephone antenna wire is cut or the mounting position of either is changed causing the antenna to stop receiving the signal the user would not ordinarily know of this problem quickly. In accordance with one embodiment, if the ignition is turned on a predetermined number of times, such as about three, and each time ignition turns on if no GPS or no cell signal is received for a minimum time, such as about 15 to 30 minutes or longer, an audible warning beeper may be activated in the vehicle. This beeper may be sounded once every 15-minutes. At anytime if the GPS or cell signal is received properly then the system re-sets automatically stopping the beeper sound.

[0197] As an example, if the ignition key is turned on and no GPS or no Cell signal is being received for 15-minutes, and the vehicle ignition stays on for 45-minutes and there is still no GPS or no cell signal, the unit counts one. Thereafter, if the ignition key is turned on and no GPS or no cell signal is being received for 15-minutes, and the vehicle ignition stays on for 60-minutes and there is still no GPS or no cell signal, a second count is determined. Thereafter, if the ignition is turned on and no GPS or no cell signal is received for 10-minutes, and the vehicle ignition stays on for only 10-minutes and there is still no GPS or no cell signal, no count is determined. Thereafter, if the ignition is turned on and no GPS or no cell signal is being received for 15-minutes, a third count is determined and the beeper is activated as described above. This beeping may continue every 15-minutes while the vehicle ignition stays on as long as the vehicle ignition stays on for 16-minutes and still no GPS or no Cell signal is being received. If thereafter, the ignition is turned on and no GPS or no cell signal is being received, the beeper beeps once and again beeps once every 15-minutes while vehicle ignition stays on. If in 10-minutes both GPS or cell signal is being received, the beeper system is turned off and the warning count is reset.

[0198] By way of example, if the ignition key is turned on and no GPS or no cell signal is being received for only 5, 10 or 12 minutes (with the threshold set at 15 minutes), then no count is determined.

[0199] In certain circumstances, the GPS signal may fail, but the cell signal may still be working. Accordingly, it may be desirable to send an indication of the failure of the GPS signal to the central monitoring station to thereby alert the user as described above. If the cell signal also failed, or if the cell signal failed by itself, in other embodiments a separate paging device would transmit the failure or loss of the cell signal information to the central monitoring station, to thereby alert the user.

[0200] Yet another feature is directed to efficient use of a relatively small number of codes available to communicate with the tracking unit from the cellular network and central station. More particularly, a typical arrangement may provide eight basic codes and two Awildcard@ codes. The two wildcard codes are reserved for future or other uses. A particular tracking device will respond directly to any of the eight basic codes. For example, the doors could be locked or unlocked, a present location downloaded from the vehicle, etc.

[0201] In accordance with this feature, the tracking device may respond differently to the same code or command depending upon the state or condition of the tracking device. For example, if an alarm is triggered at the vehicle, it may be desired that the tracking device continue to send the alarm signal until confirmation is received that the central monitoring station has received the alarm signal. This confirmation can be sent using the same code as may provide another function if the device were not indicating an alarm. Any of a number of such tracking device conditions may trigger a different message to be interpreted from the received code. For example, if any of the above Alerts A-E were triggered, the receipt of a predetermined code, such as code eight, would confirm receipt of the alert by the central station, and this receipt of code eight would not cause the other response (no alarm triggered) in the tracking device. Of course this concept can be extended to other features as will be appreciated by those skilled in the art.

[0202] In accordance with another feature, the rate of sending the location or position data (or change in position data) from the vehicle may be varied to reduce system usage and thereby reduce expenses. More particularly, in one embodiment, the rate of sending may be based upon how long the vehicle has remained stationary. This time period may be selected by the user. For example, the selected time may be in the range of 15 minutes to six hours. If the vehicle has been stationary for the selected time period, then the rate of transmission may be reduced. This reduces or eliminates the need to send home position data and send all the over 15-minute stops made that day. Otherwise, that is when the vehicle is moving, the device may send data at a faster rate. Of course, a system user would not likely be interested in quick updates, especially where the position information is not changing. Conversely, if the vehicle is being moved, it may be desirable to receive more frequent position updates.

[0203] Another variation of this transmission rate conservation feature bases the rate of transmission on the vehicle position. For example, a reduced rate of transmission may be selected if the vehicle is in a predetermined area where the user has a lesser interest in quickly updated position information. The user may also have a reduced interest in an area that can be defined outside of a predetermined distance from a reference point.

[0204] Yet another variation of the vehicle position transmission rate conservation feature is based upon the vehicle's speed, such as the vehicle's average or maximum speed, for example. Accordingly, if the vehicle is traveling above a preset speed, the rate of transmission may be increased.

[0205] In accordance with another aspect of the invention, the tracking device may send the alert indication a predetermined number of times without receiving an acknowledgment as described above, and then wait until the vehicle position has changed before trying again or the cell re-registers or its RSS (received signal strength) changes. Thus, power is conserved. When the vehicle has moved to a new position, any obstructions may no longer be present thereby increasing the likelihood of a successful communication. In addition, the change in position may be determined when the vehicle is sensed to be moving about a predetermined relatively small speed, such as greater than 1 mph, for example.

[0206] In all of the embodiments and variations described herein, the tracking device may communicate with one or more other vehicle devices via a vehicle data communications bus. Further aspects of interfacing with a vehicle data communications bus are described in U.S. Pat. Nos. 5,719,551 and 6,011,460 assigned to the assignee of the present invention, the entire contents of which are incorporated herein by reference.

[0207] Yet another aspect relates to efficient use of available codes on the cellular telephone control channel. In one particular example, ten codes may be available to be transmitted from the monitoring station to the vehicle trackers. The first eight or nine codes are command codes that will cause a specific action by the tracking device at the vehicle. The other one or two codes may be wildcard codes as mentioned above, that may set a stand-by mode for one or a group of vehicles, for example.

[0208] It may be desirable to provide more than eight commands at the vehicle responsive to the corresponding eight available codes. For example, it may be desirable to set a feature on or off, or to set a different feature setting or threshold. In accordance with this aspect of the invention, the commands at the tracker are determined based upon a series of different command codes being received within a predetermined time window.

[0209] For example, the monitoring station may send code 9 that switches the tracker in the car into a stand-by mode for a predetermined time and which causes the tracker to respond with an upstream confirmation code 7 or 9 indicating receiving code 9. During the predetermined time of the stand-by mode another code follows that causes a system programmable feature or setting to change. Note that the second code would otherwise cause a different function at the vehicle. Note that system might operate a function 9 if another code 1-9 is not received in the predetermined time. The following list is exemplary for features resulting from second codes 1-9:

[0210] Code 1—Tracker will turn off feature of upstream code caused by vehicle alert being detected.

[0211] Code 2—Tracker will turn on feature of upstream code caused by vehicle alert being detected.

[0212] Code 3—Tracker deactivates cell receiver from operating due to a non-paying customer for monitoring service. That phone number can then be allocated to another customer.

[0213] Code 4—Turn on audio buzzer feature that will sound once each 10 minutes. The monitoring station need only send the command to activate the feature, as the tracker will time the period and drive the buzzer thereafter. The monitoring station will normally not need to send this command because the tracker will be configured out of the box with this feature activated to sound the buzzer every 10 minutes until the next command is received.

[0214] Code 5—Turn off the audio buzzer. This is to be sent by the monitoring station after a user has successfully activated his account.

[0215] Code 6—Turn on the 80 mph speed limit reporting. This will normally not be sent as this feature will be the default setting of the tracker.

[0216] Code 7—a Turn off the 80 mph speed limit reporting.

[0217] Code 8—Increase speed limit 5 mph and increase the time 5 minutes.

[0218] Code 9—Decrease speed limit 5 mph and decrease the time 5 minutes, and wait 5 minutes if another code number follows. It could operate this way to allow another set of codes to change more features.

[0219] In this example, in response to the tracker receiving the system code 1-9, the tracker sends an upstream code 7 to acknowledge receipt of the system code 1-9. Upon receipt of code 9 the tracker waits up to 5 minutes to determine if another system code is received. If no code is received, then the tracker performs the code 9 operation. Of course, in other embodiments other features or settings can be selected. In general, it may be preferred that the first code sent in a series of two codes, for example, be a code that causes only a minor function to be performed at the vehicle. This is so because if the second code is sent from the monitoring station, but not received at the tracker, only a minor function is performed. For example, the first code may switch between armed and disarmed modes. This is in contrast to using a remote engine starting code or engine shutdown code as the first code. The vehicle may be moving or positioned in a marginal reception area, and the second command may not be received by the tracker within the predetermined time window. As will be appreciated by those skilled in the art, this concept of multiple digit codes, can be extended beyond two digits to three or more.

[0220] To further conserve cellular transmissions and as described above, the tracker may be set to record a position based upon a determined event. Only this recorded position information may be downloaded either by user request or at set times. It is desired that such events be relatively few, but that the information still be helpful to the user.

[0221] For example, an event for recording of position may be determined based upon the vehicle being stopped for greater than a first time and less than a second time. For example, the first time may be 15 minutes and the second time may be 6 hours. Determination of the vehicle being stopped can be made based upon one or both of the GPS position or the vehicle ignition being turned off. The second time prevents the recording of position information when the vehicle is stopped at the owner's home during the evening, for example. Accordingly, the important information of the vehicle stops being made is recorded and made available to the user, while system communications resources are conserved.

[0222] In another example, if the mode is selected to send the vehicle's location every 10 min and the vehicle is in the same location for greater than a set time, then no more vehicle locations are sent until the vehicle location has changed to start the every 10 min reporting again.

[0223] Now referring to FIGS. 10 and 11, in yet another embodiment the potential difficulties of interfacing to a vehicle data bus and devices connected thereto are further discussed. The multi-vehicle compatible tracking unit **110** is for a vehicle comprising a vehicle data bus **122** extending throughout the vehicle. The multi-vehicle compatible tracking unit **110** includes a vehicle position determining device **112**, a wireless communications device **113**, and a multi-vehicle compatible controller **111** for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The vehicle position determining device **112** may be provided by a GPS receiver, for example, or any of the other such devices described in detail above.

[0224] The wireless communications device **113** may be provided by a cellular telephone transceiver configured to operate on a control channel of the cellular network, or any of the other such devices described in detail above.

[0225] The multi-vehicle compatible controller **111** is coupled to the vehicle data bus **122** for communication thereover with a vehicle device **121**. The controller **111** illustratively includes a central processing unit (CPU) **126** or other logic circuitry which is connected to a clock signal generator **124**, a memory **125**, and input/output circuitry **127** to interface with the vehicle device **121** using at least one corresponding vehicle device code from among a plurality thereof for different vehicles. The corresponding vehicle code may be for reading from the vehicle device **121**. Similarly, the corresponding vehicle code may be additionally or alternatively for writing to the vehicle device **121**.

[0226] The multi-vehicle compatible tracking unit **110** also illustratively includes a downloading interface **116** for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller **111**. The enabling data may be the vehicle device code or codes, an instruction to select a code or codes from among those already stored, or the data or sequence to allow the controller **111** to generate the vehicle device code or codes, for example.

[0227] In the embodiment as shown in FIG. 11, the downloading interface **116** is a category of wireless signal downloading interfaces that illustratively include a wireless receiver **114**, such as for temporary connection to the downloading device **115**. The wireless downloading interface **116** may communicate with the downloading device **115** via any one or more of a number of wireless technologies, such as cellular, satellite, IR, Bluetooth or WiFi technologies for example, as will also be appreciated by those skilled in the art. Interface circuitry **132** is included in the wireless signal downloading interface **116** for controlling communication with the downloading device **115**. The interface circuitry **132** may be logic circuitry or other control circuitry along with switching components.

[0228] In other embodiments, for example as shown in FIG. 12, the wireless downloading interface **116'** does not include the wireless receiver **114**, as a temporary wireless communication link is instead provided by sharing the wireless communications device **113** that sends position data as described above.

[0229] The downloading interface may also be in the form of a wired signal downloading interface **116"** as shown in FIG. 13. The wired signal downloading interface **116"** comprises a connector **133*a*** for temporary connection to a downloading device **115"** with a mating connector **133*b***. Interface circuitry **132"** is provided for controlling communication with the downloading device **115"**. The wired downloading interface **116"** may connect directly to a downloading device **115"**, such as a laptop computer, via RS232/429 protocol, USB, FireWire, TCP/IP (Internet), or any other wired protocol as will be appreciated by those skilled in the art. The connector **133*a*** of the wired downloading interface **116"** may alternatively be in the form of a socket to accept a memory card or other data storage medium capable of transferring data. The downloading interfaces **116**, **116'** and **116"**, may also advantageously be for permitting downloading of programming instructions for the multi-vehicle compatible controller **111**, to allow remote programming, for example, as will also be appreciated by those skilled in the art.

[0230] Referring again briefly to FIG. 10, the multi-vehicle compatible tracking unit **110** further comprises a remote transmitter **117**, such as typically in the form of a small handheld device to be carried by a user when away from the vehicle. The multi-vehicle compatible controller **111** also performs at least one vehicle remote control function responsive to the remote transmitter **117**. The remote transmitter **117** illustratively communicates with the remote receiver **118**, which is coupled to the multi-vehicle compatible controller **111**. The vehicle remote control functions may include a vehicle security function, a remote keyless entry function, and a remote engine starting function, for example, implemented via the data bus **122** using one or more vehicle devices **121**. Such a vehicle device **121** may also include another vehicle controller, as well as a sensor, or actuator as will be appreciated by those skilled in the art.

[0231] The multi-vehicle compatible tracking unit **110** illustratively includes a common housing **123** for its various components. In other embodiments, more than one housing may be used for the various components.

[0232] Referring additionally to FIGS. 14 and 15, several methods for using a multi-vehicle compatible tracking unit **110** for a vehicle comprising a vehicle data bus **122** extending throughout the vehicle are described with reference to the respective flowcharts **148**, **148'**. Beginning at Block **150**, the multi-vehicle compatible tracking unit **110** is installed in vehicle (Block **151**). At Block **152** a connection is then established between the multi-vehicle compatible tracking unit **110** and a downloading device **115** using a downloading interface **116**. Enabling data related to at least one corresponding vehicle device code for use by the multi-vehicle compatible controller **111** is downloaded via a downloading interface **116** (Block **153**). Once the enabling data is downloaded, the connection between the multi-vehicle tracking unit **110** and the downloading device **115** is terminated at Block **154**. Of course the multi-vehicle compatible tracking unit **110** may be optionally programmed via the downloading interface while the connection is established. The operation of the tracking unit may be tested at Block **155** before stopping at Block **156**. With particular reference to the flowchart **148'** of FIG. 15, the multi-vehicle compatible tracking unit **110** may be connected to the downloading device **115** (Block **152'**), etc., before installation in the vehicle (Block **151'**) and testing (Block **155'**).

[0233] Other features relating to vehicle control systems are disclosed in copending patent applications entitled VEHICLE TRACKER INCLUDING STATIONARY TIME DETERMINATION AND ASSOCIATED METHODS, Ser. No. 09/859,727 filed May 17, 2001, now U.S. Pat. No. 6,512,465; VEHICLE TRACKER CONSERVING CODES AND RELATED METHODS, Ser. No. 09/859,673 filed May 17, 2001, now U.S. Pat. No. 6,522,267; VEHICLE TRACKER WITH POWER SAVING FEATURES AND RELATED METHODS, Ser. No. 09/859,728 filed May 17, 2001, now U.S. Pat. No. 6,512,466; VEHICLE TRACKER COOPERATING WITH A STARTER INTERRUPT AND RELATED METHODS, Ser. No. 09/859,973 filed May 17, 2001; VEHICLE TRACKER WITH USER NOTIFICATIONS AND ASSOCIATED METHODS, Ser. No. 09/859,733 filed May 17, 2001, now U.S. Pat. No. 6,509,868; VEHICLE TRACKER WITH USER REGISTRATION REMINDER AND RELATED METHODS, Ser. No. 09/859,971 filed May 17, 2001, now U.S. Pat. No. 6,507,786; VEHICLE TRACKER INCLUDING INPUT/OUTPUT FEATURES AND RELATED METHODS, Ser. No. 09/859,972 filed May 17, 2001, now U.S. Pat. No. 6,606,561; and VEHICLE TRACKER WITH TEST FEATURES AND RELATED METHODS, Ser. No. 09/859,729 filed May 17, 2001, now U.S. Pat. No. 6,809,659, the entire disclosures of which are incorporated herein by reference.

[0234] Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Accordingly, it is understood that the invention is not to be limited to the embodiments disclosed, and that other modifications and embodiments are intended to be included within the spirit and scope of the appended claims.

Original

Classifications

IPC	CPC	US Class	ECLA	ICO
G01C21/00	B60R25/04	701/36	G08G1/20	L60R325:20B
	B60R25/045	382/104	B60R25/04	L60R325:20D
	B60R25/102	455/575.9	B60R25/045	L60W550:40A
	B60R25/104	701/29.3	B60R25/102	
	B60R25/33	701/29.6	B60R25/104	
	B60R2325/202		B60R25/33	
	B60R2325/205		G07C5/00T	
	G07C5/008		G08G1/127	
	G08G1/127		G08G1/20B	
	G08G1/20			
	G08G1/205			
	B60W2556/50			

Persons

Ultimate Owner

Original
Voxx International (/api/control?client=&query=uo:("Voxx%20International")&autosearch=true)

Original Assignees

Original	Standardized	Normalized
Kenneth E. Flick (/api/control?client=&query=pa:("Kenneth%20E.%20Flick")&autosearch=true) Douglasville, Georgia, United States of America, US		

Current Assignees

Original	Standardized	Normalized
OMEGA PATENTS, L.L.C. (/api/control?client=&query=pacu:("OMEGA%20PATENTS%2C%20L.L.C.")&autosearch=true) 5326 PRESLEY PLACE, 30135, DOUGLASVILLE, GEORGIA, UNITED STATES OF AMERICA	OMEGA PATENTS (/api/control?client=&query=pacus:("OMEGA%20PATENTS")&autosearch=true)	

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Legal representative(s)

Original	Standardized	Normalized
Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A. (/api/control?client=&query=ag:("Allen%2C%20Dyer%2C%20Doppelt%2C%20Milbrath%20%26%20Gilchrist%2C%20P.A.")&autosearch=true)		

Legal information

Standardized Post issuance INPADOC

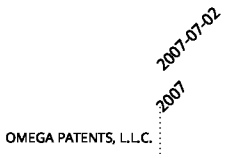
Legal status

Event	Date	Description
Granted	2011-10-04	GRANTED
Filed	2007-07-03	FILED

Designated states

Date	Event code	Description

Ownership



Payment status

Date	Status	Event code	Description
2023-03-22	Fee paid	M1553	PAYMENT OF MAINTENANCE FEE, 12TH YEAR, LARGE ENTITY.
2019-03-21	Fee paid	M1552	PAYMENT OF MAINTENANCE FEE, 8TH YEAR, LARGE ENTITY.
2015-03-18	Fee paid	M1551	PAYMENT OF MAINTENANCE FEE, 4TH YEAR, LARGE ENTITY.

Litigation/Opposition

Docket number	Docket description	Court	Date Filed
IPR2023-00504	GEOTAB USA, INC. et al. Vs. --		2023-01-26
6:13cv1950	Omega Patents, Llc V. Calamp Corp.		2013-12-19
20-1793	Omega Patents, LLC v. CalAmp Corp.		2020-05-13
18-1309	Omega Patents, LLC v. CalAmp Corp.		2017-12-18
20-1794	Omega Patents, LLC v. CalAmp Corp.		2020-05-13
6:20cv693	Omega Patents, Llc V. Dei Holdings, Inc.		2020-04-20
1:17cv2769	Omega Patents, Llc V. Enfora, Inc.		2017-07-20
1:13cv646	Omega Patents, Llc V. Enfora, Inc.		2013-02-27
2:20cv1344	Omega Patents Llc V. Firstech Llc		2020-09-09
1:23cv382	Omega Patents, Llc V. Geotab, Inc.		2023-04-03

Page: 1 2

Pharmaceuticals

Product	Type	Active Ingredient	Applicant	Application No.	Application Type	Approval Date	Patent Expiry Date	Patent usage code	Exclusivity Code	Exclusivity Date	Dosage	Strength	Product Number	Route	RLD	Pa Re

No pharmaceuticals data

Citations

Display in a list (/api/control?client=&citationsSearch=_)

☐	backward	US5223844A	By other than the examiner	1993-06-29	Vehicle tracking and security system	AUTO TRAC	
☐	backward	US5515043A	By other than the examiner	1996-05-07	Cellular/GPS system for vehicle tracking	BERARD ALFREDO J MENTZER JAMES L NIXON DAVID C	
☐	backward	US5635693A	Cited by the examiner	1997-06-03	System and method for tracking vehicles in vehicle lots	IBM	
☐	backward	US5654688A	By other than the examiner	1997-08-05	Vehicle security system having enhanced remote transmitter security	OMEGA RESEARCH & DEV	
☐	backward	US5719551A	By other than the examiner	1998-02-17	Vehicle security system for a vehicle having a data communications bus and related methods	FLICK KENNETH E	
☐	backward	US5940007A	Cited by the examiner	1999-08-17	Remote control system for motor vehicle related devices	DAIMLER BENZ	
☐	backward	US6011460A	By other than the examiner	2000-01-04	Vehicle security system for a vehicle having a data communications bus and related methods	FLICK KENNETH E	
☐	backward	US6253064B1	Cited by the examiner	2001-06-26	Terminal based traffic management and security surveillance system for aircraft and other commercial vehicles	MONROE DAVID	
☐	backward	US6611755B1	Cited by the examiner	2003-08-26	Vehicle tracking, communication and fleet management system	TRIMBLE NAVIGATION	
☐	backward	US6628233B2	Cited by the examiner	2003-09-30	Vehicle information system	SIEMENS VDO AUTOMOTIVE	
☐	backward	US6657587B1	Cited by the examiner	2003-12-02	Tracking system using miniaturized concealable communications module	VERIDIAN ERIM INTERNATIONAL	
☐	backward	US6756885B1	By other than the examiner	2004-06-29	Multi-vehicle compatible control system for reading from a data bus and associated methods	OMEGA PATENTS	
☐	backward	US6859831B1	Cited by the examiner	2005-02-22	Method and apparatus for internetworked wireless integrated network sensor (WINS) nodes		
☐	backward	US6888495B2	Cited by the examiner	2005-05-03	Vehicle tracker with user notifications and associated methods		
☐	backward	US7015830B2	Cited by the examiner	2006-03-21	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods		
☐	backward	US7085775B2	Cited by the examiner	2006-08-01	Database method and system for conducting integrated dispatching		
☐	backward	US7149623B2	Cited by the examiner	2006-12-12	Vehicle tracker including input/output features and related methods		
☐	backward	US7196621B2	Cited by the examiner	2007-03-27	Tracking system and associated method		

☐	backward	US7305293B2	Cited by the examiner	2007-12-04	Vehicle tracker including input/output features and related methods	
☐	backward	US7308341B2	Cited by the examiner	2007-12-11	Vehicle communication system	

1 - 20 of 91

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A self-organizing hybrid sensor system with distributed data fusion for intruder tracking and surveillance; Palaniappan, R.; Clarke, T.; Wahid, P.; Behdad, N.; Kincaid, P.; Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE; Jul. 5-11, 2008 pp. 1-4; Digital Object Identifier 10.1109/APS.2008.4619564.
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Security Challenges of Location-Aware Mobile Business; Tatly, E.I.; Stegemann, D.; Lucks, S.; Mobile Commerce and Services, 2005. WMCS '05. The Second IEEE International Workshop on; Jul. 19, 2005 pp. 84-95; Digital Object Identifier 10.1109/WMCS.2005.23. (/intapi/scopus/33847135216) **0** Citations in Scopus
Motion tracking: no silver bullet, but a respectable arsenal; Welch, G.; Foxlin, E.; Computer Graphics and Applications, IEEE vol. 22, Issue 6, Nov.-Dec. 2002 pp. 24-38; Digital Object Identifier 10.1109/MCG.2002.1046626. (/intapi/scopus/0036857027) **201** Citations in Scopus
Localization of ahead vehicles with on-board stereo cameras; Zanin, M.; Image Analysis and Processing, 2007. ICIAP 2007. 14th International Conference on; Sep. 10-14, 2007 pp. 111-116; Digital Object Identifier 10.1109/ICIAP.2007.4362766.

Similar documents

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User Name: Karen Ward
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Document (1)

1. *6:13cv1950, Omega Patents, Llc V. Calamp Corp.*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

6:13cv1950, Omega Patents, Llc V. Calamp Corp.

US District Court Docket

United States District Court, Florida Middle

(Orlando)

This case was retrieved on 12/04/2023

Header

Case Number: 6:13cv1950
Date Filed: 12/20/2013
Assigned To: Judge Paul G. Byron
Referred To: Magistrate Judge Daniel C. Irick
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: Federal Circuit, 20-01793, Federal Circuit, 20-01794, USCAFC, 18-01309-FS
Jurisdiction: Federal Question

Class Code: Closed
Closed: 05/19/2022
Statute: 35:271
Jury Demand: Both
Demand Amount: $0
NOS Description: Patent

Participants

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Proceedings

#	Date	Proceeding Text	Source
1	12/20/2013	COMPLAINT Injunctive Relief Requested against Calamp Corp. with Jury Demand (Filing fee $ 400 receipt number Orl-030433) filed by Omega Patents, LLC. (Attachments: # 1 Civil Cover Sheet, # 2 Exhibit A-C, # 3 Exhibit D-F)(JEV) (Entered: 12/20/2013)	
2	12/20/2013	SUMMONS Issued as to Calamp Corp. (JEV) (Entered: 12/20/2013)	
3	12/20/2013	Patent Report sent to Alexandria, VA. (Attachments: # 1 Complaint, # 2 Exhibit A-C, # 3 Exhibit D-F) (JEV) (Entered: 12/20/2013)	
4	12/30/2013	RELATED CASE ORDER AND NOTICE of designation under Local Rule 3.05 - track 2. Notice of pendency of other actions due by 1/13/2014. Signed by Judge Gregory A. Presnell on 12/30/2013. Copies mailed.(LAM) (Entered: 12/30/2013)	
5	12/30/2013	INTERESTED PERSONS ORDER. Certificate of interested persons and corporate disclosure statement due by 1/13/2014. Signed by Judge Gregory A. Presnell on 12/30/2013. Copies mailed.(LAM) (Entered: 12/30/2013)	
6	01/14/2014	NOTICE of pendency of related cases re 4 Related case order and track 2 notice per Local Rule 1.04(d) by Omega Patents, LLC. Related case(s): Yes. (Santurri, Ryan) Modified on 1/15/2014 (JEV). (Entered: 01/14/2014)	
7	01/14/2014	CERTIFICATE of interested persons and corporate disclosure statement re 5 Interested persons order by Omega Patents, LLC. (Santurri, Ryan) (Entered: 01/14/2014)	
8	01/15/2014	NOTICE of Appearance by Christopher S. Carver on behalf of Calamp Corp. (Carver, Christopher) (Entered: 01/15/2014)	
9	01/15/2014	NOTICE of pendency of related cases re 4 Related Case Order per Local Rule 1.04(d) by Calamp Corp. Related case(s): yes	

#	Date	Proceeding Text	Source
		(Carver, Christopher) Modified on 1/16/2014 (JET). (Entered: 01/15/2014)	
10	01/15/2014	ANSWER and affirmative defenses to 1 Complaint with Jury Demand , COUNTERCLAIM against Omega Patents, LLC by Calamp Corp. (Carver, Christopher) Modified on 1/16/2014 (JET). (Entered: 01/15/2014)	
11	01/15/2014	CERTIFICATE of interested persons and corporate disclosure statement re 5 Interested persons order by Calamp Corp.. (Carver, Christopher) (Entered: 01/15/2014)	
12	01/15/2014	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Joel A. Kauth, appearing on behalf of Calamp Corp. (Filing fee $10 receipt number ORL31013) re 22 MOTION for Joel A. Kauth to appear pro hac vice by Calamp Corp. (JET) (JET). Modified on 3/4/2014 (IGC). (Entered: 01/15/2014)	
13	01/16/2014	NOTICE to counsel Joel A. Kauth of Local Rule 2.02 (signed by deputy clerk). (JET) (Entered: 01/16/2014)	
14	01/17/2014	NOTICE to counsel Christopher S. Carver of Local Rule 2.01 (signed by deputy clerk). (JET) (Entered: 01/17/2014)	
15	01/17/2014	NOTICE of Appearance by Peter A. Chiabotti on behalf of Calamp Corp. (Chiabotti, Peter) (Entered: 01/17/2014)	
16	01/29/2014	CERTIFICATE of compliance re: Service of documents 4, 5, 6and 7 on Defendant by Omega Patents, LLC. (Gilchrist, Brian) Modified on 1/30/2014 (JET). (Entered: 01/29/2014)	
17	02/05/2014	MOTION to Dismiss Counterclaims and Memorandum in Support by Omega Patents, LLC. (Santurri, Ryan) (Entered: 02/05/2014)	
18	02/06/2014	Unopposed MOTION to Appear Telephonically at Case Management Conference by Calamp Corp. (Carver, Christopher) Modified on 2/7/2014 (JET). (Entered: 02/06/2014)	
19	02/07/2014	ORDER granting 18 Motion to attend case management conference by phone. Signed by Judge Gregory A. Presnell on 2/7/2014. (TKW) (Entered: 02/07/2014)	
20	02/24/2014	Amended COUNTERCLAIM -- CalAmp Corp.'s First Amended Counterclaim against Omega Patents, LLC filed by Calamp Corp..(Carver, Christopher) (Entered: 02/24/2014)	
21	02/26/2014	ORDER denying as moot 17 motion to dismiss original counterclaim. Signed by Judge Gregory A. Presnell on 2/26/2014. (TKW) (Entered: 02/26/2014)	
22	03/03/2014	MOTION for Joel A. Kauth to appear pro hac vice by Calamp Corp.. (Attachments: # 1 Exhibit A - (proposed) Order Granting Motion to Appeal Pro Hac Vice of Attorney Joel A. Kauth)(Carver, Christopher) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/03/2014)	
23	03/03/2014	Written designation and consent to act by Christopher S. Carver on behalf of Calamp Corp.. Local Counsel: Christopher S. Carver. Non-Resident Counsel: Joel A. Kauth. (Carver, Christopher) (Entered: 03/03/2014)	
24	03/04/2014	ENDORSED ORDER granting 22 motion to appear pro hac vice. Provided, all counsel shall register for and use the electronic filing system as adopted by the Court. After this Order, the Clerk will no longer send copies of docket entries by U.S. Mail to counsel in this case. Appearance and participation by more than one attorney at any hearing or trial is subject to the discretion of the presiding judge. Signed by Magistrate Judge David A. Baker on 3/4/2014. (Baker, David) (Entered: 03/04/2014)	
25	03/11/2014	REPLY to 20 Counterclaim by Omega Patents, LLC.(Santurri, Ryan) (Entered: 03/11/2014)	
26	03/11/2014	CASE MANAGEMENT REPORT. (Gilchrist, Brian) (Entered:	

#	Date	Proceeding Text	Source
		03/11/2014)	
27	03/12/2014	ORDER of recusal. Signed by Judge Gregory A. Presnell on 3/12/2014. (TKW) (Entered: 03/12/2014)	
28	03/12/2014	Case Reassigned to Judge Charlene Edwards Honeywell. New case number: 6:13-cv-1950-Orl-36DAB. Judge Gregory A. Presnell no longer assigned to the case. (iGC) (Entered: 03/12/2014)	
29	03/14/2014	CASE MANAGEMENT AND SCHEDULING ORDER: Amended Pleadings due by 4/18/2014, Joinder of Parties due by 4/18/2014, Discovery due by 6/1/2015, Dispositive motions due by 7/1/2015, Pretrial statement due by 9/15/2015, Conduct mediation hearing by 6/16/2015. Lead counsel to coordinate dates. Claim Construction Hearing set for 11/24/2014 at 10:00 AM in Orlando Courtroom 5 B before Judge Charlene Edwards Honeywell. Final Pretrial Conference set for 10/20/2015 at 01:30 PM in Orlando Courtroom 5 B before Judge Charlene Edwards Honeywell, Jury Trial set for 11/2/2015 term in Orlando Courtroom 5 B before Judge Charlene Edwards Honeywell. Signed by Judge Charlene Edwards Honeywell on 3/14/2014. (NBL) (Entered: 03/14/2014)	
30	03/14/2014	CASE REFERRED to Mediation. (MAA) (Entered: 03/19/2014)	
31	03/27/2014	NOTICE of mediation conference/hearing to be held on 11/10/2014 at 9:30 a.m. before Emery H. Rosenbluth, Jr., Esq..(Santurri, Ryan) (Entered: 03/27/2014)	
32	04/16/2014	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Eugene K. Chong, appearing on behalf of Calamp Corp. (Filing fee $10 receipt number ORL-33338). (MAA) (MAA). (Entered: 04/16/2014)	
33	05/07/2014	MOTION for Eugene Chong to appear pro hac vice by Calamp Corp.. (Attachments: # 1 Exhibit A - (proposed) Order Granting Motion to Appear Pro Hace Vice)(Carver, Christopher) Motions referred to Magistrate Judge David A. Baker. (Entered: 05/07/2014)	
34	05/07/2014	ENDORSED ORDER granting 33 motion to appear pro hac vice. Provided, all counsel shall register for and use the electronic filing system as adopted by the Court. After this Order, the Clerk will no longer send copies of docket entries by U.S. Mail to counsel in this case. Signed by Magistrate Judge David A. Baker on 5/7/2014. (Baker, David) (Entered: 05/07/2014)	
35	07/02/2014	Case Reassigned to Judge Paul G. Byron. New case number: 6:13-cv-1950-Orl-40-DAB. Judge Charlene Edwards Honeywell no longer assigned to the case. (SC) (Entered: 07/02/2014)	
36	07/03/2014	AMENDED NOTICE of Claim Construction Hearing: Claim Construction Hearing set for 11/24/2014 at 10:00 AM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. (NBL) copies e-mailed (Entered: 07/03/2014)	
37	07/07/2014	AMENDED NOTICE of hearing: Final Pretrial Conference set for 10/20/2015 at 1:30 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, Jury Trial set for the November 2015 Trial term, term commencing 11/2/2015 at 09:00 AM in Orlando Courtroom 4 B before Judge Paul G. Byron. (NBL) copies e-mailed (Entered: 07/07/2014)	
38	09/05/2014	MOTION for miscellaneous relief, specifically Motion for Claim Construction by Omega Patents, LLC. (Attachments: # 1 Exhibit A - U.S. Patent 6,346,876, # 2 Exhibit B - U.S. Patent 6,756,885, # 3 Exhibit C - U.S. Patent 5,719,551)(Santurri, Ryan) (Entered: 09/05/2014)	
39	09/05/2014	DEFENDANT'S Opening Claim Construction Brief re 29 Case	

#	Date	Proceeding Text	Source
		management and scheduling orderSet Hearings filed by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D)(Kauth, Joel) Modified on 9/8/2014 (MAA). (Entered: 09/05/2014)	
40	10/03/2014	RESPONSE in opposition to 39 Motion for Claim Construction filed by Omega Patents, LLC. (Santurri, Ryan) Modified on 10/6/2014 (LAK). (Entered: 10/03/2014)	
41	10/03/2014	RESPONSIVE Claim Construction brief filed by Calamp Corp. (Kauth, Joel) Modified on 10/6/2014 (LAK). (Entered: 10/03/2014)	
42	10/30/2014	ORDER re: Claim Construction Hearing. Signed by Judge Paul G. Byron on 10/30/2014. (RML) (Entered: 10/30/2014)	
43	11/11/2014	MEDIATION report Hearing held on 111014. Hearing outcome: Impasse.. (Rosenbluth, Emery) (Entered: 11/11/2014)	
44	11/17/2014	RESPONSE re 42 Order pdf -- Joint Pre-Hearing Statement filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 11/17/2014)	
45	11/21/2014	NOTICE of Appearance by Carrie Ann Wozniak on behalf of Calamp Corp. (Wozniak, Carrie) (Entered: 11/21/2014)	
46	11/24/2014	Minute Entry (CLAIM CONSTRUCTION HEARING) Proceedings held before Judge Paul G. Byron on 11/24/2014. Written Order to issue. Court Reporter: Koretta Stanford (NBL) (Entered: 11/24/2014)	
47	11/28/2014	NOTICE RESCHEDULING FINAL PRETRIAL CONFERENCE (TIME ONLY): Final Pretrial Conference reset for 10/20/2015 at 3:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. *(previously noticed for 1:30 p.m.) (NBL) copies mailed/e-mailed (Entered: 11/28/2014)	
48	12/12/2014	PLAINTIFF'S BRIEF/Memorandum of Law on Markman Issues re 46 Miscellaneous Hearing filed by Omega Patents, LLC. (Santurri, Ryan) Text modified on 12/15/2014 (RDO). (Entered: 12/12/2014)	
49	12/12/2014	SUPPLEMENTAL BRIEF on Claim Construction re 46 Miscellaneous Hearing filed by Calamp Corp.. (Kauth, Joel) Text modified on 12/15/2014 (RDO). (Entered: 12/12/2014)	
50	02/20/2015	ORDER ON CLAIM CONSTRUCTION re: 38, 39. Signed by Judge Paul G. Byron on 2/20/2015. (RML) (Entered: 02/20/2015)	
51	03/23/2015	Joint MOTION for Extension of Time to Complete Discovery to June 15, 2015 by Calamp Corp.. (Kauth, Joel) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/23/2015)	
52	03/24/2015	ENDORSED ORDER granting 51 Motion for Extension of Time to Complete Discovery. Provided, however, this extension in no way relieves the parties of other obligations and deadlines set forth in the Scheduling Order. Further, this extension shall not be the basis for seeking relief from that Order. Provided further, this extension assumes that there will be no disputes regarding discovery within this extended period, and the Court will not entertain any motions pertaining to such disputes. In particular, the parties are reminded that the deadline for filing of dispositive motions is NOT extended. Signed by Magistrate Judge David A. Baker on 3/24/2015. (Baker, David) (Entered: 03/24/2015)	
	03/25/2015	Set/reset scheduling order deadlines: Discovery due by 6/15/2015 (RDO) (Entered: 03/25/2015)	
53	07/01/2015	Joint MOTION for leave to file Exhibits Under Seal in Connection with Daubert and Dispositive Motions by Omega Patents, LLC. (Santurri, Ryan) (Entered: 07/01/2015)	
54	07/01/2015	MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition by Omega Patents, LLC. (Santurri, Ryan) (Entered: 07/01/2015)	
55	07/01/2015	MOTION for miscellaneous relief, specifically Motion and	

#	Date	Proceeding Text	Source
		Memorandum of Law to Exclude the Testimony of Defendant's Expert Eric Andrews by Omega Patents, LLC. (Santurri, Ryan) (Entered: 07/01/2015)	
56	07/01/2015	MOTION for miscellaneous relief, specifically Motion and Memorandum to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. by Omega Patents, LLC. (Santurri, Ryan) (Entered: 07/01/2015)	
57	07/01/2015	APPENDIX re 56 MOTION for miscellaneous relief, specifically Motion and Memorandum to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. , 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition, 55 MOTION for miscellaneous relief, specifically Motion and Memorandum of Law to Exclude the Testimony of Defendant's Expert Eric Andrews by Omega Patents, LLC. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6, # 7 Exhibit 7, # 8 Exhibit 8, # 9 Exhibit 9, # 10 Exhibit 10, # 11 Exhibit 11, # 12 Exhibit 12)(Santurri, Ryan) (Entered: 07/01/2015)	
58	07/01/2015	(** STRICKEN per 77 Order **) MOTION for summary judgment of invalidity by Calamp Corp. (Kauth, Joel) Modified on 7/22/2015 (SWT). (Entered: 07/01/2015)	
59	07/01/2015	DECLARATION of Eric Andrews by Calamp Corp. in support of 58 Motion for Summary Judgment. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D, # 5 Exhibit E, # 6 Exhibit F, # 7 Exhibit G, # 8 Exhibit H, # 9 Exhibit I, # 10 Exhibit J, # 11 Exhibit K, # 12 Exhibit L, # 13 Exhibit M, # 14 Exhibit N)(Kauth, Joel) Modified on 7/2/2015 (RDO). (Entered: 07/01/2015)	
60	07/01/2015	(** STRICKEN per 77 Order **) MOTION for summary judgment of noninfringement by Calamp Corp. (Kauth, Joel) Modified on 7/22/2015 (SWT). (Entered: 07/02/2015)	
61	07/02/2015	DECLARATION of Eric Andrews by Calamp Corp.in support of 60 Motion for Summary Judgment. (Attachments: # 1 Exhibit A)(Kauth, Joel) Modified on 7/2/2015 (RDO). (Entered: 07/02/2015)	
62	07/02/2015	ENDORSED ORDER granting 53 Joint Motion for Leave to File Exhibits Under Seal in Connection with Daubert and Dispositive Motions. Signed by Judge Paul G. Byron on 7/2/2015. (MMW) (Entered: 07/02/2015)	
63	07/02/2015	APPENDIX re 61 Declaration of Eric Andrews in Support of Motion for Summary Judgment of Noninfringement by Calamp Corp.. (Attachments: # 1 Exhibit B-1, # 2 Exhibit B-2, # 3 Exhibit C-1, # 4 Exhibit C-2, # 5 Exhibit D-1, # 6 Exhibit D-2, # 7 Exhibit E-1, # 8 Exhibit E-2, # 9 Exhibit F-1, # 10 Exhibit F-2, # 11 Exhibit F-3)(Kauth, Joel) (Entered: 07/02/2015)	
64	07/02/2015	MOTION to Strike 60 MOTION for summary judgment of noninfringement in Exceedence of CMSO Limitation on Motions for Summary Judgment by Omega Patents, LLC. (Santurri, Ryan) Motions referred to Magistrate Judge David A. Baker. (Entered: 07/02/2015)	
65	07/06/2015	SUMMARY JUDGMENT NOTICE re 58 MOTION for summary judgment of invalidity, 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition, 60 MOTION for summary judgment of noninfringement. Unless the Court notifies the parties otherwise, there will not be a hearing on this motion. (NBL) copies e-mailed (Entered: 07/06/2015)	
	07/06/2015	Sealed Document S-66. (MAA) (Entered: 07/08/2015)	
67	07/08/2015	Unopposed MOTION for Extension of Time to File Response to Document 60 Pending Ruling on Plaintiff's Motion to Strike by Omega Patents, LLC. (Santurri, Ryan) (Entered: 07/08/2015)	

#	Date	Proceeding Text	Source
68	07/09/2015	ENDORSED ORDER granting 67 Motion for Extension of Time to File. Signed by Judge Paul G. Byron on 7/9/2015. (MMW) (Entered: 07/09/2015)	
69	07/09/2015	AMENDED CASE MANAGEMENT AND SCHEDULING ORDER. Signed by Judge Paul G. Byron on 7/9/2015. (MMW) (Entered: 07/09/2015)	
	07/10/2015	Set/reset scheduling order deadlines: Pretrial statement due by 9/22/2015, All other motions due by 9/29/2015, Final Pretrial Conference set for 10/20/2015 at 03:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron. Jury Trial set for trial term beginning on 11/2/2015 at 09:00 AM in Orlando Courtroom 4 B before Judge Paul G. Byron. (RDO) (Entered: 07/10/2015)	
70	07/20/2015	RESPONSE in Opposition re 58 MOTION for summary judgment of invalidity filed by Omega Patents, LLC. (Attachments: # 1 Exhibit 13)(Santurri, Ryan) (Entered: 07/20/2015)	
71	07/20/2015	STIPULATION of Undisputed Facts; re 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition by Omega Patents, LLC. (Santurri, Ryan) Modified on 7/21/2015 (SWT). (Entered: 07/20/2015)	
72	07/20/2015	RESPONSE in Opposition re 64 MOTION to Strike 60 MOTION for summary judgment of noninfringement in Exceedence of CMSO Limitation on Motions for Summary Judgment filed by Calamp Corp.. (Kauth, Joel) (Entered: 07/20/2015)	
73	07/20/2015	Joint STIPULATION of Agreed Material Facts; re 58 MOTION for summary judgment of invalidity by Calamp Corp. (Kauth, Joel) Modified on 7/21/2015 (SWT). (Entered: 07/20/2015)	
74	07/20/2015	RESPONSE in Opposition re 56 MOTION for miscellaneous relief, specifically Motion and Memorandum to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. filed by Calamp Corp.. (Kauth, Joel) (Entered: 07/20/2015)	
75	07/20/2015	RESPONSE in Opposition re 55 MOTION for miscellaneous relief, specifically Motion and Memorandum of Law to Exclude the Testimony of Defendant's Expert Eric Andrews filed by Calamp Corp.. (Kauth, Joel) (Entered: 07/20/2015)	
76	07/20/2015	RESPONSE in Opposition re 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition filed by Calamp Corp.. (Attachments: # 1 Appendix, # 2 Exhibit 1, # 3 Exhibit 2, # 4 Exhibit 3, # 5 Exhibit 4, # 6 Exhibit 5, # 7 Exhibit 6, # 8 Exhibit 7, # 9 Exhibit 8, # 10 Exhibit 9, # 11 Exhibit 10, # 12 Exhibit 11, # 13 Exhibit 12)(Kauth, Joel) (Entered: 07/21/2015)	
77	07/21/2015	ORDER granting in part 64 Motion to strike 58 MOTION for summary judgment and 60 MOTION for summary judgment. Defendant shall have until Monday, July 27, 2015, in which to file a single compliant motion for summary judgment. Signed by Magistrate Judge David A. Baker on 7/21/2015. (LAK) (Entered: 07/21/2015)	
78	07/27/2015	MOTION for summary judgment and memorandum of law regarding invalidity and noninfringement by Calamp Corp.. (Kauth, Joel) (Entered: 07/27/2015)	
79	08/03/2015	REPLY to Response to Motion re 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 08/03/2015)	
80	08/04/2015	SUMMARY JUDGMENT NOTICE re 78 MOTION for summary judgment and memorandum of law regarding invalidity and noninfringement. Unless the Court notifies the parties otherwise, there will not be a hearing on this motion. (NBL) copies e-mailed (Entered: 08/04/2015)	

#	Date	Proceeding Text	Source
81	08/06/2015	RESPONSE in Opposition re 78 MOTION for summary judgment and memorandum of law regarding invalidity and noninfringement filed by Omega Patents, LLC. (Attachments: # 1 Exhibit 13)(Santurri, Ryan) (Entered: 08/06/2015)	
82	08/06/2015	REQUEST for oral argument re 56 MOTION for miscellaneous relief, specifically Motion and Memorandum to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. , 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition, 55 MOTION for miscellaneous relief, specifically Motion and Memorandum of Law to Exclude the Testimony of Defendant's Expert Eric Andrews by Omega Patents, LLC. (Santurri, Ryan) (Entered: 08/06/2015)	
83	08/24/2015	REPLY in support of 78 MOTION for summary judgment and memorandum of law regarding invalidity and noninfringement filed by Calamp Corp.. (Kauth, Joel) Text modified on 8/25/2015 (RDO). (Entered: 08/24/2015)	
84	08/27/2015	UNOPPOSED MOTION for miscellaneous relief, specifically For Lead Counsel To Attend Meeting to Prepare Joint Final Pretrial Statement by Video Conference by Calamp Corp.. (Kauth, Joel) Text modified on 8/28/2015 (RDO). (Entered: 08/27/2015)	
85	08/28/2015	ENDORSED ORDER granting 84 Unopposed Motion for Lead Counsel to Attend Meeting to Prepare Joint Final Pretrial Statement by Video Conference. Signed by Judge Paul G. Byron on 8/28/2015. (MMW) (Entered: 08/28/2015)	
86	09/08/2015	MOTION for Charles Halloran to appear pro hac vice by Calamp Corp.. (Wozniak, Carrie) Motions referred to Magistrate Judge David A. Baker. (Entered: 09/08/2015)	
87	09/09/2015	ENDORSED ORDER granting 86 motion to appear pro hac vice. Signed by Magistrate Judge David A. Baker on 9/9/2015. (Baker, David) (Entered: 09/09/2015)	
88	09/09/2015	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Charles Halloran, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL-46938.) Related document: 86 MOTION for Charles Halloran to appear pro hac vice. (MAA) (MAA). (Entered: 09/09/2015)	
89	09/17/2015	SUPPLEMENT re 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition by Omega Patents, LLC. (Attachments: # 1 Exhibit Exhibit A)(Santurri, Ryan) (Entered: 09/17/2015)	
90	09/22/2015	Joint PRETRIAL statement by Omega Patents, LLC and Calamp Corp. (Attachments: # 1 Exhibit A - Plaintiff's Exhibit List, # 2 Exhibit B - Defendant's Exhibit List, # 3 Exhibit C - Plaintiff's Witness List, # 4 Exhibit D - Defendant's Witness List, # 5 Exhibit E - Plaintiff's Deposition Designations, # 6 Exhibit F - Defendant's Deposition Designations, # 7 Exhibit G - Plaintiff's Proposed Voir Dire, # 8 Exhibit H - Defendant's Proposed Voir Dire, # 9 Exhibit I - Jury Instructions, # 10 Exhibit J - Plaintiff's Proposed Verdict Form, # 11 Exhibit K - Defendant's Proposed Verdict Form)(Santurri, Ryan) Modified on 9/23/2015 (SWT). (Entered: 09/22/2015)	
91	09/23/2015	NOTICE OF CONTINUANCE OF TRIAL TERM and FINAL PRETRIAL CONFERENCE: Final Pretrial Conference is rescheduled for 11/17/2015 at 3:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron. Jury Trial set for the DECEMBER 2015 TRIAL TERM, term commencing 12/1/2015 in Orlando Courtroom 4 B before Judge Paul G. Byron. (NBL) copies e-mailed (Entered: 09/23/2015)	
92	09/24/2015	NOTICE by Calamp Corp. of Conflict with Trial Docket (Wozniak, Carrie) (Entered: 09/24/2015)	

#	Date	Proceeding Text	Source
93	09/29/2015	MOTION to Bifurcate Issues of Inequitable Conduct and Prosecution Laches by Omega Patents, LLC. (Santurri, Ryan) (Entered: 09/29/2015)	
94	09/29/2015	MOTION in limine by Omega Patents, LLC. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D, # 5 Exhibit E, # 6 Exhibit F)(Santurri, Ryan) (Entered: 09/29/2015)	
95	09/29/2015	MOTION for miscellaneous relief, specifically That U.S. Patent Nos. 6,346,876 B1, 6,756,885 B1, 7,671,727 B2, and 8,032,278 B2 are not entitled to any priority date earlier than their actual filing dates by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D, # 5 Exhibit E, # 6 Exhibit F, # 7 Exhibit G, # 8 Exhibit H, # 9 Exhibit I, # 10 Exhibit J)(Kauth, Joel) (Entered: 09/29/2015)	
96	09/29/2015	MOTION in limine by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Kauth, Joel) (Entered: 09/29/2015)	
97	10/13/2015	RESPONSE in Opposition re 95 MOTION for miscellaneous relief, specifically That U.S. Patent Nos. 6,346,876 B1, 6,756,885 B1, 7,671,727 B2, and 8,032,278 B2 are not entitled to any priority date earlier than their actual filing dates filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 10/13/2015)	
98	10/13/2015	RESPONSE in Opposition re 96 MOTION in limine filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 10/13/2015)	
99	10/13/2015	TRIAL BRIEF by Calamp Corp.. (Kauth, Joel) (Entered: 10/13/2015)	
100	10/16/2015	RESPONSE in Opposition re 93 MOTION to Bifurcate Issues of Inequitable Conduct and Prosecution Laches filed by Calamp Corp.. (Attachments: # 1 Exhibit, # 2 Exhibit, # 3 Exhibit, # 4 Exhibit, # 5 Exhibit, # 6 Exhibit)(Kauth, Joel) (Entered: 10/16/2015)	
101	10/16/2015	RESPONSE in Opposition re 94 MOTION in limine filed by Calamp Corp.. (Attachments: # 1 Exhibit, # 2 Exhibit, # 3 Exhibit, # 4 Exhibit, # 5 Exhibit, # 6 Exhibit, # 7 Exhibit)(Kauth, Joel) (Entered: 10/16/2015)	
102	11/02/2015	NOTICE RESCHEDULING FINAL PRETRIAL CONFERENCE (TIME ONLY): Final Pretrial Conference is reset for 11/17/2015 at 1:30 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. *(previously noticed for 3:00 pm) (NBL) copies e-mailed (Entered: 11/02/2015)	
103	11/13/2015	ENDORSED ORDER re 102 Notice of Hearing. All counsel may appear by telephone for the final pretrial conference. This case will not be on the December trial term, therefore another final pretrial conference will be noticed for the month prior to the start of the new trial term. Signed by Judge Paul G. Byron on 11/13/2015. (MMW) (Entered: 11/13/2015)	
104	11/16/2015	NOTICE TO COUNSEL REGARDING TELEPHONIC FINAL PRETRIAL CONFERENCE: Counsel shall appear by calling into the Toll Free Meeting Number: 1-888-363-4735, Access Code: 3126210 and Security Code: 111715. (NBL) copies e-mailed (Entered: 11/16/2015)	
105	11/17/2015	Minute Entry. (PRETRIAL CONFERENCE) Proceedings held before Judge Paul G. Byron on 11/17/2015. Court Reporter: Koretta Stanford (NBL) (Entered: 11/17/2015)	
106	11/17/2015	NOTICE of Daubert Hearing (Oral Argument) re 56 MOTION to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. Daubert Hearing is set for 12/8/2015 at 1:30 PM in Orlando Courtroom 4 B before Judge Paul G. Byron. The Court has set aside (30) minutes per side. (NBL) copies e-mailed (Entered: 11/17/2015)	

#	Date	Proceeding Text	Source
107	11/17/2015	NOTICE OF DATE CERTAIN JURY TRIAL: Jury Trial shall commence on Tuesday, 2/16/2016 at 9:00 AM in Orlando Courtroom 4 B before Judge Paul G. Byron,U.S. District Court, 401 West Central Blvd., Orlando, Florida. Trial is estimated at (5)days. (NBL) copies e-mailed (Entered: 11/17/2015)	
108	11/17/2015	NOTICE OF FINAL PRETRIAL CONFERENCE: Final Pretrial Conference is set for 1/20/2016 at 3:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. (NBL) copies emailed (Entered: 11/17/2015)	
109	11/17/2015	NOTICE Regarding Summary Judgment Exhibits by Omega Patents, LLC re 54 MOTION for summary judgment as to Validity, Infringement, Enforceability, and Unfair Competition (Attachments: # 1 Exhibit PX5)(Santurri, Ryan) Text modified on 11/18/2015 (RDO). (Entered: 11/17/2015)	
110	11/19/2015	NOTICE RESCHEDULING DAUBERT HEARING: re 56 Motion and Memorandum to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. The Daubert Hearing is rescheduled for Friday, 12/11/2015 at 1:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. The Court has set aside (30) minutes per side. (NBL) copies e-mailed (Entered: 11/19/2015)	
111	11/19/2015	NOTICE TO COUNSEL: The Daubert Hearing scheduled for December 11, 2015 at 1:00 pm will be Oral Argument, (30) minutes per side. (NBL) copies e-mailed (Entered: 11/19/2015)	
112	11/19/2015	NOTICE of Appearance as Additional Counsel Appearance by Thomas R. Yaegers on behalf of Calamp Corp. (Yaegers, Thomas) (Entered: 11/19/2015)	
113	11/30/2015	NOTICE by Omega Patents, LLC Regarding Accused Products (Santurri, Ryan) (Entered: 11/30/2015)	
114	11/30/2015	NOTICE by Calamp Corp. Regarding Accused Devices (Attachments: # 1 Exhibit 1, # 2 Exhibit 2)(Kauth, Joel) (Entered: 11/30/2015)	
115	12/11/2015	Minute Entry (DAUBERT HEARING) Proceedings held before Judge Paul G. Byron re 56 MOTION to Exclude the Testimony of Defendant's Expert on Damages, DeForest McDuff, Ph.D. Court takes motion under advisement. Court Reporter: Koretta Stanford (NBL) (Entered: 12/11/2015)	
116	12/22/2015	NOTICE RESCHEDULING FINAL PRETRIAL CONFERENCE (TIME ONLY): Final Pretrial Conference is reset for 1/20/2016 at 4:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. *(previously noticed for 3:00 pm) (NBL) copies e-mailed (Entered: 12/22/2015)	
117	12/23/2015	ORDER granting in part and denying in part 55 Plaintiff's Motion and Memorandum of Law to Exclude the Testimony of Defendant's Expert Eric Andrews; granting 56 Plaintiff's Motion and Memorandum of Law to Exclude the Testimony of Defendant's Expert on Damages. Signed by Judge Paul G. Byron on 12/23/2015. (RML) (Entered: 12/23/2015)	
118	12/23/2015	ORDER granting in part and denying in part 54 Plaintiff's Motion and Memorandum for Summary Judgment as to Validity, Infringement, Enforceability and Unfair Competition; denying 78 Defendant CalAmp Corp.'s Motion for Summary Judgment and Memorandum of Law Regarding Invalidity and Noninfringement. Signed by Judge Paul G. Byron on 12/23/2015. (RML) (Entered: 12/23/2015)	
119	01/05/2016	ORDER granting in part and denying in part 93 Plaintiff's Motion to	

#	Date	Proceeding Text	Source
		Bifurcate Issues of Inequitable Conduct and Prosecution Laches. Signed by Judge Paul G. Byron on 1/5/2016. (RML) (Entered: 01/05/2016)	
120	01/07/2016	ENDORSED ORDER directing the parties to file with the Court all full deposition transcripts which they intend to designate for use at trial. Transcripts must be filed by 5:00 P.M. on January 11, 2016. Signed by Judge Paul G. Byron on 1/7/2016. (MMW) (Entered: 01/07/2016)	
121	01/13/2016	ORDER denying without prejudice as premature 95 Defendant CalAmp Corp.'s Motion That U.S. Patent Nos. '876, '885, '727, and '278 Are Not Entitled To Any Priority Date Earlier Than Their Actual Filing Dates. Signed by Judge Paul G. Byron on 1/13/2016. (RML) (Entered: 01/13/2016)	
122	01/19/2016	ORDER granting in part and denying in part 94 Plaintiff Omega Patents, LLC's Motion in Limine. Signed by Judge Paul G. Byron on 1/19/2016. (RML) (Entered: 01/19/2016)	
123	01/20/2016	Minute Entry (FINAL PRETRIAL CONFERENCE) Proceedings held before Judge Paul G. Byron on 1/20/2016. Court Reporter: Diane Peede (NBL) (Entered: 01/21/2016)	
124	01/21/2016	FEBRIARY 2016 TRIAL CALENDAR for United States District Judge Paul G. Byron.(NBL) copies e-mailed (Entered: 01/21/2016)	
125	01/22/2016	CIVIL PRETRIAL ORDER and ORDER denying 96 Defendant CalAmp Corp.'s Motion in Limine. Signed by Judge Paul G. Byron on 1/22/2016. (RML) (Entered: 01/22/2016)	
126	02/01/2016	ORDER re: [90-5] [90-6] the parties' objections to deposition designations and counter-designations. Signed by Judge Paul G. Byron on 2/1/2016. (RML) (Entered: 02/01/2016)	
127	02/12/2016	Exhibit List by Calamp Corp.. (Kauth, Joel) (Entered: 02/12/2016)	
128	02/12/2016	Witness List by Calamp Corp.. (Kauth, Joel) (Entered: 02/12/2016)	
129	02/15/2016	Exhibit List (Corrected) by Calamp Corp.. (Kauth, Joel) (Entered: 02/15/2016)	
130	02/16/2016	Minute Entry (JURY TRIAL DAY 1) Proceedings held before Judge Paul G. Byron on 2/16/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/17/2016)	
131	02/17/2016	Minute Entry (JURY TRIAL DAY 2) Proceedings held before Judge Paul G. Byron on 2/17/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/17/2016)	
132	02/18/2016	Minute Entry (JURY TRIAL DAY 3) Proceedings held before Judge Paul G. Byron on 2/18/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/18/2016)	
133	02/19/2016	Minute Entry (JURY TRIAL DAY 4) Proceedings held before Judge Paul G. Byron on 2/19/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/19/2016)	
134	02/22/2016	Minute Entry (JURY TRIAL DAY 5) Proceedings held before Judge Paul G. Byron on 2/22/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/23/2016)	
135	02/22/2016	ORAL MOTION for judgment as a matter of law by Calamp Corp. (NBL) (Entered: 02/23/2016)	
136	02/22/2016	ORAL ORDER denying for the reasons stated on the record 135 Defendant's Oral Motion for Judgment as a Matter of Law. Rendered in Open Court by Judge Paul G. Byron on 2/22/2016. (NBL) (Entered: 02/23/2016)	
137	02/23/2016	Minute Entry (JURY TRIAL DAY 6) Proceedings held before Judge Paul G. Byron on 2/23/2016. Court Reporter: Koretta Stanford (NBL) (Entered: 02/23/2016)	
138	02/23/2016	ORAL MOTION for judgment as a matter of law on the issues of Obviousness, Written Description and Infringement by Omega	

#	Date	Proceeding Text	Source
		Patents, LLC. (NBL) (Entered: 02/23/2016)	
139	02/23/2016	ORAL ORDER re: 138 Plaintiff's Oral Motion for Judgment as a Matter of Law. For the reasons stated on the record, the Court WITHHOLDS as to the issue of Obviousness, GRANTS as to Written Description and DENIES as to Infringement. Rendered in Open Court by Judge Paul G. Byron on 2/23/2016. (NBL) Modified on 2/23/2016 (NBL). (Entered: 02/23/2016)	
140	02/23/2016	ORAL MOTION for judgment as a matter of law as to the issues of Obviousness, Willful Infringement and Notice Date by Calamp Corp. (NBL) (Entered: 02/23/2016)	
141	02/23/2016	ORAL ORDER denying for the reasons stated on the record 140 Defendant's Oral Motion for Judgment as a Matter of Law as to Obviousness, Willful Infringement and Notice Date. Rendered in Open Court by Judge Paul G. Byron on 2/23/2016. (NBL) (Entered: 02/23/2016)	
142	02/24/2016	Minute Entry(JURY TRIAL DAY 7) Proceedings held before Judge Paul G. Byron on 2/24/2016. Jury Verdict for the Plaintiff. Court Reporter: Koretta Stanford (NBL) (Entered: 02/24/2016)	
143	02/24/2016	COURT'S INSTRUCTIONS to the Jury (NBL) (Entered: 02/24/2016)	
144	02/24/2016	JURY VERDICT in favor of the Plaintiff.(NBL) (Entered: 02/24/2016)	
145	02/25/2016	PLAINTIFF and JOINT Exhibit List (Trial) by Omega Patents, LLC. (NBL) (Additional attachment(s) added on 8/3/2017: # 1 Exhibit Joint 1, # 2 Exhibit Joint 3, # 3 Exhibit Joint 4, # 4 Exhibit Joint 5, # 5 Exhibit Joint 6 Part 1, # 6 Exhibit Joint 6 Part 2, # 7 Exhibit Joint 6 Part 3, # 8 Exhibit Joint 6 Part 4, # 9 Exhibit Joint 6 Part 5, # 10 Exhibit Joint 6 Part 6, # 11 Exhibit Joint 6 Part 7, # 12 Exhibit Joint 8, # 13 Exhibit Joint 9, # 14 Exhibit Joint 10, # 15 Exhibit Joint 11, # 16 Exhibit Joint 12, # 17 Exhibit Joint 13, # 18 Exhibit Joint 14, # 19 Exhibit 1, # 20 Exhibit 2, # 21 Exhibit 3, # 22 Exhibit 4, # 23 Exhibit 5, # 24 Exhibit 6, # 25 Exhibit 8, # 26 Exhibit 9, # 27 Exhibit 10, # 28 Exhibit 11, # 29 Exhibit 12, # 30 Exhibit 14, # 31 Exhibit 15, # 32 Exhibit 16, # 33 Exhibit 17, # 34 Exhibit 18, # 35 Exhibit 19, # 36 Exhibit 20, # 37 Exhibit 21, # 38 Exhibit 22, # 39 Exhibit 23, # 40 Exhibit 38, # 41 Exhibit 39, # 42 Exhibit 45, # 43 Exhibit 47, # 44 Exhibit 48, # 45 Exhibit 49, # 46 Exhibit 59, # 47 Exhibit 60, # 48 Exhibit 62, # 49 Exhibit 63, # 50 Exhibit 64, # 51 Exhibit 65, # 52 Exhibit 66, # 53 Exhibit 67, # 54 Exhibit 68, # 55 Exhibit 69, # 56 Exhibit 70, # 57 Exhibit 71, # 58 Exhibit 72, # 59 Exhibit 73, # 60 Exhibit 74, # 61 Exhibit 75, # 62 Exhibit 76, # 63 Exhibit 77, # 64 Exhibit 78, # 65 Exhibit 79, # 66 Exhibit 80, # 67 Exhibit 81, # 68 Exhibit 82, # 69 Exhibit 83, # 70 Exhibit 84, # 71 Exhibit 85, # 72 Exhibit 86, # 73 Exhibit 88, # 74 Exhibit 90, # 75 Exhibit 92, # 76 Exhibit 93, # 77 Exhibit 96, # 78 Exhibit 97, # 79 Exhibit 98, # 80 Exhibit 99, # 81 Exhibit 100, # 82 Exhibit 101, # 83 Exhibit 102, # 84 Exhibit 103, # 85 Exhibit 104, # 86 Exhibit 105, # 87 Exhibit 106, # 88 Exhibit 141, # 89 Exhibit 154, # 90 Exhibit 156, # 91 Exhibit 159, # 92 Exhibit 160, # 93 Exhibit 161, # 94 Exhibit 162, # 95 Exhibit 163, # 96 Exhibit 164) (AKJ). (Entered: 02/25/2016)	
146	02/25/2016	DEFENDANT Exhibit List (Trial) by CalAmp Corp.(NBL) (Additional attachment(s) added on 8/3/2017: # 1 Exhibit 2, # 2 Exhibit 4, # 3 Exhibit 5, # 4 Exhibit 6, # 5 Exhibit 10, # 6 Exhibit 11, # 7 Exhibit 12, # 8 Exhibit 17, # 9 Exhibit 24, # 10 Exhibit 26, # 11 Exhibit 27, # 12 Exhibit 28, # 13 Exhibit 29, # 14 Exhibit 30, # 15 Exhibit 31, # 16 Exhibit 32, # 17 Exhibit 33, # 18 Exhibit 34, # 19 Exhibit 37, # 20 Exhibit 38 part 1, # 21 Exhibit 38 part 2, # 22 Exhibit 38 part 3, # 23 Exhibit 38 part 4, # 24 Exhibit 38 part 5, #	

#	Date	Proceeding Text	Source
		25 Exhibit 39, # 26 Exhibit 40, # 27 Exhibit 41, # 28 Exhibit 42, # 29 Exhibit 43, # 30 Exhibit 44, # 31 Exhibit 45, # 32 Exhibit 46, # 33 Exhibit 47 part 1, # 34 Exhibit 47 part 2, # 35 Exhibit 47 part 3, # 36 Exhibit 47 part 4, # 37 Exhibit 47 part 5, # 38 Exhibit 47 part 6, # 39 Exhibit 48, # 40 Exhibit 49, # 41 Exhibit 50, # 42 Exhibit 51, # 43 Exhibit 52, # 44 Exhibit 54, # 45 Exhibit 55, # 46 Exhibit 56, # 47 Errata 57, # 48 Exhibit 58, # 49 Exhibit 59, # 50 Exhibit 65, # 51 Exhibit 66, # 52 Exhibit 67, # 53 Exhibit 68, # 54 Exhibit 69, # 55 Exhibit 70, # 56 Exhibit 71, # 57 Exhibit 73, # 58 Exhibit 74, # 59 Exhibit 75, # 60 Exhibit 76, # 61 Exhibit 77, # 62 Exhibit 78, # 63 Exhibit 79, # 64 Exhibit 80, # 65 Exhibit 81) (AKJ). (Entered: 02/25/2016)	
147	02/25/2016	COURT'S EXHIBIT LIST (Trial)(NBL) (Additional attachment(s) added on 8/1/2017: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6, # 7 Exhibit 7, # 8 Exhibit 8, # 9 Exhibit 9, # 10 Exhibit 10, # 11 Exhibit 11, # 12 Exhibit 12, # 13 Exhibit 13, # 14 Exhibit 14, # 15 Exhibit 15) (AKJ). (Entered: 02/25/2016)	
148	03/09/2016	MOTION and Memorandum for Entry of Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment by Omega Patents, LLC. (Gilchrist, Brian) Text modified on 3/10/2016 (RDO). (Entered: 03/09/2016)	
149	03/09/2016	PROPOSED BILL OF COSTS by Omega Patents, LLC. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5)(Gilchrist, Brian) (Entered: 03/09/2016)	
150	03/14/2016	UNOPPOSED MOTION for Leave to File a Motion in Excess of Twenty-Five Pages by Calamp Corp.. (Kauth, Joel) Text modified on 3/15/2016 (RDO). (Entered: 03/14/2016)	
151	03/15/2016	ENDORSED ORDER granting in part 150 Motion for Leave to File Excess Pages. Defendant may file a post-trial motion with a page limit of 35 pages and Plaintiff may file a response with a page limit of 30 pages. Signed by Judge Paul G. Byron on 3/15/2016. (MMW) (Entered: 03/15/2016)	
152	03/16/2016	MOTION and Memorandum for miscellaneous relief, specifically to Award Prejudgment Interest by Omega Patents, LLC. (Attachments: # 1 Exhibit A)(Gilchrist, Brian) Text modified on 3/17/2016 (RDO). (Entered: 03/16/2016)	
153	03/18/2016	ENDORSED ORDER denying without prejudice for failure to comply with Local Rule 3.01(g) 152 Motion to Award Prejudgment Interest. Signed by Judge Paul G. Byron on 3/18/2016. (MMW) (Entered: 03/18/2016)	
154	03/18/2016	MOTION for miscellaneous relief, specifically Renewed Motion to Award Prejudgment Interest by Omega Patents, LLC. (Attachments: # 1 Exhibit A)(Gilchrist, Brian) (Entered: 03/18/2016)	
155	03/22/2016	MOTION for Extension of Time to File and Enlargement of the Page Limitation for its Response to 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment by Calamp Corp.. (Kauth, Joel) Motions referred to Magistrate Judge David A. Baker. Text modified on 3/23/2016 (RDO). (Entered: 03/22/2016)	
156	03/24/2016	MOTION for Charles R. Halloran to withdraw as attorney by Calamp Corp.. (Halloran, Charles) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/24/2016)	
157	03/24/2016	MOTION for Eugene K. Chong to withdraw as attorney by Calamp Corp.. (Chong, Eugene) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/24/2016)	

#	Date	Proceeding Text	Source
158	03/25/2016	ENDORSED ORDER granting 156 Motion to Withdraw as Attorney Attorney Eugene Chong and Charles R. Halloran terminated; granting 157 Motion to Withdraw as Attorney. Signed by Magistrate Judge David A. Baker on 3/25/2016. (Baker, David) (Entered: 03/25/2016)	
159	03/25/2016	RESPONSE in Opposition re 155 MOTION for Extension of Time to File Response/Reply as to 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 03/25/2016)	
160	03/28/2016	MOTION for Stephanie P. Koh to appear pro hac vice by Calamp Corp.. (Wozniak, Carrie) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/28/2016)	
161	03/28/2016	MOTION for Thomas D. Rein to appear pro hac vice by Calamp Corp.. (Wozniak, Carrie) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/28/2016)	
162	03/28/2016	MOTION for Constantine L. Trela, Jr. to appear pro hac vice by Calamp Corp.. (Wozniak, Carrie) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/28/2016)	
	03/28/2016	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Constantine L. Trela, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL052203.) Related document: 162 MOTION for Constantine L. Trela, Jr. to appear pro hac vice. (RDO) (Entered: 03/28/2016)	
	03/28/2016	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Thomas D. Rein, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL052202.) Related document: 161 MOTION for Thomas D. Rein to appear pro hac vice. (RDO) (Entered: 03/28/2016)	
	03/28/2016	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Stephanie P. Koh, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL052205.) Related document: 160 MOTION for Stephanie P. Koh to appear pro hac vice. (RDO) (Entered: 03/28/2016)	
163	03/28/2016	ENDORSED ORDER granting in part and denying in part 155 Defendant Calamp Corp.'s Motion for Extension of Time to File and Enlargement of the Page Limitation for its Response to Plaintiff's Motion for Entry of Judgment. Calamp shall file its response to Plaintiff's Motion and Memorandum for Entry of Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction on or before April 11, 2016. The response shall not exceed thirty (30) pages in length. Signed by Judge Paul G. Byron on 3/28/2016. (RML) (Entered: 03/28/2016)	
	03/29/2016	Set/reset deadlines as to 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment . Responses due by 4/11/2016 (RDO) (Entered: 03/29/2016)	
164	03/30/2016	ENDORSED ORDER granting 160 motion to appear pro hac vice; granting 161 motion to appear pro hac vice; granting 162 motion to appear pro hac vice. Provided, all counsel shall register for and use the electronic filing system as adopted by the Court. After this Order, the Clerk will no longer send copies of docket entries by U.S. Mail to counsel in this case. Appearance and participation by more than one attorney at any hearing or trial is subject to the discretion of the presiding judge. Signed by Magistrate Judge David A. Baker on 3/30/2016. (Baker, David) (Entered: 03/30/2016)	

#	Date	Proceeding Text	Source
165	03/31/2016	MOTION for Bryan C. Mulder to appear pro hac vice by Calamp Corp.. (Wozniak, Carrie) Motions referred to Magistrate Judge David A. Baker. (Entered: 03/31/2016)	
	03/31/2016	***PRO HAC VICE FEES paid and Special Admission Attorney Certification Form filed by attorney Bryan C. Mulder, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL052334.) Related document: 165 MOTION for Bryan C. Mulder to appear pro hac vice. (RDO) (Entered: 03/31/2016)	
166	04/04/2016	RESPONSE in Opposition re 154 MOTION for miscellaneous relief, specifically Renewed Motion to Award Prejudgment Interest filed by Calamp Corp.. (Kauth, Joel) (Entered: 04/04/2016)	
167	04/05/2016	ENDORSED ORDER granting 165 motion to appear pro hac vice. Provided, all counsel shall register for and use the electronic filing system as adopted by the Court. After this Order, the Clerk will no longer send copies of docket entries by U.S. Mail to counsel in this case. Appearance and participation by more than one attorney at any hearing or trial is subject to the discretion of the presiding judge. Signed by Magistrate Judge David A. Baker on 4/5/2016. (Baker, David) (Entered: 04/05/2016)	
168	04/08/2016	MOTION to Review 149 Bill of Costs (filed as Response in Opposition/Objection) filed by Calamp Corp. (Kauth, Joel) Modified on 4/25/2016 (LMM). Motions referred to Magistrate Judge David A. Baker. (Entered: 04/08/2016)	
169	04/11/2016	RESPONSE in Opposition re 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment filed by Calamp Corp.. (Kauth, Joel) (Entered: 04/11/2016)	
170	04/11/2016	APPENDIX re 169 Response in Opposition to Motion by Calamp Corp.. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6, # 7 Exhibit 7, # 8 Exhibit 8, # 9 Exhibit 9, # 10 Exhibit 10, # 11 Exhibit 11, # 12 Exhibit 12, # 13 Exhibit 13, # 14 Exhibit 14, # 15 Exhibit 15, # 16 Exhibit 16, # 17 Exhibit 17, # 18 Exhibit 18, # 19 Exhibit 19, # 20 Exhibit 20, # 21 Exhibit 21, # 22 Exhibit 22, # 23 Exhibit 23, # 24 Exhibit 24)(Kauth, Joel) (Entered: 04/11/2016)	
171	04/11/2016	MOTION for miscellaneous relief, specifically Request for Hearing re 148 Motion for Entry of Final Judgment by Calamp Corp.. (Kauth, Joel) Modified on 4/12/2016 (RDO). (Entered: 04/11/2016)	
172	04/14/2016	ENDORSED ORDER granting 171 Defendant's Motion for Hearing Regarding Plaintiff's Motion for Entry of Final Judgment, Including Entitlement to Attorney's Fees, Enhanced Damages, and Entry of a Permanent Injunction. A separate Notice of Hearing will follow. Signed by Judge Paul G. Byron on 4/14/2016. (RML) (Entered: 04/14/2016)	
173	04/14/2016	NOTICE OF MOTION HEARING: re 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment. Motion Hearing is set for Tuesday, 4/26/2016 at 2:00 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. The Court has set aside (3) hours for this hearing. (NBL) copies e-mailed (Entered: 04/14/2016)	
174	04/18/2016	Unopposed MOTION for miscellaneous relief, specifically Reschedule Hearing (Currently Scheduled for April 26, 2016) by Omega Patents, LLC. (Santurri, Ryan) (Entered: 04/18/2016)	
175	04/19/2016	ENDORSED ORDER granting 174 Plaintiff's Unopposed Motion to Reschedule Hearing. A separate Notice of Hearing will follow. Signed by Judge Paul G. Byron on 4/19/2016. (RML) (Entered: 04/19/2016)	

#	Date	Proceeding Text	Source
176	04/19/2016	NOTICE RESCHEDULING MOTION HEARING re 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment. Motion Hearing is rescheduled for 5/2/2016 at 1:30 PM in Orlando Courtroom 4 B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd., Orlando, Florida. The Court has set aside (3) hours for this hearing. *(previously set for 4/26/16)(NBL) copies e-mailed (Entered: 04/19/2016)	
177	04/22/2016	RESPONSE in opposition to 168 Motion to Review Bill of Costs filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Santurri, Ryan) Modified on 4/25/2016 (LMM). Modified on 4/25/2016 (LMM). (Entered: 04/22/2016)	
178	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 1 held on 2/16/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, Telephone number 407-872-1715 or skoretta@bellsouth.net. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
179	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 2 held on 02/17/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
180	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 3 held on 02/18/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford,Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
181	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 4 held on 2/19/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford,Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
182	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 5 held on 2/22/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due	

#	Date	Proceeding Text	Source
		5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
183	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 6 held on 2/23/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford,Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
184	04/25/2016	TRANSCRIPT of Civil Jury Trial - Day 7 held on 2/24/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford,Telephone number 407-872-1715. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/16/2016, Redacted Transcript Deadline set for 5/26/2016, Release of Transcript Restriction set for 7/25/2016. (KS) (Entered: 04/25/2016)	
185	04/25/2016	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT, Doc 178 through 184. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 04/25/2016)	
186	04/26/2016	ORDER denying without prejudice 168 Motion to review bill of costs. Signed by Magistrate Judge David A. Baker on 4/26/2016. (SWT) (Entered: 04/26/2016)	
187	04/28/2016	NOTICE by Omega Patents, LLC of Filing Declarations (Attachments: # 1 Exhibit Declaration of Robert Leale II, # 2 Exhibit Declaration of Thomas Malone)(Santurri, Ryan) (Entered: 04/28/2016)	
188	04/29/2016	NOTICE by Calamp Corp. re 187 Notice (Other) of Filing Responsive Declarations (Attachments: # 1 Exhibit Declaration of Wade Files, # 2 Exhibit Declaration of Wade Huber)(Kauth, Joel) (Entered: 04/29/2016)	
189	05/02/2016	Minute Entry (MOTION HEARING) Proceedings held before Judge Paul G. Byron on 5/2/2016 re 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment filed by Omega Patents, LLC. Written Order to issue.Court Reporter: Koretta Stanford (NBL) (Entered: 05/03/2016)	
190	05/12/2016	TRANSCRIPT of the final pretrial conference held on 1/20/16 before Judge Paul G. Byron. Court Reporter/Transcriber Diane Peede, FlaDiane@att.net, telephone number 407-615-0305. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter.. Redaction Request due 6/2/2016, Redacted Transcript Deadline set for 6/13/2016, Release of Transcript Restriction set for 8/10/2016. (DP) (Entered: 05/12/2016)	

#	Date	Proceeding Text	Source
191	05/12/2016	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT (Doc. No. 190). The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Diane Peede. (DP) (Entered: 05/12/2016)	
192	05/17/2016	NOTICE of supplemental authority re 169 Response in Opposition to 148 Motion for entry of Judgment by Calamp Corp.. (Attachments: # 1 Exhibit 1)(Kauth, Joel) Modified on 5/18/2016 (RDO). (Entered: 05/17/2016)	
193	06/06/2016	NOTICE of Grant of Reexamination of '885 Patent re 169 Response in Opposition to Motion by Calamp Corp.. (Attachments: # 1 Exhibit 1)(Kauth, Joel) Text modified on 6/7/2016 (RDO). (Entered: 06/06/2016)	
194	06/13/2016	NOTICE of supplemental authority re 148 MOTION for Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction judgment by Omega Patents, LLC. (Attachments: # 1 Exhibit A)(Gilchrist, Brian) (Entered: 06/13/2016)	
195	06/14/2016	RESPONSE re 194 Notice of filing supplemental authority by Calamp Corp.. (Wozniak, Carrie) (Entered: 06/14/2016)	
196	06/22/2016	TRANSCRIPT of Motion Hearing held on 05/02/16 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, Telephone number 407-872-1715 or skoretta@bellsouth.net. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 7/13/2016, Redacted Transcript Deadline set for 7/25/2016, Release of Transcript Restriction set for 9/20/2016. (KS) (Entered: 06/22/2016)	
197	06/22/2016	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT, Doc. 196. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 06/22/2016)	
198	07/19/2016	RESPONSE re 192 Notice of filing supplemental authority filed by Omega Patents, LLC. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3)(Gilchrist, Brian) (Entered: 07/19/2016)	
199	07/22/2016	REPLY to 198 Response filed by Calamp Corp.. (Attachments: # 1 Exhibit 1, Beckert, # 2 Exhibit 2, Suman, # 3 Exhibit 3, J1850, # 4 Exhibit 4, J2178, # 5 Exhibit 5, 876 Claim Chart)(Mulder, Bryan) Text modified on 7/25/2016 (RDO). (Entered: 07/22/2016)	
200	08/30/2016	NOTICE of supplemental authority re 169 Response in Opposition to Motion by Calamp Corp.. (Wozniak, Carrie) (Entered: 08/30/2016)	
201	08/30/2016	NOTICE of supplemental authority re 169 Response in Opposition to Motion by Calamp Corp.. (Attachments: # 1 Exhibit 1)(Wozniak, Carrie) (Entered: 08/30/2016)	
202	09/19/2016	NOTICE of supplemental authority re 169 Response in Opposition to Motion for Entry of Final Judgment by Calamp Corp.. (Attachments: # 1 Exhibit 1)(Wozniak, Carrie) (Entered:	

#	Date	Proceeding Text	Source
		09/19/2016)	
203	10/03/2016	Case Reassigned to Magistrate Judge Daniel C. Irick. New case number: 6:13-cv-1950-ORL-40-DCI. Magistrate Judge David A. Baker no longer assigned to the case. (EJS) (Entered: 10/03/2016)	
204	10/21/2016	ENDORSED ORDER: The Court has taken the various notices of supplemental authority and related declarations and exhibits under advisement and is currently drafting its opinion. Prior to submitting any additional material relating to the post trial motions, the proponent SHALL seek leave of Court. Signed by Judge Paul G. Byron on 10/21/2016. (MMW) (Entered: 10/21/2016)	
205	03/20/2017	MOTION for miscellaneous relief, specifically Motion for Status Conference by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 03/20/2017)	
206	04/05/2017	ORDER granting in part and denying in part 148 Motion for Entry of Final Judgment, Including Entitlement to Attorneys' Fees, Enhanced Damages, and Entry of a Permanent Injunction. The Motion is granted as to entry of final judgment, attorneys' fees, and enhanced damages. The Motion is denied as to the request for entry of a permanent injunction. Plaintiff's 154 Renewed Motion to Award Prejudgment Interest is also granted. Signed by Judge Paul G. Byron on 4/5/2017. (ALJ) (RDO). (Entered: 04/05/2017)	
207	04/05/2017	ENDORSED ORDER denying as moot 205 Motion for Status Conference by Omega Patents, LLC. The Motion is rendered moot by the Court's Order entered on April 5, 2017 206. Signed by Judge Paul G. Byron on 4/5/2017. (ALJ) (Entered: 04/05/2017)	
208	04/19/2017	NOTICE by Omega Patents, LLC of Firm Name Change (Gilchrist, Brian) (Entered: 04/19/2017)	
209	04/19/2017	STIPULATION Regarding Attorneys' Fees and Costs by both parties. (Gilchrist, Brian) Modified on 4/20/2017 (RDO). (Entered: 04/19/2017)	
210	04/19/2017	STIPULATION for Entry of Proposed Final Judgment by both parties. (Attachments: # 1 Text of Proposed Order)(Gilchrist, Brian) Modified on 4/20/2017 (RDO). (Entered: 04/19/2017)	
211	04/24/2017	FINAL JUDGMENT. Signed by Judge Paul G. Byron on 4/24/2017. (ALJ) (Entered: 04/24/2017)	
212	04/24/2017	ENDORSED ORDER directing the Clerk of Court to close the file. Signed by Judge Paul G. Byron on 4/24/2017. (ALJ) (Entered: 04/24/2017)	
213	04/25/2017	Patent Report sent to Alexandria, VA. (Attachments: # 1 Judgment, # 2 Complaint) (RDO) (Entered: 04/25/2017)	
214	05/08/2017	MOTION to Stay Execution of 211 Judgment pending post-trial motions and for approval of supersedeas bond by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Wozniak, Carrie) Modified on 5/9/2017 (RDO). (Entered: 05/08/2017)	
215	05/12/2017	RESPONSE in Opposition re 214 MOTION to Stay Execution of 211 Judgment pending post-trial motions and for approval of supersedeas bond filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 05/12/2017)	
216	05/22/2017	RENEWED MOTION for judgment as a matter of law , MOTION for New Trial by Calamp Corp.. (Attachments: # 1 Exhibit 1, JE1 - US Patent No 6,346,876, # 2 Exhibit 2, JE3 - US Patent No 6,756,885, # 3 Exhibit 3, PTX104 (excerpts), # 4 Exhibit 4, JE5 - US Patent No 8,032,278, # 5 Exhibit 5, JE4 - US Patent No 7,671,727, # 6 Exhibit 6, 8-18-14 Hergesheimer Tr (excerpts), # 7 Exhibit 7, Eiberger Tr (excerpts), # 8 Exhibit 8, PTX161, # 9 Exhibit 9, 4-22-15 Hergesheimer Tr (excerpts), # 10 Exhibit 10, 885 reexam office action, # 11 Exhibit 11, PTX38, # 12 Exhibit 12,	

#	Date	Proceeding Text	Source
		PTX47, # 13 Exhibit 13, PTX14, # 14 Exhibit 14, CalAmp 2016 10K (excerpts), # 15 Exhibit 15, DTX73 (excerpts), # 16 Exhibit 16, DTX74 (excerpts), # 17 Exhibit 17, DTX75 (excerpts), # 18 Exhibit 18, 278 reexam office action, # 19 Exhibit 19, 727 reexam office action, # 20 Exhibit 20, 876 reexam office action, # 21 Exhibit 21, 727 reexam 5-13-17 response, # 22 Exhibit 22, Chen Tr (excerpts), # 23 Exhibit 23 - McDuff Report (excerpts))(Mulder, Bryan) Modified on 5/23/2017 (RDO). (Entered: 05/22/2017)	
217	05/23/2017	CERTIFICATE of compliance with Rule 3.01(g) re 216 MOTION for judgment as a matter of law MOTION for New Trial by Calamp Corp.. (Wozniak, Carrie) Modified on 5/24/2017 (RDO). (Entered: 05/23/2017)	
218	05/23/2017	STIPULATION Regarding Supplemental and On-going Royalties by both parties. (Attachments: # 1 Text of Proposed Order)(Gilchrist, Brian) Modified on 5/24/2017 (RDO). (Entered: 05/23/2017)	
219	05/31/2017	Unopposed MOTION for Extension of Time until 7/5/2017 to File Response/Reply as to 216 MOTION for judgment as a matter of law MOTION for New Trial by Omega Patents, LLC. (Gilchrist, Brian) Motions referred to Magistrate Judge Daniel C. Irick. Text modified on 6/1/2017 (RDO). (Entered: 05/31/2017)	
220	06/01/2017	ENDORSED ORDER granting 219 Unopposed Motion for Extension of Time to Respond to Defendant's Renewed Motion for Judgment as a Matter of Law and for New Trial. Plaintiff's response shall be due on or before July 5, 2017. Additional extensions should not be sought absent extraordinary good cause. Signed by Magistrate Judge Daniel C. Irick on 6/1/2017. (Irick, Daniel) (Entered: 06/01/2017)	
221	06/01/2017	STIPULATION to Stay Execution of 211 Final Judgment Secured by Supersedeas Bond by both parties. (Attachments: # 1 Exhibit, # 2 Text of Proposed Order)(Kauth, Joel) Modified on 6/2/2017 (RDO). (Entered: 06/01/2017)	
	06/02/2017	Set/reset deadlines as to 216 MOTION for judgment as a matter of law MOTION for New Trial . Responses due by 7/5/2017 (RDO) (Entered: 06/02/2017)	
222	06/02/2017	MOTION to Vacate 211 Final Judgment and Dismiss the Case for Lack of Venue by Calamp Corp.. (Attachments: # 1 Declaration of Garo Sarkissian)(Mulder, Bryan) Text modified on 6/5/2017 (RDO). (Entered: 06/02/2017)	
223	06/02/2017	ORDER re 221 Stipulation filed by Calamp Corp. The execution of the Final Judgment, and any Amended Judgment, and any proceedings to enforce either, are hereby STAYED pending disposition of post-trial motions, and any subsequent appeal. CalAmp SHALL post a supersedeas bond in the amount of $17,000,000.00 within 21 days of this order. The terms of the Stipulation to Stay Execution of Judgment (Doc. 221) are INCORPORATED and made part of this order. Hartford Fire Insurance Company is approved as the surety for such bond. CalAmp's currently pending Motion for Stay (Doc. 214) is DENIED AS MOOT. Signed by Judge Paul G. Byron on 6/2/2017. (MMW) (Entered: 06/02/2017)	
224	06/12/2017	NOTICE of Filing Supersedeas Bond by Calamp Corp. re 223 Order (Attachments: # 1 Exhibit A)(Wozniak, Carrie) Text modified on 6/13/2017 (RDO). (Entered: 06/12/2017)	
225	06/16/2017	RESPONSE in Opposition re 222 MOTION to Vacate 211 Final Judgment and Dismiss the Case for Lack of Venue filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 06/16/2017)	
226	07/05/2017	RESPONSE in Opposition re 216 MOTION for judgment as a matter of law MOTION for New Trial filed by Omega Patents,	

#	Date	Proceeding Text	Source
		LLC. (Gilchrist, Brian) (Entered: 07/05/2017)	
227	07/19/2017	AMENDED FINAL JUDGMENT. Signed by Judge Paul G. Byron on 7/19/2017. (MMW) Text modified on 7/20/2017 (RDO). (Entered: 07/19/2017)	
228	07/26/2017	Supplemental MOTION for judgment as a matter of law , for a new trial, and to vacate the judgment by Calamp Corp.. (Mulder, Bryan) (Entered: 07/26/2017)	
229	08/01/2017	RESPONSE in Opposition re 228 Supplemental MOTION for judgment as a matter of law , for a new trial, and to vacate the judgment filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 08/01/2017)	
230	09/22/2017	ORDER denying 222 Motion to Vacate the Judgment and Dismiss for Lack of Venue. Signed by Judge Paul G. Byron on 9/22/2017. (ALJ) (Entered: 09/22/2017)	
231	11/14/2017	ORDER denying 216 CalAmp's Renewed Motion for Judgment as a Matter of Law and for a New Trial; denying 228 CalAmp's Supplemental Renewed Motion for Judgment as a Matter of Law, for a New Trial, and to Vacate the Judgment. Signed by Judge Paul G. Byron on 11/14/2017. (JRJ) (Entered: 11/14/2017)	
232	12/11/2017	NOTICE OF APPEAL as to 227 Order, 211 Order, 206 Order on motion for judgment Order on Motion for Miscellaneous Relief, 230 Order on Motion to Vacate, 50 Order, 118 Order on motion for summary judgment, 125 Order on Motion in Limine, 117 Order on Motion for Miscellaneous Relief, 122 Order on Motion in Limine, 231 Order on Motion for Judgment as a Matter of Law Order on Motion for New Trial by Calamp Corp. Filing fee not paid. (Mulder, Bryan) (Entered: 12/11/2017)	
233	12/12/2017	TRANSMITTAL of initial appeal package to USCA for the Federal Circuit by email to appeal@cafc.uscourts.gov consisting of copies of notice of appeal, docket sheet, order/judgment being appealed, and motion, if applicable to USCA re 232 Notice of appeal. Transcript information form forwarded to pro se litigants and available to counsel at www.flmd.uscourts.gov under Forms and Publications/General. (JEV) (Entered: 12/12/2017)	
	12/14/2017	USCA appeal fees received $ 505 receipt number Orl-069431 re 232 Notice of appeal filed by Calamp Corp. (JEV) (Entered: 12/14/2017)	
	12/14/2017	TRANSMITTAL to USCA for the Federal Circuit by email to appeal@cafc.uscourts.gov forwarding notification of fee payment received re 232 Notice of appeal. (JEV) (Entered: 12/14/2017)	
234	12/21/2017	TRANSCRIPT information form filed by Calamp Corp. for proceedings held on 11/24/14 before Judge Paul G. Byron re 232 Notice of appeal. USCA number: 18-1309. (Wozniak, Carrie) (Entered: 12/21/2017)	
235	01/05/2018	COURT REPORTER ACKNOWLEDGMENT by Koretta Stanford re 232 Notice of appeal Estimated transcript filing date: 02/05/18. USCA number: 18-1309. (KS) (Entered: 01/05/2018)	
236	02/12/2018	TRANSCRIPT of Claims Construction Hearing held on 11/24/14 before Judge Paul G. Byron re 232 Notice of appeal. Court Reporter/Transcriber Koretta Stanford, Telephone number stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date, it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 3/5/2018. Redacted Transcript Deadline set for 3/15/2018. Release of Transcript Restriction set for 5/14/2018. (KS) (Entered: 02/12/2018)	

#	Date	Proceeding Text	Source
237	02/12/2018	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT, Doc. 236. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 02/12/2018)	
238	02/12/2018	NOTIFICATION that transcript has been filed by Koretta Stanford re: 232 Notice of appeal. USCA number: 18-1309. (KS) (Entered: 02/12/2018)	
239	04/08/2019	OPINION of USCA as to 232 Notice of appeal filed by Calamp Corp. EOD: 04/08/19; Mandate to issue at a later date. USCA number: 18-1309. AFFIRMED-IN-PART, REVERSED-IN-PART.VACATED-IN-PART, and REMANDED. (JP) (Entered: 04/08/2019)	
240	04/08/2019	JUDGMENT from USCA for the Federal Circuit as to 232 Notice of appeal filed by Calamp Corp. USCA number: 18-1309. AFFIRMED-IN-PART, REVERSED-IN-PART, VACATED-IN-PART, and REMANDED. (JP) (Entered: 04/08/2019)	
241	04/08/2019	NOTICE of hearing: Status Conference set for 4/19/2019 at 10:00 AM in Orlando Courtroom 4B before Judge Paul G. Byron. At least one attorney for each side is required to be present. Counsel shall be prepared to discuss scheduling with the Court.(GNB) copies e-mailed (Entered: 04/08/2019)	
242	04/12/2019	NOTICE of Additional Appearance by David Storrs Wood on behalf of Calamp Corp. (Wood, David) (Entered: 04/12/2019)	
243	04/19/2019	NOTICE to the parties regarding exhibit disposal. The parties are notified that they have thirty (30) days in which to contact the Courtroom Deputy Clerk to arrange for the removal of the exhibits from the custody of the Clerk's Office, or the exhibits will be disposed of, or destroyed, pursuant to Local Rule 5.04. (GNB) copies e-mailed (GNB). (Entered: 04/19/2019)	
244	04/19/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: STATUS CONFERENCE held on 4/19/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 04/19/2019)	
245	04/23/2019	Unopposed MOTION for Leif E. Peterson II to appear pro hac vice by Calamp Corp.. (Attachments: # 1 Exhibit Special Admission Attorney Certification)(Wood, David) Motions referred to Magistrate Judge Daniel C. Irick. (Entered: 04/23/2019)	
246	04/23/2019	NOTICE of Plaintiff Exhibit Return re 243 Notice. Plaintiff's exhibits returned on 4/19/2019. (GNB) copies e-mailed (Entered: 04/23/2019)	
247	04/23/2019	NOTICE of Defendant Exhibit Return re 243 Notice. Defendant's exhibits returned on 4/19/2019. (GNB) copies e-mailed (Entered: 04/23/2019)	
248	04/23/2019	CLERK'S certificate of destruction of COURT exhibits and/or exhibit substitutes. All Court exhibits have been made available electronically. (GNB) copies e-mailed (Entered: 04/23/2019)	
249	04/23/2019	ORDER granting 245 motion for Leif E. Peterson II, Esq.to appear pro hac vice. Counsel shall register for and use the electronic filing system as adopted by the Court. After this Order, the Clerk will no longer send copies of docket entries by U.S. Mail to counsel in this case. Signed by Magistrate Judge Daniel C. Irick on 4/23/2019. (DMA) (Entered: 04/23/2019)	
	04/24/2019	***PRO HAC VICE FEES paid by attorney Leif E. Peterson, II, appearing on behalf of Calamp Corp. (Filing fee $150 receipt number ORL082229.) Related document: 245 Unopposed	

#	Date	Proceeding Text	Source
		MOTION for Leif E. Peterson II to appear pro hac vice. (JP) (Entered: 04/24/2019)	
250	04/26/2019	NOTICE by Omega Patents, LLC re 244 Status Conference -- Notice Regarding Issues on Remand (Santurri, Ryan) (Entered: 04/26/2019)	
251	05/01/2019	MOTION for Reconsideration and/or Clarification as to Certain Oral Statements Made at Status Conference Conducted on April 19, 2019 by Calamp Corp.. (Wood, David) (Entered: 05/01/2019)	
252	05/01/2019	MOTION for clarification re 117 Order on Motion for Miscellaneous Relief by Calamp Corp.. (Wood, David) (Entered: 05/01/2019)	
253	05/02/2019	TRANSCRIPT of Status Conference held on 04/19/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 5/23/2019; Redacted Transcript Deadline set for 6/3/2019; Release of Transcript Restriction set for 7/31/2019. (KS) (Entered: 05/02/2019)	
254	05/02/2019	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT, Doc. 253. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 05/02/2019)	
255	05/03/2019	NOTICE by Omega Patents, LLC re 244 Status Conference - Notice of Filing Jury Instructions and Verdict Forms (Attachments: # 1 Exhibit A - Omega's Proposed Jury Instructions, # 2 Exhibit B - Calamp's Proposed Jury Instructions, # 3 Exhibit C - Omega's Proposed Verdict Form, # 4 Exhibit D - Calamp's Proposed Verdict Form)(Santurri, Ryan) (Entered: 05/03/2019)	
256	05/08/2019	NOTICE by Omega Patents, LLC of Filing Petition With the Federal Circuit (Attachments: # 1 Exhibit A - Combined Petition for Rehearing and Rehearing En Banc, # 2 Exhibit B - Federal Circuit Invitation on Response to Petition)(Santurri, Ryan) (Entered: 05/08/2019)	
257	05/13/2019	ENDORSED ORDER re 256 Notice of Filing Petition With the Federal Circuit filed by Omega Patents, LLC. The Clerk of Court is DIRECTED to terminate all pending motions and close the file. Signed by Judge Paul G. Byron on 5/13/2019. (GNB) copies e-mailed (Entered: 05/13/2019)	
258	05/20/2019	MOTION for Joel A. Kauth to withdraw as attorney by Calamp Corp.. (Kauth, Joel) Motions referred to Magistrate Judge Daniel C. Irick. (Entered: 05/20/2019)	
259	05/21/2019	ENDORSED ORDER granting 258 Unopposed Motion to Withdraw. Attorney Joel A. Kauth terminated. Signed by Magistrate Judge Daniel C. Irick on 5/21/2019. (Irick, Daniel) (Entered: 05/21/2019)	
260	06/24/2019	NOTICE by Omega Patents, LLC of Filing Order From the Federal Circuit and Request for Scheduling Consideration (Gilchrist, Brian) (Entered: 06/24/2019)	
261	06/24/2019	NOTICE by Calamp Corp. of Order from The Federal Circuit and Request for Scheduling Considerations (Peterson, Leif) (Entered: 06/24/2019)	

#	Date	Proceeding Text	Source
262	06/24/2019	ORDER of USCA as to 232 Notice of appeal filed by Calamp Corp.. EOD: 06/24/19; USCA number: 18-1309. (JP) (Entered: 06/25/2019)	
263	06/25/2019	ENDORSED ORDER re 262 Order of the United States Court of Appeals for the Federal Circuit denying Appellee's petitions for panel rehearing and rehearing en banc. This matter is due to be reopened. The Clerk is DIRECTED to reopen the file for further proceedings. Signed by Judge Paul G. Byron on 6/25/2019. (MMW) Modified on 6/25/2019 (RDO). (Entered: 06/25/2019)	
264	06/25/2019	NOTICE of Hearing: Status Conference set for 7/16/2019 at 3:30 PM in Orlando Courtroom 4B before Judge Paul G. Byron. The Court has set aside one (1) hour for this hearing.(GNB) copies e-mailed (Entered: 06/25/2019)	
265	07/01/2019	MANDATE of USCA as to 232 Notice of appeal filed by Calamp Corp. Issued as Mandate: 07/01/19 USCA number: 18-1309. AFFIRMED-IN-PART, REVERSED-IN-PART,VACATED-IN-PART, and REMANDED. (JP) (Entered: 07/01/2019)	
266	07/01/2019	MOTION for clarification re 117 Order on Motion for Miscellaneous Relief by Calamp Corp.. (Peterson, Leif) (Entered: 07/01/2019)	
267	07/01/2019	MOTION for Reconsideration And/Or Clarification by Calamp Corp.. (Peterson, Leif) (Entered: 07/01/2019)	
268	07/01/2019	MOTION for leave to file Motions In Limine by Calamp Corp.. (Peterson, Leif) (Entered: 07/01/2019)	
269	07/08/2019	CERTIFICATE under Local Rule 3.01(g) re 268 MOTION for leave to file Motions In Limine by Calamp Corp.. (Peterson, Leif) Modified on 7/9/2019 (RDO). (Entered: 07/08/2019)	
270	07/10/2019	NOTICE of Filing Updated Jury Instructions by Calamp Corp. (Peterson, Leif) Modified on 7/11/2019 (RDO). (Entered: 07/10/2019)	
271	07/12/2019	RESPONSE to Motion re 266 MOTION for clarification re 117 Order on Motion for Miscellaneous Relief filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 07/12/2019)	
272	07/12/2019	RESPONSE to Motion re 267 MOTION for Reconsideration And/Or Clarification filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 07/12/2019)	
273	07/12/2019	RESPONSE to Motion re 268 MOTION for leave to file Motions In Limine filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 07/12/2019)	
274	07/16/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: STATUS CONFERENCE held on 7/16/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 07/17/2019)	
275	07/16/2019	ORAL ORDER denying 266 Motion for clarification; denying 267 Motion for Reconsideration; denying 268 Motion for Leave to File for the reasons stated on the record. Rendered in Open Court by Judge Paul G. Byron on 7/16/2019. (GNB) (Entered: 07/17/2019)	
276	07/16/2019	NOTICE of Hearing: Jury Trial set for 9/23/2019 at 9:00 AM in Orlando Courtroom 4B before Judge Paul G. Byron. The Court has set aside four (4) days for this trial. (GNB) copies e-mailed (Entered: 07/17/2019)	
277	07/24/2019	TRANSCRIPT of Status Conference held on 07/16/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 8/14/2019; Redacted Transcript Deadline set for 8/26/2019; Release of Transcript Restriction set for 10/22/2019. (KS)	

#	Date	Proceeding Text	Source
		(Entered: 07/24/2019)	
278	07/24/2019	NOTICE to counsel of filing of OFFICIAL TRANSCRIPT, Doc. 277. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 07/24/2019)	
279	07/31/2019	NOTICE by Omega Patents, LLC re 274 Status Conference - Notice Regarding Claim Construction (Santurri, Ryan) (Entered: 07/31/2019)	
280	07/31/2019	NOTICE by Omega Patents, LLC Regarding Proposed Joint Stipulations (Attachments: # 1 Exhibit A - Plaintiff's Proposal, # 2 Exhibit B - Defendant's Proposal)(Santurri, Ryan) (Entered: 07/31/2019)	
281	08/12/2019	NOTICE by Omega Patents, LLC re 274 Status Conference Regarding Proposed Jury Instructions and Verdict Form (Attachments: # 1 Exhibit A - Proposed Jury Instructions w/Parties' Positions, # 2 Exhibit B - Omega's Proposed Verdict Form, # 3 Exhibit C - Calamp's Proposed Verdict Form, # 4 Exhibit D - Revised Interim Instruction on Willfulness with Parties' Positions)(Santurri, Ryan) (Entered: 08/12/2019)	
282	08/14/2019	ORDER directing supplemental briefing as to Defendant CalAmp Corp. See Order for details. Signed by Judge Paul G. Byron on 8/14/2019. (SCM) (Entered: 08/14/2019)	
283	08/23/2019	NOTICE of Hearing: Charge Conference set for 9/19/2019 at 10:00 AM in Orlando Courtroom 4B before Judge Paul G. Byron, U.S. District Court, 401 West Central Blvd, Orlando, Florida. The Court has set aside three (3) hours for this hearing.(GNB) copies e-mailed (Entered: 08/23/2019)	
284	08/23/2019	CIVIL PRETRIAL ORDER. Signed by Judge Paul G. Byron on 8/23/2019. (SCM) (Entered: 08/23/2019)	
285	08/28/2019	STATUS report/Statement regarding Chen and Bailey Anticipated Testimony re 282 Order by Calamp Corp.. (Peterson, Leif) Modified on 8/29/2019 (RDO). (Entered: 08/28/2019)	
286	09/16/2019	Witness List by Calamp Corp.. (Peterson, Leif) (Entered: 09/16/2019)	
287	09/16/2019	Exhibit List by Calamp Corp.. (Peterson, Leif) (Entered: 09/16/2019)	
288	09/16/2019	Exhibit List by Omega Patents, LLC. (Santurri, Ryan) (Entered: 09/16/2019)	
289	09/16/2019	Witness List by Omega Patents, LLC. (Santurri, Ryan) (Entered: 09/16/2019)	
290	09/18/2019	Proposed Voir Dire by Calamp Corp.. (Peterson, Leif) (Entered: 09/18/2019)	
291	09/19/2019	Exhibit List (Joint) by Omega Patents, LLC. (Santurri, Ryan) (Entered: 09/19/2019)	
292	09/19/2019	Exhibit List (Plaintiff's) by Omega Patents, LLC. (Santurri, Ryan) (Entered: 09/19/2019)	
293	09/19/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: Charge Conference held on 9/19/2019. Court Reporter: Koretta Stanford (GNB) copies e-mailed (Entered: 09/19/2019)	
294	09/19/2019	NOTICE by Calamp Corp. of Supplemental Authority Regarding Jury Instruction on Willfulness (Mulder, Bryan) (Entered: 09/19/2019)	

#	Date	Proceeding Text	Source
295	09/20/2019	NOTICE by Calamp Corp. of Proposed Stipulation (Attachments: # 1 Exhibit A, Proposed Stipulation)(Mulder, Bryan) (Entered: 09/20/2019)	
296	09/23/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 1) held on 9/23/2019. Court Reporter: Koretta Stanford (GNB) copies e-mailed (Entered: 09/24/2019)	
297	09/24/2019	NOTICE of Filing Deposition Designations by Omega Patents, LLC (Attachments: # 1 Exhibit Gallin Chen 4/21/2015 Depo Designations, # 2 Exhibit Jeffrey L. Eigberger 3/12/2015 Depo Designations, # 3 Exhibit Pete Hergesheimer 8/18/2014 Depo Designations, # 4 Exhibit Peter Hergesheimer 4/22/2015 Depo Designations, # 5 Exhibit Stephen Hall 3/11/2015 Depo Designations)(Santurri, Ryan) Modified on 9/25/2019 (RDO). (Entered: 09/24/2019)	
298	09/24/2019	NOTICE of Filing Corrected Deposition Designation by Omega Patents, LLC . (Attachments: # 1 Exhibit - Corrected Pete Hergesheimer 8/18/2014 Depo Designation)(Santurri, Ryan) Modified on 9/25/2019 (RDO). (Entered: 09/24/2019)	
299	09/24/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 2) held on 9/24/2019. Court Reporter: Koretta Stanford (GNB) copies e-mailed (Entered: 09/24/2019)	
300	09/25/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 3) held on 9/25/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 09/26/2019)	
301	09/26/2019	Supplement to 303 ORAL MOTION for Judgment as a Matter of Law by Calamp Corp. (Peterson, Leif) Modified on 9/27/2019 (GNB). (Entered: 09/26/2019)	
302	09/26/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 4) held on 9/26/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 09/27/2019)	
303	09/26/2019	ORAL MOTION for Judgment as a Matter of law by Calamp Corp for the reasons stated on the record. (GNB) (Entered: 09/27/2019)	
304	09/26/2019	ORAL ORDER denying 303 Motion for Judgment as a Matter of Law for the reasons stated on the record. Rendered in Open Court by Judge Paul G. Byron on 9/26/2019. (GNB) (Entered: 09/27/2019)	
305	09/27/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 5) held on 9/27/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 09/27/2019)	
306	09/27/2019	RENEWED ORAL MOTION for Judgment as a Matter of Law for the reasons stated on the record by Calamp Corp. (GNB) (Entered: 09/27/2019)	
307	09/27/2019	ORAL ORDER denying 306 Motion for Judgment as a Matter of Law for the reasons stated on the record. Rendered in Open Court by Judge Paul G. Byron on 9/27/2019. (GNB) (Entered: 09/27/2019)	
308	09/30/2019	Minute Entry. Proceedings held before Judge Paul G. Byron: JURY TRIAL (Day 6) completed on 9/30/2019. Court Reporter: Koretta Stanford (GNB) (Entered: 10/01/2019)	
309	09/30/2019	Jury Instructions. (GNB) (Entered: 10/01/2019)	
310	09/30/2019	JURY VERDICT. (GNB) (Entered: 10/01/2019)	
311	09/30/2019	Joint Exhibit List (Trial) by Omega Patents, LLC and Calamp Corp. (GNB) (Additional attachment(s) added on 10/1/2019: # 1 Exhibit 1, # 2 Exhibit 3, # 3 Exhibit 4, # 4 Exhibit 5, # 5 Exhibit 6 Part 1, # 6 Exhibit 6 Part 2, # 7 Exhibit 6 Part 3, # 8 Exhibit 6 Part 4, # 9 Exhibit 6 Part 5, # 10 Exhibit 6 Part 6, # 11 Exhibit 8, # 12 Exhibit 9, # 13 Exhibit 10, # 14 Exhibit 11, # 15 Exhibit 12, # 16 Exhibit 13, # 17 Exhibit 14) (GNB). (Entered: 10/01/2019)	

#	Date	Proceeding Text	Source
312	09/30/2019	Plaintiff's Exhibit List (Trial) by Omega Patents, LLC. (GNB) (Additional attachment(s) added on 10/1/2019: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6 Part 1, # 7 Exhibit 6 Part 2, # 8 Exhibit 8, # 9 Exhibit 9, # 10 Exhibit 10, # 11 Exhibit 11, # 12 Exhibit 12 Part 1, # 13 Exhibit 12 Part 2, # 14 Exhibit 14, # 15 Exhibit 15, # 16 Exhibit 16, # 17 Exhibit 18, # 18 Exhibit 19, # 19 Exhibit 20, # 20 Exhibit 21, # 21 Exhibit 22, # 22 Exhibit 23, # 23 Exhibit 38, # 24 Exhibit 39, # 25 Exhibit 40, # 29 Exhibit 45, # 31 Exhibit 47, # 32 Exhibit 48, # 33 Exhibit 49, # 34 Exhibit 59, # 35 Exhibit 60 Part 1, # 36 Exhibit 60 Part 2, # 37 Exhibit 60 Part 3, # 38 Exhibit 60 Part 4, # 39 Exhibit 60 Part 5, # 40 Exhibit 60 Part 6, # 41 Exhibit 64, # 42 Exhibit 67, # 43 Exhibit 68, # 44 Exhibit 69, # 45 Exhibit 71, # 46 Exhibit 81, # 47 Exhibit 82, # 48 Exhibit 83, # 49 Exhibit 84, # 50 Exhibit 85, # 51 Exhibit 86, # 52 Exhibit 92, # 53 Exhibit 93, # 54 Exhibit 96, # 55 Exhibit 97, # 56 Exhibit 99, # 57 Exhibit 100, # 58 Exhibit 102, # 59 Exhibit 103, # 60 Exhibit 104A, # 61 Exhibit 156, # 62 Exhibit 157, # 63 Exhibit 162) (GNB). (Entered: 10/01/2019)	
313	09/30/2019	Defendant's Exhibit List (Trial) by Calamp Corp. (GNB) (Additional attachment(s) added on 10/1/2019: # 1 Exhibit 12, # 2 Exhibit 17, # 3 Exhibit 18, # 4 Exhibit 22, # 5 Exhibit 54, # 6 Exhibit 54A) (GNB). (Entered: 10/01/2019)	
314	09/30/2019	Court's Exhibit List (Trial). (GNB) (Additional attachment(s) added on 10/1/2019: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6) (GNB). (Entered: 10/01/2019)	
315	09/30/2019	EXHIBIT CERTIFICATION by Omega Patents, LLC and Calamp Corp. (GNB) (Entered: 10/01/2019)	
316	10/29/2019	MOTION for Entry of Final judgment by Omega Patents, LLC. (Attachments: # 1 Exhibit A - Declaration)(Gilchrist, Brian) (Entered: 10/29/2019)	
317	10/29/2019	PROPOSED BILL OF COSTS by Omega Patents, LLC. (Attachments: # 1 Appendix, # 2 Exhibit 1, # 3 Exhibit 2, # 4 Exhibit 3, # 5 Exhibit 4, # 6 Exhibit 5)(Gilchrist, Brian) (Entered: 10/29/2019)	
318	11/08/2019	RESPONSE re 317 Bill of costs - proposed filed by Calamp Corp.. (Peterson, Leif) (Entered: 11/08/2019)	
319	11/12/2019	RESPONSE in Opposition re 316 MOTION for Entry of Final judgment filed by Calamp Corp.. (Peterson, Leif) (Entered: 11/12/2019)	
320	11/22/2019	RESPONSE in Opposition to 318 Response to Bill of Costs) filed by Omega Patents, LLC. (Santurri, Ryan) Modified on 11/25/2019 (RDO). (Entered: 11/22/2019)	
321	11/25/2019	ORDER granting 316 Motion for Entry of Final Judgment. See Order for details. Signed by Judge Paul G. Byron on 11/25/2019. (SCM) (Entered: 11/25/2019)	
322	11/26/2019	JUDGMENT in favor of Omega Patents, LLC against Calamp Corp..(see Judgment for details). (Signed by Deputy Clerk) (RDO) (Entered: 11/26/2019)	
323	11/27/2019	Patent Report sent to Alexandria, VA. (Attachments: # 1 Complaint, # 2 Judgment) (RDO) (Entered: 11/27/2019)	
324	12/09/2019	Unopposed MOTION for miscellaneous relief, specifically for leave to cite uncertified transcripts in post-trial motions by Calamp Corp.. (Peterson, Leif) (Entered: 12/09/2019)	
325	12/09/2019	ENDORSED ORDER granting 324 Motion for miscellaneous relief, specifically for leave to cite uncertified transcripts in post-trial motions. Signed by Judge Paul G. Byron on 12/9/2019. (SCM) (Entered: 12/09/2019)	
326	12/18/2019	Unopposed MOTION to stay Execution Of Judgment Pending	

#	Date	Proceeding Text	Source
		Post-Trial Motions And Appeal And For Approval Of Supersedeas Bond by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Peterson, Leif) (Entered: 12/18/2019)	
327	12/19/2019	ENDORSED ORDER re 326. Defendant shall email the Court a proposed order in Word format to CHAMBERS_FLMD_BYRON@flmd.uscourts.gov. Signed by Judge Paul G. Byron on 12/19/2019. (SCM) (Entered: 12/19/2019)	
328	12/20/2019	ORDER granting 326 Motion to Stay Execution Of Judgment Pending Post-Trial Motions And Appeal And For Approval Of Supersedeas Bond. Signed by Judge Paul G. Byron on 12/20/2019. (SCM) (Entered: 12/20/2019)	
329	12/23/2019	Joint MOTION for Extension of Time to File Opposition Briefs by Calamp Corp.. (Peterson, Leif) (Entered: 12/23/2019)	
330	12/23/2019	MOTION for judgment as a matter of law , MOTION for New Trial , MOTION for miscellaneous relief, specifically for a remittitur of damages by Calamp Corp.. (Peterson, Leif) (Entered: 12/23/2019)	
331	12/23/2019	MOTION for New Trial on Willfulness Under Rule 59 by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 12/23/2019)	
332	12/23/2019	MOTION for Judgment of Infringement of VPOD Units Under Rule 59 judgment by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 12/23/2019)	
333	12/23/2019	MOTION for Attorney Fees Award by Omega Patents, LLC. (Gilchrist, Brian) Motions referred to Magistrate Judge Daniel C. Irick. (Entered: 12/23/2019)	
334	12/23/2019	MOTION for miscellaneous relief, specifically Impose An Ongoing Royalty by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 12/23/2019)	
335	12/23/2019	MOTION for miscellaneous relief, specifically Leave to Conduct Post-Trial Discovery by Omega Patents, LLC. (Attachments: # 1 Exhibit A - Brochure, # 2 Exhibit B - Email, # 3 Exhibit C - Email, # 4 Exhibit D - Website Printout, # 5 Exhibit E - Email, # 6 Exhibit F - Email)(Gilchrist, Brian) (Entered: 12/23/2019)	
336	12/25/2019	ENDORSED ORDER granting 329 Motion for Extension of Time to File. Signed by Judge Paul G. Byron on 12/25/2019. (SCM) (Entered: 12/25/2019)	
344	01/06/2020	Supersedeas BOND in the amount of $ $6,757,830.50 posted by Calamp Corp. (RDO) Modified on 1/10/2020 (RDO). (Entered: 01/09/2020)	
337	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 1 held on 09/23/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered: 01/07/2020)	
338	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 2 held on 09/24/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered:	

#	Date	Proceeding Text	Source
		01/07/2020)	
339	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 3 held on 09/25/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered: 01/07/2020)	
340	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 4 held on 09/26/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered: 01/07/2020)	
341	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 5 held on 09/27/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered: 01/07/2020)	
342	01/07/2020	TRANSCRIPT of Civil Jury Trial - Day 6 held on 09/30/19 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 1/28/2020; Redacted Transcript Deadline set for 2/7/2020; Release of Transcript Restriction set for 4/6/2020. (KS) (Entered: 01/07/2020)	
343	01/07/2020	NOTICE to counsel of filing of OFFICIAL TRANSCRIPTS: Doc. 337, 338, 339, 340, 341, and 342. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the Clerk's Office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 01/07/2020)	
345	01/13/2020	ORDER denying without prejudice 333 Motion for an Award of Attorney Fees. Plaintiff may refile its motion for attorney fees within thirty days of the disposition of the pending post-trial motions and any subsequent appeal; the time for the response shall run from the date of the disposition of any subsequent appeal or the expiration of the time to file a notice of appeal if none is filed. Signed by Magistrate Judge Daniel C. Irick on 1/13/2020. (SPM) (Entered: 01/13/2020)	

#	Date	Proceeding Text	Source
346	01/20/2020	RESPONSE in Opposition re 330 MOTION for judgment as a matter of law MOTION for New Trial MOTION for miscellaneous relief, specifically for a remittitur of damages filed by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 01/20/2020)	
347	01/21/2020	RESPONSE in Opposition re 331 MOTION for New Trial on Willfulness Under Rule 59 filed by Calamp Corp.. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D)(Peterson, Leif) (Entered: 01/21/2020)	
348	01/21/2020	RESPONSE in Opposition re 334 MOTION for miscellaneous relief, specifically Impose An Ongoing Royalty filed by Calamp Corp.. (Peterson, Leif) (Entered: 01/21/2020)	
349	01/21/2020	RESPONSE in Opposition re 332 MOTION for Judgment of Infringement of VPOD Units Under Rule 59 judgment filed by Calamp Corp.. (Peterson, Leif) (Entered: 01/21/2020)	
350	01/21/2020	RESPONSE in Opposition re 335 MOTION for miscellaneous relief, specifically Leave to Conduct Post-Trial Discovery filed by Calamp Corp.. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6)(Peterson, Leif) (Entered: 01/21/2020)	
351	03/20/2020	ORDER denying 330 Motion for Judgment as a Matter of Law; denying 330 Motion for New Trial; denying 330 Motion for Remittitur of Damages. Signed by Judge Paul G. Byron on 3/20/2020. (SCM) (Entered: 03/20/2020)	
352	03/20/2020	ORDER denying 331 Motion for New Trial on Willfulness. Signed by Judge Paul G. Byron on 3/20/2020. (SCM) (Entered: 03/20/2020)	
353	04/01/2020	ORDER granting in part 334 Motion to Impose an Ongoing Royalty. Signed by Judge Paul G. Byron on 4/1/2020. (SCM) (Entered: 04/01/2020)	
354	04/01/2020	ORDER denying 335 Motion for Leave to Conduct Post-Trial Discovery. Signed by Judge Paul G. Byron on 4/1/2020. (SCM) (Entered: 04/01/2020)	
355	04/03/2020	ORDER denying 332 Motion for Judgment of Infringement of VPOD Units Under Rule 59. Signed by Judge Paul G. Byron on 4/3/2020. (SCM) (Entered: 04/03/2020)	
356	04/30/2020	NOTICE OF APPEAL as to 304 Order on Motion for Judgment as a Matter of Law, 322 Judgment, 321 Order on Motion for Judgment, 351 Order on Motion for Judgment as a Matter of LawOrder on Motion for New TrialOrder on Motion for Miscellaneous Relief, 353 Order on Motion for Miscellaneous Relief, 275 Order on Motion for ClarificationOrder on Motion for Reconsideration / ClarificationOrder on Motion for Leave to File Document by Calamp Corp.. Filing fee $ 505, receipt number 113A-16760207. (Peterson, Leif) (Entered: 04/30/2020)	
357	04/30/2020	NOTICE OF CROSS APPEAL as to 352 Order on Motion for New Trial, 353 Order on Motion for Miscellaneous Relief, 355 Order on Motion for Judgment by Omega Patents, LLC. (Attachments: # 1 Exhibit Dkt. 352, # 2 Exhibit Dkt #353, # 3 Exhibit Dkt #355)(Gilchrist, Brian) (Entered: 04/30/2020)	
	05/04/2020	Notice of Appeal packages submitted to the U.S. Court of Appeals for the Federal Circuit via emails re 356 Notice of Appeal and 357 Notice of Cross Appeal. (ALL) (Entered: 05/04/2020)	
	05/12/2020	USCA appeal fees received $ 505 receipt number ORL090685 re 357 Notice of cross appeal filed by Omega Patents, LLC (KNC) (Entered: 05/12/2020)	
358	05/14/2020	TRANSCRIPT information form filed by Calamp Corp. for proceedings held on September 19, 2019 before Judge Paul G. Byron re 356 Notice of Appeal. (Peterson, Leif) (Entered:	

#	Date	Proceeding Text	Source
		05/14/2020)	
359	05/27/2020	COURT REPORTER ACKNOWLEDGMENT by Koretta Stanford re 356 Notice of Appeal Estimated transcript filing date: 06/27/20. (KES) (Entered: 05/27/2020)	
360	06/26/2020	TRANSCRIPT of Charge Conference held on 09/19/19 before Judge Paul G. Byron re 356 Notice of Appeal. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date, it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 7/17/2020; Redacted Transcript Deadline set for 7/27/2020; Release of Transcript Restriction set for 9/24/2020. (KS) (Entered: 06/26/2020)	
361	06/26/2020	NOTICE to Counsel of filing of OFFICIAL TRANSCRIPT, Doc. 360. The parties have seven (7) calendar days to file with the court a Notice of Intent to Request Redaction of this transcript. If no such Notice is filed, the transcript may be made remotely electronically available to the public without redaction after 90 calendar days. Any party needing a copy of the transcript to review for redaction purposes may purchase a copy from the court reporter or view the document at the clerk's office public terminal. Court Reporter: Koretta Stanford. (KS) (Entered: 06/26/2020)	
362	06/26/2020	NOTIFICATION that transcript has been filed by Koretta Stanford re: 356 Notice of Appeal (KS) (Entered: 06/26/2020)	
363	12/22/2020	Unopposed MOTION for Bryan C. Mulder, Esq. to Withdraw as Attorney by Calamp Corp.. (Wozniak, Carrie) Motion referred to Magistrate Judge Daniel C. Irick. Modified on 12/23/2020 (RDO). (Entered: 12/22/2020)	
364	12/23/2020	ENDORSED ORDER granting 363 Motion to Withdraw. Attorney Bryan C. Mulder is terminated as counsel in this case. Signed by Magistrate Judge Daniel C. Irick on 12/23/2020. (Irick, Daniel) (Entered: 12/23/2020)	
365	04/06/2021	Unopposed MOTION for Carrie Ann Wozniak to Withdraw as Attorney by All Defendants. (Wozniak, Carrie) Motions referred to Magistrate Judge Daniel C. Irick. (Entered: 04/06/2021)	
366	04/07/2021	ENDORSED ORDER granting 365 Motion to Withdraw. Attorney Carrie Ann Wozniak is terminated as counsel in this case. Signed by Magistrate Judge Daniel C. Irick on 4/7/2021. (Irick, Daniel) (Entered: 04/07/2021)	
367	09/14/2021	OPINION USCA for the Federal Circuit as to 356 Notice of Appeal filed by Calamp Corp. EOD: 9/14/2021; Mandate to issue at a later date. USCA number: 20-1793. (TNP) (Entered: 09/14/2021)	
368	09/14/2021	USCA for the Federal Circuit JUDGMENT as to 356 Notice of Appeal filed by Calamp Corp. Entered on docket 9/14/2021. USCA number: 20-1793. AFFIRMED-IN-PART, VACATED-IN-PART, AND REMANDED. (TNP) (Entered: 09/15/2021)	
369	09/14/2021	USCA for the Federal Circuit JUDGMENT as to 357 Notice of cross appeal filed by Omega Patents, LLC. Entered on docket 9/14/2021. USCA number: 20-1794. DISMISSED. (TNP) (Entered: 09/15/2021)	
370	12/13/2021	MANDATE of USCA as to 356 Notice of Appeal filed by Calamp Corp., 357 Notice of cross appeal filed by Omega Patents, LLC. Issued as Mandate: 12/13/2021. USCA number: 20-1793, 20-1794. (TNP) (Entered: 12/16/2021)	
371	12/17/2021	ENDORSED ORDER re 370 USCA Mandate. The Clerk of Court is DIRECTED to re-open the case. Signed by Judge Paul G. Byron on 12/17/2021. (GNB) ctp (Entered: 12/17/2021)	

#	Date	Proceeding Text	Source
372	12/17/2021	NOTICE of Hearing: Final Pretrial Conference set for 1/19/2022 at 1:30 PM in Orlando Courtroom 4B before Judge Paul G. Byron. The Court has set aside sixty (60) minutes for this hearing.(GNB) ctp (Entered: 12/17/2021)	
373	01/10/2022	Joint MOTION for Miscellaneous Relief, specifically To Convert Final Pretrial Conference From In-Person To Videoconference by Calamp Corp.. (Peterson, Leif) (Entered: 01/10/2022)	
374	01/11/2022	ENDORSED ORDER denying 373 Joint Motion to Convert Final Pretrial Conference From In-Person to Vdieoconference. All local counsel are required to appear in person. Out of state counsel will be permitted to appear via telephone. Signed by Judge Paul G. Byron on 1/11/2022. (CPH) (Entered: 01/11/2022)	
375	01/11/2022	NOTICE re 372 Notice setting Final Pretrial Conference. Out-of-state counsel shall call 888-363-4735 ten (10) minutes before the hearing is set to begin. Access Code: 3126210. Security Code: 011922. (GNB) ctp (Entered: 01/11/2022)	
376	01/17/2022	MOTION for Miscellaneous Relief, specifically Motion to Reopen Discovery For Limited Purpose and To Permit A Supplement to the Damages Expert Report by Omega Patents, LLC. (Santurri, Ryan) (Entered: 01/17/2022)	
377	01/18/2022	NOTICE of Additional Appearance by Kimberly A. Lopez on behalf of Calamp Corp. (Lopez, Kimberly) (Entered: 01/18/2022)	
378	01/19/2022	Minute Entry. In Person Proceedings held before Judge Paul G. Byron: FINAL PRETRIAL CONFERENCE held on 1/19/2022. Court Reporter: Koretta Stanford (GNB) ctp (Entered: 01/19/2022)	
379	01/26/2022	SUPPLEMENT/Proposed Post-Discovery Schedule re 376 MOTION for Miscellaneous Relief, specifically Motion to Reopen Discovery For Limited Purpose and To Permit A Supplement to the Damages Expert Report by Omega Patents, LLC. (Gilchrist, Brian) Modified on 1/27/2022 (RDO). (Entered: 01/26/2022)	
380	02/09/2022	RESPONSE in Opposition re 376 MOTION for Miscellaneous Relief, specifically Motion to Reopen Discovery For Limited Purpose and To Permit A Supplement to the Damages Expert Report filed by Calamp Corp.. (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6, # 7 Exhibit 7, # 8 Exhibit 8, # 9 Exhibit 9, # 10 Exhibit 10)(Peterson, Leif) (Entered: 02/09/2022)	
381	02/14/2022	TRANSCRIPT of Final Pre-Trial Conference held on 01/19/22 before Judge Paul G. Byron. Court Reporter/Transcriber Koretta Stanford, stanarm2014@gmail.com. Transcript may be viewed at the court public terminal or purchased through the Court Reporter/Transcriber before the deadline for Release of Transcript Restriction. After that date it may be obtained through PACER or purchased through the Court Reporter. Redaction Request due 3/7/2022 Redacted Transcript Deadline set for 3/17/2022 Release of Transcript Restriction set for 5/16/2022. (KS) (Entered: 02/14/2022)	
382	02/18/2022	REPLY to Response to Motion re 376 MOTION for Miscellaneous Relief, specifically Motion to Reopen Discovery For Limited Purpose and To Permit A Supplement to the Damages Expert Report filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A)(Gilchrist, Brian) (Entered: 02/18/2022)	
383	03/16/2022	ORDER granting 376 Motion to Reopen Discovery for Limited Purpose and to Permit a Supplement to the Damages Expert Report. CalAmp Corp. may conduct limited discovery and supplement its expert's report on the issue of damages, as set forth in this Order. The Case Management Scheduling Order is AMENDED to reflect the discovery deadlines set forth in 379. Signed by Judge Paul G. Byron on 3/16/2022. (CPH) (Entered:	

#	Date	Proceeding Text	Source
		03/16/2022)	
384	03/17/2022	NOTICE of Hearing: Final Pretrial Conference set for 2/21/2023 at 3:00 PM in Orlando Courtroom 4B before Judge Paul G. Byron. The Court will set the case for a date certain trial at the Final Pretrial Conference.(GNB) ctp (Entered: 03/17/2022)	
385	04/01/2022	NOTICE of mediation conference/hearing to be held on April 12, 2022, at 8:30 a.m. before James M. Matulis, Esq.. (Gilchrist, Brian) (Entered: 04/01/2022)	
386	04/01/2022	NOTICE of Mediator's Appearance by James Michael Matulis on behalf of Matulis IP Law (Matulis, James) (Entered: 04/01/2022)	
387	04/19/2022	MEDIATION report Hearing held on April 12, 2022. Hearing outcome: Continued.. (Matulis, James) (Entered: 04/19/2022)	
388	05/05/2022	NOTICE of Continued Mediation. Conference to be held on May 10, 2022, at 10:00 a.m. before James M. Matulis, Esq.. (Gilchrist, Brian) Text modified on 5/6/2022 (RDO). (Entered: 05/05/2022)	
389	05/17/2022	SUPPLEMENTAL MEDIATION report. Hearing held on April 12, 2022 and May 10, 2022. Hearing outcome: Settled, with Joint Request for 60-day Administrative Closure.. (Matulis, James) Text modified on 5/17/2022 (RDO). (Entered: 05/17/2022)	
390	05/19/2022	ORDER re 389 Notice of Settlement. The Clerk of Court is DIRECTED to administratively close the file. Signed by Judge Paul G. Byron on 5/19/2022. (CPH) (Entered: 05/19/2022)	
391	06/15/2022	JOINT STIPULATION of Dismissal With Prejudice by both parties. (Gilchrist, Brian) Modified on 6/16/2022 (RDO). (Entered: 06/15/2022)	
392	06/16/2022	ORDER re 391 Joint Stipulation of Dismissal. Plaintiff's claims against Defendant are DISMISSED WITH PREJUDICE. The Clerk of Court is DIRECTED to close the file. Signed by Judge Paul G. Byron on 6/16/2022. (CPH) (Entered: 06/16/2022)	
393	06/16/2022	Patent Report sent to Alexandria, VA. (Attachments: # 1 Complaint, # 2 Exhibits A-C, # 3 Exhibits D-F, # 4 Order of Dismissal) (RDO) (Entered: 06/16/2022)	

Judgments

Date	In Favor Of	Against	Amount	Interest	Court Cost	Status	Status Date
11/26/2019	Omega Patents, LLC	Calamp Corp.	$4586111.00	0.00%	$ 0.00	No Payment	11/26/2019

Patents

Number	Title	Issued	Class	Subclass
6,346,876	Multi-vehicle compatible control system generating command signals on a data bus and associated methods	02/12/2002	340	426.13
6,737,989	Vehicle tracker including variable frequency transmission and related methods	05/18/2004	Er	undefined
6,756,885	Multi-vehicle compatible control system for reading from a data bus and associated methods	06/29/2004	340	426.1
7,671,727	Speed exceeded notification device for vehicle having a data bus and associated methods	03/02/2010	340	466
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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User Name: Karen Ward
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Job Number: 211855029

Document (1)

1. *6:20cv693, Omega Patents, Llc V. Dei Holdings, Inc.*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

6:20cv693, Omega Patents, Llc V. Dei Holdings, Inc.

US District Court Docket

United States District Court, Florida Middle

(Orlando)

This case was retrieved on 12/04/2023

Header

Case Number: 6:20cv693
Date Filed: 04/21/2020
Assigned To: Judge Carlos E. Mendoza
Referred To: Magistrate Judge Leslie Hoffman Price
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: None
Jurisdiction: Federal Question

Class Code: Closed
Closed: 07/21/2020
Statute: 35:271
Jury Demand: Plaintiff
Demand Amount: $0
NOS Description: Patent

Participants

Litigants

Omega Patents, LLC
a Georgia limited liability company |
Plaintiff

DEI Holdings, Inc.
a Florida corporation |
Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	04/21/2020	COMPLAINT against DEI Holdings, Inc. with Jury Demand (Filing fee $ 400 receipt number 113A-16727465) filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A - US Patent RE47,225, # 2 Exhibit B - US Patent 8,032,278, # 3 Exhibit C - US Patent RE47,354, # 4 Exhibit D - US Patent 8,362,886, # 5 Exhibit E - US Patent 9,981,615, # 6 Exhibit F - US Patent 7,305,293, # 7 Exhibit G - US Patent 8,410,929, # 8 Exhibit H - US Patent 8,258,948, # 9 Civil Cover Sheet, # 10 Proposed Summons)(Gilchrist, Brian) (Entered: 04/21/2020)	
2	04/21/2020	NEW CASE ASSIGNED to Judge Carlos E. Mendoza and Magistrate Judge Leslie R. Hoffman. New case number: 6:20-cv-693-Orl-41LRH. (SJB) (Entered: 04/21/2020)	
3	04/22/2020	SUMMONS issued as to DEI Holdings, Inc.. (DMA) (Entered: 04/22/2020)	
4	04/22/2020	Patent Report sent to Alexandria, VA. (Attachments: # 1 Complaint & Exhibits Part 1, # 2 Complaint & Exhibits Part 2, # 3 Complaint & Exhibits Part 3) (DMA) (Entered: 04/22/2020)	
5	04/24/2020	RELATED CASE ORDER AND NOTICE of designation under Local Rule 3.05 - Track 2. Notice of pendency of other actions due by 5/8/2020. Signed by Judge Carlos E. Mendoza on 4/24/2020. (MEH) ctp (Entered: 04/24/2020)	
6	04/24/2020	INTERESTED PERSONS ORDER Certificate of Interested Persons and corporate disclosure statement due by 5/8/2020. Signed by Judge Carlos E. Mendoza on 4/24/2020. (MEH) ctp (Entered: 04/24/2020)	
7	04/24/2020	NOTICE TO COUNSEL AND PARTIES: Failure to comply with ANY Local Rules or Court Orders may result in the imposition of sanctions including, but not limited to, the dismissal of this action or entry of default without further notice. Signed by Judge Carlos E. Mendoza on 4/24/2020. (MEH) ctp (Entered: 04/24/2020)	
8	04/27/2020	STANDING ORDER on Discovery Motions. Signed by Magistrate Judge Leslie R. Hoffman on 1/6/2020. (MKH) (Entered: 04/27/2020)	
9	05/07/2020	NOTICE of pendency of related cases re 5 Related case order per Local Rule 1.04(d) by Omega Patents, LLC. Related case(s): Yes (Attachments: # 1 Exhibit A)(Gilchrist, Brian) Modified on 5/8/2020 (DMA). (Entered: 05/07/2020)	
10	05/07/2020	CERTIFICATE of interested persons and corporate disclosure statement re 6 Interested persons order by Omega Patents, LLC. (Gilchrist, Brian) (Entered: 05/07/2020)	
11	06/08/2020	RETURN of service executed on May 15, 2020 by Omega Patents, LLC as to DEI Holdings, Inc.. (Gilchrist, Brian) (Entered: 06/08/2020)	
12	06/08/2020	MOTION for Clerk's Default against DEI Holdings, Inc. by Omega Patents, LLC. (Gilchrist, Brian) Motions referred to Magistrate Judge Leslie R. Hoffman. (Entered: 06/08/2020)	

#	Date	Proceeding Text	Source
13	06/09/2020	ORDER denying without prejudice 12 Motion for Clerk's Default. Signed by Magistrate Judge Leslie R. Hoffman on 6/9/2020. (MKH) (Entered: 06/09/2020)	
14	06/26/2020	NOTICE of Appearance by Eleanor Martha Yost on behalf of DEI Holdings, Inc. (Yost, Eleanor) (Entered: 06/26/2020)	
15	06/26/2020	NOTICE of pendency of related cases re 5 Related case order and track 2 notice per Local Rule 1.04(d) by DEI Holdings, Inc.. Related case(s): Yes (Yost, Eleanor) (Entered: 06/26/2020)	
16	06/26/2020	CERTIFICATE of interested persons and corporate disclosure statement re 6 Interested persons order by DEI Holdings, Inc. identifying Corporate Parent Viper Holdings Corporation, Other Affiliate DEI Sales, Inc., Other Affiliate D&M Holdings Inc. (Japan), Other Affiliate Sound United, LLC, Other Affiliate Directed Electronics Hong Kong Limited (Hong Kong), Other Affiliate DEI China Holdings Limited (Hong Kong) for DEI Holdings, Inc... (Yost, Eleanor) (Entered: 06/26/2020)	
17	06/26/2020	Unopposed MOTION for Extension of Time to File Answer re 1 Complaint by DEI Holdings, Inc.. (Yost, Eleanor) Motions referred to Magistrate Judge Leslie R. Hoffman. (Entered: 06/26/2020)	
18	06/26/2020	NOTICE of Appearance by Daniel C. Johnson on behalf of DEI Holdings, Inc. (Johnson, Daniel) (Entered: 06/26/2020)	
19	06/26/2020	ORDER granting 17 Motion for Extension of Time to Answer or Respond re 1 Complaint. DEI Holdings, Inc. answer or response due 7/21/2020. Signed by Magistrate Judge Leslie R. Hoffman on 6/26/2020. (MKH) (Entered: 06/26/2020)	
20	07/17/2020	NOTICE of voluntary dismissal by Omega Patents, LLC (Gilchrist, Brian) (Entered: 07/17/2020)	
21	07/20/2020	ORDER directing the Clerk of Court to close this case re 20 Notice of voluntary dismissal. Signed by Judge Carlos E. Mendoza on 7/20/2020. (MEH) ctp (Entered: 07/20/2020)	
22	07/21/2020	Patent Report sent to Alexandria, VA. (Attachments: # 1 Order) (ARJ) (Entered: 07/21/2020)	

Patents

Number	Title	Issued	Class	Subclass
RE47,225	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	02/05/2019	1	1
RE47,354	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	04/16/2019	1	1
7,305,293	Vehicle tracker including input/output features and related methods	12/04/2007	701	45
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36
8,258,948	Remote vehicle starting system providing a tactile indication relating to remote starting and associated methods	09/04/2012	340	540
8,362,886	Multi-controller data bus adaptor and associated methods	01/29/2013	340	426.17
8,410,929	Remote vehicle starting system providing an audible indication relating to remote starting and associated methods	04/02/2013	340	540
9,981,615	Remote function control system for a vehicle having a data communications bus and related methods	05/29/2018	1	1

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Job Number: 211855181

Document (1)

1. *IPR2023-00504, GEOTAB USA, INC. et al. Vs. Omega Patents, LLC*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

US Patent Trial and Appeals Board - Alexandria

Alexandria

This case was retrieved on 12/04/2023

Header

Case Number: IPR2023-00504
Date Filed: 01/27/2023
Date Full Case Retrieved: 12/04/2023
Status: Open
Misc: (0) Unknown; Civil

Summary

Court Case Status: Instituted
Case Type: IPR: Inter partes review
Date of Decision to Institute Case: 7/25/2023
Technical Center Number: 3600
Patent Application Number: 11773272
Patent Number: 8032278

Participants

Litigants
GEOTAB USA, INC. et al.
Petitioner
Omega Patents, LLC
PatentOwner

Attorneys

Proceedings

Date	#	Proceeding Text	Details
11/14/2023	1	Exhibit 3001	Filed By: BOARD Document Type: EXHIBIT Paper/Exhibit No: 3001 Public? Yes
11/06/2023	2	EXPUNGED_Omega Royalty Report (April 2023)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2024 Public? No
11/06/2023	3	EXPUNGED_Declaration of Kenneth E. Flick	Filed By: PATENT OWNER

Date	#	Proceeding Text	Details
			Document Type: EXHIBIT Paper/Exhibit No: 2023 Public? No
10/18/2023	4	D.I. 145-38, PL22, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2022 Public? Yes
10/18/2023	5	Master And Cross-License Agreement, dated May 12, 2007, between Omega R&D, Omega Patents and Directed Electronics, Inc	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2021 Public? Yes
10/18/2023	6	D.I. 145-59, PL73, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2020 Public? Yes
10/18/2023	7	D.I. 145-36, PL20, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2019 Public? Yes
10/18/2023	8	D.I. 145-34, PL18, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2018 Public? Yes
10/18/2023	9	D.I. 145-20, PL2, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2017 Public? Yes
10/18/2023	10	D.I. 145-19, PL1, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2016

Date	#	Proceeding Text	Details
			Public? Yes
10/18/2023	11	D.I. 145-43, PL47, Omega Patents, LLC v. CalAmp Corp., No. 6:13-cv-1950 (M.D. Fla. Feb 25, 2016)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2015 Public? Yes
10/18/2023	12	Declaration of Mr. Christian Tregillis	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2014 Public? Yes
10/18/2023	13	U.S. Patent No. 6,628,233 to Knockeart et al.	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2013 Public? Yes
10/18/2023	14	U.S. Patent No. 5,515,043 to Berard et al.	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2012 Public? Yes
10/18/2023	15	Reexamination Certificate Issued May 17, 2023, in 90/014,675 (RX5).	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2011 Public? Yes
10/18/2023	16	Second Declaration of Mr. Joseph C. McAlexander, III	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2010 Public? Yes
04/27/2023	17	U.S. Patent No. 5,732,074 to Spaur et al.	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2009 Public? Yes
04/27/2023	18	Intent to issue Reexamination Certificate,	Filed By:

Date	#	Proceeding Text	Details
		mailed on April 14, 2023 in 90/014,675 (RX5)	PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2008 Public? Yes
04/27/2023	19	D.I. 39, Defendant CalAmp Corp???s Opening Claim Construction Brief, Omega Patents, LLC v. CalAmp Corp., No. 6:13- cv-1950 (M.D. Fla. September 5, 2014)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2007 Public? Yes
04/27/2023	20	D.I. 297-5, Deposition of Stephen Hall, Omega Patents, LLC v. CalAmp Corp., No. 6:13- cv-1950 (M.D. Fla. September 24, 2019)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2006 Public? Yes
04/27/2023	21	D.I. 297-4, Deposition of Peter Hergesheimer, Omega Patents, LLC v. CalAmp Corp., No. 6:13- cv-1950 (M.D. Fla. September 24, 2019)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2005 Public? Yes
04/27/2023	22	D.I. 297-1, Deposition of Galin Chen, Omega Patents, LLC v. CalAmp Corp., No. 6:13- cv-1950 (M.D. Fla. September 24, 2019)	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2004 Public? Yes
04/27/2023	23	Curriculum Vitae of Mr. Joseph C. McAlexander, III	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2003 Public? Yes
04/27/2023	24	Declaration of Mr. Joseph C. McAlexander, III	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No: 2002 Public? Yes
04/27/2023	25	U.S. Patent No. 6,636,790 to Lightner	Filed By: PATENT OWNER Document Type: EXHIBIT Paper/Exhibit No:

Date	#	Proceeding Text	Details
			2001 Public? Yes
05/22/2023	26	Board E-Mail Authorizing Reply to Patent Owner???s Preliminary Response (May 15, 2023)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1114 Public? Yes
01/27/2023	27	D.I. 145-78, PL97, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1113 Public? Yes
01/27/2023	28	D.I. 145-82, PL101, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1112 Public? Yes
01/27/2023	29	D.I. 145-72, PL86, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1111 Public? Yes
01/27/2023	30	D.I. 145-71, PL85, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1110 Public? Yes
01/27/2023	31	D.I. 145-55, PL69, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1109 Public? Yes
01/27/2023	32	D.I. 145-88, PL141, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1108 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	33	D.I. 145-84, PL103, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1107 Public? Yes
01/27/2023	34	D.I. 145-83, PL102, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1106 Public? Yes
01/27/2023	35	D.I. 145-81, PL100, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1105 Public? Yes
01/27/2023	36	D.I. 145-79, PL98, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1104 Public? Yes
01/27/2023	37	D.I. 145-77, PL96, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1103 Public? Yes
01/27/2023	38	D.I. 145-76, PL93, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1102 Public? Yes
01/27/2023	39	D.I. 145-75, PL92, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1101 Public? Yes
01/27/2023	40	D.I. 145-74, PL90, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1100 Public? Yes
01/27/2023	41	D.I. 145-73, PL88, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1099 Public? Yes
01/27/2023	42	D.I. 145-70, PL84, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1098 Public? Yes
01/27/2023	43	D.I. 145-69, PL83, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1097 Public? Yes
01/27/2023	44	D.I. 145-68, PL82, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1096 Public? Yes
01/27/2023	45	D.I. 145-57, PL71, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1095 Public? Yes
01/27/2023	46	D.I. 145-42, PL45, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1094 Public? Yes
01/27/2023	47	D.I. 145-67, PL81, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1093 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	48	D.I. 145-53, PL67, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1092 Public? Yes
01/27/2023	49	D.I. 145-54, PL68, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1091 Public? Yes
01/27/2023	50	D.I. 145-80, PL99, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1090 Public? Yes
01/27/2023	51	ISO 14230-2 Road vehicles - Diagnostic systems - Keyword Protocol 2000	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1082 Public? Yes
01/27/2023	52	Pages from Newton???s Telecom Dictionary (2005)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1081 Public? Yes
01/27/2023	53	Pages from Collins English Dictionary (5th ed. 2000)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1080 Public? Yes
01/27/2023	54	Pages from Title 40 Code of Fed Regulations, Part 86, Subpart S (7???1???14)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1079 Public? Yes
01/27/2023	55	SAE J2178-4 Class B Data Communication Network Messages	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1078 Public? Yes
01/27/2023	56	D.I. 10, Geotab USA, Inc.???s Opening Brief In Support Of Motion To Dismiss	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1077 Public? Yes
01/27/2023	57	SAE J2178-1 Class B Data Communication Network Messages	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1076 Public? Yes
01/27/2023	58	SAE 1979 E/E Diagnostic Test Modes ??? Equivalent to ISO/DIS 15031-5	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1075 Public? Yes
01/27/2023	59	ISO 14230-4 Road vehicles - Diagnostic systems - Keyword Protocol 2000	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1074 Public? Yes
01/27/2023	60	ISO 15031-5:2006(E) Road vehicles - Communication between vehicle	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1073 Public? Yes
01/27/2023	61	ISO 15765-4:2005(E) Road vehicles - Diagnostics on Controller Area Networks	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1072 Public? Yes
01/27/2023	62	SAE J1850 Class B Data Communications Network Interface	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1071 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	63	Control of Air Pollution From New Motor Vehicles. 68 Fed. Reg. 35792	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1070 Public? Yes
01/27/2023	64	D.I. 145. Omega Patents. LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1068 Public? Yes
01/27/2023	65	February 19, 2007 Internet Archive capture of startech.com webpage	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1067 Public? Yes
01/27/2023	66	13 Cal. Code Reg. 1968.2 Malfunction and Diagnostic System Requirements	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1066 Public? Yes
01/27/2023	67	D.I. 145-85, PL104, 4/15/2015 Expert Report of Joseph C. McAlexander	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1065 Public? Yes
01/27/2023	68	U.S. Patent No. 7,617,727	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1064 Public? Yes
01/27/2023	69	U.S. Patent No. 7,209,813	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1060 Public? Yes
01/27/2023	70	U.S. Patent No. 6,611,740	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1059 Public? Yes
01/27/2023	71	U.S. Patent Application Publication No. US 2004/0138790 A1	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1058 Public? Yes
01/27/2023	72	U.S. Patent Application Publication No. US 2005/0032511 A1	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1057 Public? Yes
01/27/2023	73	U.S. Patent No. 8,856,266 B2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1056 Public? Yes
01/27/2023	74	DI 392, Order Dismissing With Prejudice, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1055 Public? Yes
01/27/2023	75	D.I. 265, Federal Circuit Mandate, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1054 Public? Yes
01/27/2023	76	Pages from IEEE 100 The Authoritative Dictionary of IEEE Standard Terms	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1053 Public? Yes
01/27/2023	77	SAE J1978 OBD-II Scan Tool - Equivalent to ISO/DIS 15031-4(revised 2002-04)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1052 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	78	Pages from Microsoft Internet & Networking Dictionary (2003)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1051 Public? Yes
01/27/2023	79	International Standard ISO 15031-4 Road Vehicles (\	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1050 Public? Yes
01/27/2023	80	SAE J1708 Serial Data Communications Between Microcomputer Systems	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1048 Public? Yes
01/27/2023	81	SAE J1939-71 Vehicle Application Layer (rev. DEC2004)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1047 Public? Yes
01/27/2023	82	Pages from Title 40 Code of Fed Regulations, Part 86, Subpart S (????1???07)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1046 Public? Yes
01/27/2023	83	U.S. District Court ??? Judicial Caseload Profile for the District of DE	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1045 Public? Yes
01/27/2023	84	Comparison of limitations in ???278 patent claims 13-22 vs. claims 1-12	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1044 Public? Yes
01/27/2023	85	D.I. 339, Transcript, Civil Jury Trial???Day 3, Omega Patents, LLC v. CalAmp	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1040 Public? Yes
01/27/2023	86	D.I. 338, Transcript, Civil Jury Trial???Day 2, Omega Patents, LLC v. CalAmp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1039 Public? Yes
01/27/2023	87	Transcript, Civil Jury Trial???Day 4, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1034 Public? Yes
01/27/2023	88	Transcript, Civil Jury Trial???Day 3, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1033 Public? Yes
01/27/2023	89	Priscoli et al, Space Communications, Vol. 19, no. 1, pp. 47-57, 2003.	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1032 Public? Yes
01/27/2023	90	Enhanced radio access technologies for next generation mobile communication	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1031 Public? Yes
01/27/2023	91	D.I. 309, Jury Instructions, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1030 Public? Yes
01/27/2023	92	D.I. 143, Jury Instructions, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1029 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	93	D.I. 310, Jury Verdict, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1028 Public? Yes
01/27/2023	94	D.I. 144, Jury Verdict, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1027 Public? Yes
01/27/2023	95	D.I. 040, Omega Patents Opposition to CalAmp Motion For Claim Construction	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1026 Public? Yes
01/27/2023	96	U.S. Patent No. 6,011,460 (\	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1025 Public? Yes
01/27/2023	97	U.S. Patent No. 6,756,885 (\	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1024 Public? Yes
01/27/2023	98	U.S. Patent No. 6,957,133 (\	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1023 Public? Yes
01/27/2023	99	Omega Patents' Answering Brief in Opposition to Geotab's Motion to Dismiss	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1022 Public? Yes
01/27/2023	100	Omega Patents, LLC v. CalAmp Corp., 13 F.4th 1361 (\	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1021 Public? Yes
01/27/2023	101	Omega Patents, LLC v. CalAmp Corp., 920 F.3d 1337 (\	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1020 Public? Yes
01/27/2023	102	D.I. 34, Claim Construction Order, Omega Patents, LLC v. Firstech, LLC	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1019 Public? Yes
01/27/2023	103	D.I. 50, Claim Construction Order, Omega Patents, LLC v. CalAmp Corp	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1018 Public? Yes
01/27/2023	104	Decision on Appeal, Ex parte Omega Patents, LLC, No. 2022-003758	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1017 Public? Yes
01/27/2023	105	Transcript of oral argument in Ex parte Omega Patents, LLC, No. 2022-003758	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1016 Public? Yes
01/27/2023	106	Patent Owner???s Appeal Brief, No. 90/014,675 (April 1, 2022)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1015 Public? Yes
01/27/2023	107	Non-Final Rejection, mailed October 5, 2021 in No. 90/014,675 (RX5)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1014 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	108	Decision granting ex parte reexamination request in No. 90/014,675 (RX5)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1013 Public? Yes
01/27/2023	109	Ex parte Omega Patents, LLC, No. 2018-008119 (Nov. 3, 2018)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1012 Public? Yes
01/27/2023	110	Decision granting ex parte reexamination request in No. 90/013,851 (RX2)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1011 Public? Yes
01/27/2023	111	Claim Rejection, mailed May 6, 2016 in No. 90/013,587 (RX1)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1010 Public? Yes
01/27/2023	112	Prosecution History of Ser. No. 90/014,675 (RX5)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1009 Public? Yes
01/27/2023	113	Prosecution History of Ser. No. 90/014,419 (RX4) - Part 1 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1008 Public? Yes
01/27/2023	114	Prosecution History of Ser. No. 90/014,419 (RX4) - Part 2 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1008 Public? Yes
01/27/2023	115	Prosecution History of Ser. No. 90/014,309 (RX3)	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1007 Public? Yes
01/27/2023	116	Prosecution History of Ser. No. 90/013,851 (RX2) - Part 1 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1006 Public? Yes
01/27/2023	117	Prosecution History of Ser. No. 90/013,851 (RX2) - Part 2 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1006 Public? Yes
01/27/2023	118	Prosecution History of Ser. No. 90/013,587 (RX1) - Part 1 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1005 Public? Yes
01/27/2023	119	Prosecution History of Ser. No. 90/013,587 (RX1) - Part 2 of 2	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1005 Public? Yes
01/27/2023	120	Curriculum Vitae of Jeffrey Miller, Ph.D.	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1004 Public? Yes
01/27/2023	121	Declaration of Jeffrey Miller, Ph.D.	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1003 Public? Yes
01/27/2023	122	Prosecution History of U.S. Patent No. 8,032,278	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1002 Public? Yes

Date	#	Proceeding Text	Details
01/27/2023	123	U.S. Patent No. 8,032,278	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1001 Public? Yes
11/14/2023	124	Patent Owner's Notice of Service of Supplemental Evidence Pursuant to 37 C.F.R. ??42.64(b)(2)	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 20 Public? Yes
11/14/2023	125	Order: ORDER Conduct of the Proceeding 37 C.F.R. ?? 42.5	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 19 Public? Yes
11/06/2023	126	EXPUNGED_Patent Owner's Notice of Filing Supplemental Evidence Pursuant to 37 C.F.R. ??42.64(b)(1)	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 18 Public? No
10/25/2023	127	Petitioner's Objections to Evidence Served with Patent Owner's Response	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 17 Public? Yes
10/18/2023	128	Patent Owner's Second Supplemental Mandatory Notice	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 16 Public? Yes
10/18/2023	129	Patent Owner's Response Under ?? 37 C.F.R. ?? 42.120	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 15 Public? Yes
08/08/2023	130	Petitioners' Objections to Evidence	Filed By: PETITIONER Document Type: PAPER

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 14 Public? Yes
08/08/2023	131	Petitioners' First Updated Mandatory Notices	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 13 Public? Yes
07/25/2023	132	Order: Scheduling Order	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 12 Public? Yes
07/25/2023	133	Institution Decision: Grant	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 11 Public? Yes
07/20/2023	134	Patent Owner's Supplemental Mandatory Notice	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 10 Public? Yes
05/30/2023	135	Patent Owner's Sur-Reply to Petitioners' Reply to Patent Owner's Preliminary Response as Authorized by Exhibit 1114	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 9 Public? Yes
05/22/2023	136	Petitioner's Reply to Patent Owner's Preliminary Response as Authorized by Exhibit 1114	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 8 Public? Yes
04/27/2023	137	Patent Owner's Preliminary Response Under 35 U.S.C. ?? 313 and 37 C.F.R. ?? 42.107	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 7 Public? Yes

Date	#	Proceeding Text	Details
02/14/2023	138	Notice : Power of Attorney	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 6 Public? Yes
02/14/2023	139	Notice : Mandatory Notice	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 5 Public? Yes
02/08/2023	140	Notice: NOTICE OF FILING DATE ACCORDED TO PETITION AND TIME FOR FILING PATENT OWNER PRELIMINARY RESPONSE	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 4 Public? Yes
01/27/2023	141	Petition for Inter Partes Review	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 3 Public? Yes
01/27/2023	142	Geotab, Inc. Power of Attorney	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 2 Public? Yes
01/27/2023	143	Geotab USA, Inc. Power of Attorney	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 1 Public? Yes

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User Name: Karen Ward
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Job Number: 211855659

Document (1)

1. *1:17cv2769, Omega Patents, Llc V. Enfora, Inc.*
   Client/Matter: -None-
   Search Terms: US PAT 8032278 or 8,032,278
   Search Type: Terms and Connectors
   Narrowed by:

Content Type	Narrowed by
Dockets	-None-

1:17cv2769, Omega Patents, Llc V. Enfora, Inc.

US District Court Docket

United States District Court, Georgia Northern

(Atlanta)

This case was retrieved on 12/04/2023

Header

Case Number: 1:17cv2769
Date Filed: 07/21/2017
Assigned To: Judge Thomas W. Thrash, Jr
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: None
Jurisdiction: Federal Question

Class Code: Closed
Closed: 01/31/2018
Statute: 28:1338
Jury Demand: Both
Demand Amount: $0
NOS Description: Patent

Participants

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a Georgia limited liability company |
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Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	07/21/2017	COMPLAINT with Jury Demand, filed by Omega Patents, LLC.; and Summon(s) issued. (Filing fee $ 400.00 receipt number 113E-7279878.) (Attachments: # 1 Ex -A -Patent No. 6,346,876, # 2 Ex -B -Patent No. 6,756,885, # 3 Ex -C -Patent No. 8,032,278, # 4 Civil Cover Sheet)(eop) Please visit our website at http://www.gand.uscourts.gov/commonly-used-forms to obtain Pretrial Instructions which includes the Consent To Proceed Before U.S. Magistrate form. (Entered: 07/25/2017)	
2	07/21/2017	Electronic Summons Issued as to Enfora, Inc.. (eop) (Entered: 07/25/2017)	
3	07/21/2017	Certificate of Interested Persons by Omega Patents, LLC. (eop) (Entered: 07/25/2017)	
4	07/25/2017	AO Form 120 forwarded to Commissioner. (eop) (Entered: 07/25/2017)	
	07/26/2017	Clerks Notation re 3 Certificate of Interested Persons, OK per TWT. (ss) (Entered: 07/26/2017)	
5	07/26/2017	Return of Service Executed by Omega Patents, LLC. Enfora, Inc. served on 7/26/2017, answer due 8/16/2017. (Lee, Cynthia) (Entered: 07/26/2017)	
6	07/27/2017	APPLICATION for Admission of Ryan T. Santurri Pro Hac Vice (Application fee $ 150, receipt number 113E-7290404)by Omega Patents, LLC. (Lee, Cynthia) (Entered: 07/27/2017)	
7	07/27/2017	APPLICATION for Admission of Brian R. Gilchrist Pro Hac Vice (Application fee $ 150, receipt number 113E-7291240)by Omega	

#	Date	Proceeding Text	Source
		Patents, LLC. (Lee, Cynthia) (Entered: 07/27/2017)	
8	07/31/2017	Application for Refund of Fees paid online through Pay.gov for receipt number 113E-7290387. (Lee, Cynthia) (Entered: 07/31/2017)	
	08/01/2017	Clerks Approval re 8 Application for Refund of Fees paid online. (mec) (Entered: 08/01/2017)	
	08/04/2017	Refund in the amount of $150.00 has been processed, effective 08/04/2017 in response to Clerks Action on Application for Refund of Fees paid online. (kns) (Entered: 08/04/2017)	
9	08/15/2017	Consent MOTION for Extension of Time to File Answer by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 08/15/2017)	
10	08/16/2017	ORDER granting 9 Motion for Extension of Time to Answer, Enfora, Inc. Answer due 10/2/2017. Signed by Judge Thomas W. Thrash, Jr on 8/16/2017. (ss) (Entered: 08/16/2017)	
11	08/16/2017	APPLICATION for Admission of Jo Dale Carothers Pro Hac Vice (Application fee $ 150, receipt number 113E-7330621)by Enfora, Inc.. (Kurtz, Ryan) (Entered: 08/16/2017)	
12	08/16/2017	APPLICATION for Admission of Eric Anthony Caligiuri Pro Hac Vice (Application fee $ 150, receipt number 113E-7330631)by Enfora, Inc.. (Kurtz, Ryan) (Entered: 08/16/2017)	
	08/17/2017	APPROVAL by Clerks Office re: 6 APPLICATION for Admission of Ryan T. Santurri Pro Hac Vice (Application fee $ 150, receipt number 113E-7290404). Attorney Ryan T. Santurri added appearing on behalf of Omega Patents, LLC (pmb) (Entered: 08/17/2017)	
	08/17/2017	APPROVAL by Clerks Office re: 7 APPLICATION for Admission of Brian R. Gilchrist Pro Hac Vice (Application fee $ 150, receipt number 113E-7291240). Attorney Brian R. Gilchrist added appearing on behalf of Omega Patents, LLC (pmb) (Entered: 08/17/2017)	
13	08/18/2017	ORDER granting Brian R. Gilchrist's 7 Application for Admission Pro Hac Vice. Signed by Judge Thomas W. Thrash, Jr on 8/18/17. (jkl) (Entered: 08/18/2017)	
14	08/18/2017	ORDER granting Ryan T. Santurri's 6 Application for Admission Pro Hac Vice. Signed by Judge Thomas W. Thrash, Jr on 8/18/17. (jkl) (Entered: 08/18/2017)	
	08/31/2017	APPROVAL by Clerks Office re: 11 APPLICATION for Admission of Jo Dale Carothers Pro Hac Vice (Application fee $ 150, receipt number 113E-7330621). Attorney Jo Dale Carothers added appearing on behalf of Enfora, Inc. (pmb) (Entered: 08/31/2017)	
	08/31/2017	APPROVAL by Clerks Office re: 12 APPLICATION for Admission of Eric Anthony Caligiuri Pro Hac Vice (Application fee $ 150, receipt number 113E-7330631). Attorney Eric Anthony Caligiuri added appearing on behalf of Enfora, Inc. (pmb) (Entered: 08/31/2017)	
15	09/01/2017	ORDER granting Eric Anthony Caligiuri's 12 Application for Admission Pro Hac Vice. Signed by Judge Thomas W. Thrash, Jr on 9/1/17. (jkl) (Entered: 09/01/2017)	
16	09/01/2017	ORDER granting Jo Dale Carothers's 11 Application for Admission Pro Hac Vice. Signed by Judge Thomas W. Thrash, Jr on 9/1/17. (jkl) (Entered: 09/01/2017)	
	09/01/2017	Clerk's Certificate of Mailing to Eric Anthony Caligiuri re 15 Order on Application for Admission PHV and Jo Dale Carothers re 16 Order on Application for Admission PHV. (jkl) (Entered: 09/01/2017)	
17	10/02/2017	MOTION to Dismiss For Improper Venue, or in the Alternative, MOTION to Transfer to Southern District of California with Brief In	

#	Date	Proceeding Text	Source
		Support by Enfora, Inc. (Attachments: # 1 Brief)(Kurtz, Ryan) . Added MOTION to Transfer Case on 10/3/2017 (jkl). (Entered: 10/02/2017)	
18	10/02/2017	SEALED NOTICE Of Filing Memorandum of Law in Support of 17 MOTION to Dismiss For Improper Venue, or in the Alternative, MOTION to Transfer to Southern District of California by Enfora, Inc. (Kurtz, Ryan) Text modified on 10/3/2017 (jkl). (Entered: 10/02/2017)	
19	10/02/2017	MOTION for Leave to File Matters Under Seal re: 18 Notice of Filing with Brief In Support by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 10/02/2017)	
20	10/02/2017	Certificate of Interested Persons and Corporate Disclosure Statement by Enfora, Inc. identifying Corporate Parent Novatel Wireless, Inc., Corporate Parent Inseego Corp. for Enfora, Inc.. (Kurtz, Ryan) (Entered: 10/02/2017)	
21	10/03/2017	ORDER granting 19 Motion for Leave to File Matters Under Seal. Signed by Judge Thomas W. Thrash, Jr on 10/3/17. (jkl) (Entered: 10/03/2017)	
	10/03/2017	Clerks Notation re 20 Certificate of Interested Persons, OK, per TWT. (ss) (Entered: 10/03/2017)	
22	10/16/2017	AMENDED COMPLAINT and Exhibits (Redacted) against Enfora, Inc.with Jury Demand, filed by Omega Patents, LLC.(Santurri, Ryan) Please visit our website at http://www.gand.uscourts.gov/commonly-used-forms to obtain Pretrial Instructions which includes the Consent To Proceed Before U.S. Magistrate form. (Entered: 10/16/2017)	
23	10/16/2017	SEALED NOTICE Of Filing Amended Complaint by Omega Patents, LLC re 1 Complaint, (Santurri, Ryan) Modified on 10/17/2017 (btql). (Entered: 10/16/2017)	
24	10/16/2017	MOTION for Leave to File Matters Under Seal re: 23 Notice of Filing Amended Complaint and Exhibits by Omega Patents, LLC. (Attachments: # 1 Text of Proposed Order)(Santurri, Ryan) (Entered: 10/16/2017)	
25	10/17/2017	ORDER GRANTING 24 Motion for Leave to File Matters Under Seal. Signed by Judge Thomas W. Thrash, Jr on 10/17/2017. (btql) (Entered: 10/17/2017)	
	10/23/2017	Submission of 17 MOTION to Dismiss For Improper Venue, or in the Alternative, MOTION to Transfer to Southern District of California to District Judge Thomas W. Thrash. (jkl) (Entered: 10/23/2017)	
26	10/30/2017	MOTION to Dismiss , MOTION to Change Venue with Brief In Support by Enfora, Inc.. (Attachments: # 1 Brief)(Kurtz, Ryan) (Entered: 10/30/2017)	
27	10/30/2017	MOTION for Leave to File Matters Under Seal re: 28 Notice of Filing with Brief In Support by Enfora, Inc. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) Modified on 10/31/2017 to link to proper document (jkl). (Entered: 10/30/2017)	
28	10/30/2017	SEALED MEMORANDUM OF LAW in support of 26 MOTION to Dismiss/MOTION to Change Venue by Enfora, Inc. (Kurtz, Ryan) Modified on 11/3/2017 (jkl). (Entered: 10/30/2017)	
29	10/31/2017	Consent MOTION to Stay Certain Pre-Discovery Deadlines by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 10/31/2017)	
31	11/03/2017	ORDER granting 27 Motion for Leave to File Matters Under Seal. Signed by Judge Thomas W. Thrash, Jr on 11/2/17. (jkl) (Entered: 11/03/2017)	
32	11/03/2017	ORDER GRANTING 29 Motion to Stay Certain Pre-Discovery Deadlines until 30 days after Defendant files its Answer to	

#	Date	Proceeding Text	Source
		Plaintiffs FAC. Signed by Judge Thomas W. Thrash, Jr. on 11/2/17. (jkl) (Entered: 11/03/2017)	
33	11/13/2017	RESPONSE in Opposition re 26 MOTION to Dismiss MOTION to Change Venue filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 11/13/2017)	
34	11/13/2017	MOTION to Stay Pending Reexamination with Brief In Support by Enfora, Inc.. (Attachments: # 1 Brief, # 2 Exhibit A - Declaration of Jo Dale Carothers, # 3 Exhibit 1 t0 Dec of Jo Dale Carothers, # 4 Exhibit 2 to Dec of Jo Dale Carothers, # 5 Exhibit 3 to Dec of Jo Dale Carothers, # 6 Exhibit 4 to Dec of Jo Dale Carothers, # 7 Exhibit 5 part 1 to Dec of Jo Dale Carothers, # 8 Exhibit 5 part 2 to Dec of Jo Dale Carothers)(Kurtz, Ryan) (Entered: 11/13/2017)	
35	11/27/2017	RESPONSE in Opposition re 34 MOTION to Stay Pending Reexamination filed by Omega Patents, LLC. (Santurri, Ryan) (Entered: 11/27/2017)	
36	11/27/2017	REPLY to Response to Motion re 26 MOTION to Dismiss MOTION to Change Venue filed by Enfora, Inc.. (Kurtz, Ryan) (Entered: 11/27/2017)	
37	11/27/2017	Per Order: SEALED and Filed at 40 Reply Brief NOTICE Of Filing by Enfora, Inc. (Kurtz, Ryan) Modified on 11/29/2017 (jkl). (Entered: 11/27/2017)	
38	11/27/2017	MOTION for Leave to File Matters Under Seal re: 37 Notice of Filing by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 11/27/2017)	
39	11/28/2017	ORDER granting 38 Motion for Leave to File Matters Under Seal. Signed by Judge Thomas W. Thrash, Jr on 11/28/17. (jkl) (Entered: 11/29/2017)	
40	11/28/2017	REPLY BRIEF re 26 MOTION to Dismiss/MOTION to Change Venue filed UNDER SEAL by Enfora, Inc. (jkl) (Entered: 11/29/2017)	
	11/29/2017	Submission of 26 MOTION to Dismiss/ MOTION to Change Venue to District Judge Thomas W. Thrash. (jkl) (Entered: 11/29/2017)	
41	12/01/2017	ORDER DENYING AS MOOT 17 Motion to Dismiss/Motion to Transfer Case. Signed by Judge Thomas W. Thrash, Jr on 11/30/17. (jkl) (Entered: 12/01/2017)	
42	12/11/2017	REPLY BRIEF re 34 MOTION to Stay Pending Reexamination filed by Enfora, Inc.. (Kurtz, Ryan) (Entered: 12/11/2017)	
43	12/18/2017	ORDER denying 26 Motion to Dismiss or Transfer. Signed by Judge Thomas W. Thrash, Jr on 12/18/17. (jpa) (Entered: 12/19/2017)	
44	12/21/2017	Consent MOTION for Extension of Time to File Answer First Amended Complaint by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 12/21/2017)	
45	12/27/2017	ORDER GRANTING 44 Motion for Extension of Time to Answer, Enfora, Inc. Answer due 1/16/2018. Signed by Judge Thomas W. Thrash, Jr. on 12/27/17. (bnw) (Entered: 12/27/2017)	
	12/28/2017	Submission of 34 MOTION to Stay Pending Reexamination, submitted to District Judge Thomas W. Thrash. (bnw) (Entered: 12/28/2017)	
46	01/12/2018	Unopposed MOTION for Leave to File Sur-Reply In Support of Its Motion for A Stay Pending Reexamination by Enfora, Inc.. (Attachments: # 1 Exhibit 1 - Proposed Sur-Reply, # 2 Exhibit 2 - Proposed Order)(Kurtz, Ryan) (Entered: 01/12/2018)	
47	01/16/2018	ORDER granting 46 Motion for Leave to File Sur-Reply In Support of Its Motion for A Stay Pending Reexamination. Signed by Judge Thomas W. Thrash, Jr on 1/16/18. (jkl) (Entered: 01/16/2018)	

#	Date	Proceeding Text	Source
48	01/16/2018	Defendant's SUR-REPLY in Support of 34 MOTION to Stay Pending Reexamination filed by Enfora, Inc. (jkl) (Entered: 01/16/2018)	
49	01/16/2018	ANSWER to 22 Amended Complaint by Enfora, Inc.. Discovery ends on 10/15/2018.(Kurtz, Ryan) Please visit our website at http://www.gand.uscourts.gov to obtain Pretrial Instructions. (Entered: 01/16/2018)	
50	01/16/2018	SEALED ANSWER to Amended Complaint by Enfora, Inc. (Attachments: # 1 Exhibit A)(Kurtz, Ryan) Modified on 1/18/2018 (jkl). (Entered: 01/16/2018)	
51	01/16/2018	MOTION for Leave to File Matters Under Seal re: 50 Notice of Filing with Brief In Support by Enfora, Inc.. (Attachments: # 1 Text of Proposed Order)(Kurtz, Ryan) (Entered: 01/16/2018)	
52	01/18/2018	ORDER GRANTING 51 Motion for Leave to File Matters Under Seal and DIRECTING Clerk to file Defendant Enfora, Inc.s Answer and Defenses to Omega Patents, LLCs First Amended Complaint for Patent Infringement under seal. Signed by Judge Thomas W. Thrash, Jr on 1/18/18. (jkl) (Entered: 01/18/2018)	
53	01/31/2018	ORDER GRANTING 34 Motion to Stay Pending Reexamination. The Clerk is directed to close the case administratively. The Plaintiff may move to reopen the case and lift the stay after 6 months. Signed by Judge Thomas W. Thrash, Jr on 1/31/18. (jkl) (Entered: 01/31/2018)	
	01/31/2018	Civil Case closed administratively. (jkl) (Entered: 01/31/2018)	
54	01/31/2018	AO Form 120 forwarded to Director of the U.S. Patent and Trademark Office. (jkl) (Entered: 01/31/2018)	
55	08/08/2019	STIPULATION of Dismissal With Prejudice by Omega Patents, LLC. (Santurri, Ryan) (Entered: 08/08/2019)	
	09/03/2019	Clerk's Entry of Dismissal APPROVING 55 Stipulation of Dismissal with Prejudice pursuant to Fed.R.Civ.P.41(a)(1)(A)(ii). (cmd) (Entered: 09/03/2019)	

Patents

Number	Title	Issued	Class	Subclass
6,346,876	Multi-vehicle compatible control system generating command signals on a data bus and associated methods	02/12/2002	340	426.13
6,756,885	Multi-vehicle compatible control system for reading from a data bus and associated methods	06/29/2004	340	426.1
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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User Name: Karen Ward
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Job Number: 211855840

Document (1)

1. *6:22cv237 1, Omega Patents, Llc V. Verizon Connect, Inc.*
   Client/Matter: -None-
   Search Terms: US PAT 8032278 or 8,032,278
   Search Type: Terms and Connectors
   Narrowed by:

Content Type	Narrowed by
Dockets	-None-

6:22cv2371, Omega Patents, Llc V. Verizon Connect, Inc.

US District Court Docket

United States District Court, Florida Middle

(Orlando)

This case was retrieved on 12/04/2023

Header

Case Number: 6:22cv2371
Date Filed: 12/20/2022
Assigned To: Judge Wendy W. Berger
Referred To: Magistrate Judge Embry J. Kidd
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: None
Jurisdiction: Federal Question

Class Code: Closed
Closed: 09/08/2023
Statute: 35:271
Jury Demand: Both
Demand Amount: $0
NOS Description: Patent

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Verizon Connect, Inc.
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Defendant

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Verizon Communications, Inc.
a Delaware corporation |
[Terminated: 02/23/2023]
Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	12/20/2022	COMPLAINT against All Defendants with Jury Demand (Filing fee $402 receipt number AFLMDC-20326813) filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A- U.S. Patent 8,032,278, # 2 Civil Cover Sheet, # 3 Proposed Summons)(Santurri, Ryan) (Entered: 12/20/2022)	
2	12/20/2022	NEW CASE ASSIGNED to Judge Wendy W. Berger and Magistrate Judge Embry J. Kidd. New case number: 6:22-cv-2371-WWB-EJK. (SJB) (Entered: 12/20/2022)	
3	12/21/2022	ORDER ON DISCOVERY MOTIONS Signed by Magistrate Judge Embry J. Kidd on 12/21/2022. (JOR) (Entered: 12/21/2022)	
4	12/21/2022	NOTICE to Plaintiff's Counsel of Local Rule 2.02(a), which requires designation of one lead counsel who - unless the party changes the designation - remains lead counsel throughout the action. File a Notice of Lead Counsel Designation to identify lead counsel. (Signed by Deputy Clerk). (KNC) (Entered: 12/21/2022)	
5	12/21/2022	Patent Report sent to Alexandria, VA. (KNC) (Entered: 12/21/2022)	
6	12/21/2022	SUMMONS issued as to All Defendants. (KNC) (Entered: 12/21/2022)	
7	12/21/2022	NOTICE of Lead Counsel Designation by Ryan Thomas Santurri on behalf of Omega Patents, LLC. Lead Counsel: Ryan T. Santurri. (Santurri, Ryan) (Entered: 12/21/2022)	
8	12/28/2022	NOTICE TO COUNSEL AND PARTIES: The Middle District of Florida's revised Local Rules become effective February 1, 2021 and can be found on the Court's public website https://www.flmd.uscourts.gov/local-rules. For a just and efficient resolution of this case, the parties are DIRECTED to read and comply with the Middle District of Florida's Local Rules. See Local Rule 1.01(a). Failure to comply with ANY Local Rules or Court Orders may result in the imposition of sanctions including, but not limited to, the dismissal of this action or entry of default without further notice. Signed by Judge Wendy W. Berger on 12/28/2022. (RMF) (Entered: 12/28/2022)	
9	12/28/2022	NOTICE of Local Rule 3.02(a)(2), which requires the parties in every civil proceeding, except those described in subsection (d), to file a case management report (CMR) using the uniform form at www.flmd.uscourts.gov. The CMR must be filed (1) within forty days after any defendant appears in an action originating in this court, (2) within forty days after the docketing of an action removed or transferred to this court, or (3) within seventy days after service on the United States attorney in an action against the United States, its agencies or employees. Judges may have a special CMR form for certain types of cases. These forms can be found at www.flmd.uscourts.gov under the Forms tab for each judge. (Signed by Deputy Clerk). (RMF) (Entered: 12/28/2022)	
10	01/05/2023	RETURN of service executed on 12/30/2022 by Omega Patents, LLC as to Verizon Connect, Inc. (Santurri, Ryan) Modified on 1/5/2023 to edit docket text (KNC). (Entered: 01/05/2023)	
11	01/05/2023	RETURN of service executed on 12/30/2022 by Omega Patents, LLC as to Verizon Communications, Inc. (Santurri, Ryan) Modified on 1/5/2023 to edit docket text (KNC). (Entered: 01/05/2023)	
12	01/13/2023	Unopposed MOTION for Extension of Time to File Response/Reply as to 1 Complaint, by Verizon Communications, Inc., Verizon Connect, Inc. (Webb, Joshua) Motions referred to Magistrate Judge Embry J. Kidd. Modified on 1/17/2023 to edit docket text (SRD). (Entered: 01/13/2023)	
13	01/13/2023	CERTIFICATE of interested persons and corporate disclosure statement by Omega Patents, LLC. (Santurri, Ryan) (Entered: 01/13/2023)	

#	Date	Proceeding Text	Source
14	01/13/2023	NOTICE of Appearance by Dennis Parker Waggoner on behalf of Verizon Communications, Inc., Verizon Connect, Inc. (Waggoner, Dennis) (Entered: 01/13/2023)	
15	01/13/2023	ENDORSED ORDER granting 12 Motion for Extension of Time. Defendants may have until and through February 19, 2023, to respond to the Complaint. Signed by Magistrate Judge Embry J. Kidd on 1/13/2023. (Kidd, Embry) (Entered: 01/13/2023)	
16	02/10/2023	Joint MOTION for Extension of Time to File Case Management Report by Verizon Communications, Inc., Verizon Connect, Inc.. (Webb, Joshua) Motions referred to Magistrate Judge Embry J. Kidd. (Entered: 02/10/2023)	
17	02/10/2023	Unopposed MOTION for Ashe P. Puri to appear pro hac vice, Special Admission fee paid, Receipt No. AFLMDC-20498901 for $150 by All Defendants. (Webb, Joshua) Motions referred to Magistrate Judge Embry J. Kidd. (Entered: 02/10/2023)	
18	02/10/2023	Unopposed MOTION for Sasha G. Rao to appear pro hac vice, Special Admission fee paid, Receipt No. AFLMDC-20498914 for $150 by All Defendants. (Webb, Joshua) Motions referred to Magistrate Judge Embry J. Kidd. (Entered: 02/10/2023)	
19	02/10/2023	ENDORSED ORDER granting 16 Motion for Extension of Time. The parties may have until and through March 24, 2023, to file their case management report. Signed by Magistrate Judge Embry J. Kidd on 2/10/2023. (Kidd, Embry) (Entered: 02/10/2023)	
	02/13/2023	Reset deadlines: Case management report due by 3/24/2023 (KNC) (Entered: 02/13/2023)	
20	02/13/2023	ORDER granting 17, 18 Defendants' Unopposed Motions to Admit Pro Hac Vice Ashe P. Puri and Sasha G. Rao. Signed by Magistrate Judge Embry J. Kidd on 2/13/2023. (RMN) (Entered: 02/13/2023)	
21	02/16/2023	NOTICE of Dismissal of Defendant Verizon Communications, Inc. by Omega Patents, LLC (Santurri, Ryan) Modified on 2/16/2023 to edit docket text (KNC). (Entered: 02/16/2023)	
22	02/17/2023	ANSWER and affirmative defenses to 1 Complaint, with Jury Demand by Verizon Connect, Inc.(Waggoner, Dennis) Modified on 2/17/2023 to edit docket text (KNC). (Entered: 02/17/2023)	
23	02/17/2023	CORPORATE Disclosure Statement by Verizon Connect, Inc. identifying Other Affiliate Verizon Communications Inc. for Verizon Connect, Inc. (Waggoner, Dennis) Modified on 2/17/2023 to edit docket text (KNC). (Entered: 02/17/2023)	
24	02/23/2023	ORDER re 21 Plaintiff's Notice of Dismissal of Defendant Verizon Communications Inc. Pursuant to Federal Rule of Civil Procedure 41(a)(1)(A)(i), the Clerk is directed to terminate Verizon Communications Inc. as a Defendant in this matter and amend the case style accordingly. Signed by Judge Wendy W. Berger on 2/23/2023. (RMF) (Entered: 02/23/2023)	
25	03/24/2023	CASE MANAGEMENT REPORT. (Santurri, Ryan) (Entered: 03/24/2023)	
26	03/31/2023	CASE MANAGEMENT AND SCHEDULING ORDER: (PATENT CASE) Amended Pleadings due by 6/2/2023 Joinder of Parties due by 6/2/2023 Dispositive motions due by 10/30/2024 Pretrial statement due by 3/4/2025 All other motions due by 2/1/2025 Trial Status Conference set for 3/11/2025 at 10:00 AM in Orlando Courtroom 3 B before Judge Wendy W. Berger Jury Trial set for the April 2025 trial term commencing on 4/1/2025 at 09:00 AM in Orlando Courtroom 3 B before Judge Wendy W. Berger. Conduct mediation hearing by 10/14/2024. Lead counsel to coordinate dates. Signed by Judge Wendy W. Berger on 3/31/2023. (RMF) (Entered: 03/31/2023)	

#	Date	Proceeding Text	Source
27	03/31/2023	NOTICE of hearing: Technology Tutorial Conference Hearing set for 10/12/2023 at 2:30 PM in Orlando Courtroom 3 B before Judge Wendy W. Berger. (RMF) (Entered: 03/31/2023)	
28	03/31/2023	NOTICE of hearing: Claims Construction Hearing set for 1/10/2024 at09:30 AM in Orlando Courtroom 3 B before Judge Wendy W. Berger. (RMF) (Entered: 03/31/2023)	
29	03/31/2023	ORDER: the parties are directed to confer, and then advise the Court, on the selection of a mediator, on or before May 1, 2023. Signed by Judge Wendy W. Berger on 3/31/2023. (RMF) (Entered: 03/31/2023)	
30	04/03/2023	CASE REFERRED to Mediation. Mediator: TBD (KNC) (Entered: 04/03/2023)	
31	04/24/2023	NOTICE of Change of Firm Name by Verizon Connect, Inc. (Webb, Joshua) Modified on 4/24/2023 to edit docket text (KNC). (Entered: 04/24/2023)	
32	05/01/2023	NOTICE OF SELECTION of James M. Matulis as mediator by Omega Patents, LLC. (Santurri, Ryan) (Entered: 05/01/2023)	
33	07/28/2023	Unopposed MOTION to Stay Pending Inter Partes Review Proceedings by Verizon Connect, Inc.. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Webb, Joshua) (Entered: 07/28/2023)	
34	09/05/2023	Joint MOTION to Stay re 26 Case Management Scheduling Order (Time Sensitive) by Verizon Connect, Inc.. (Webb, Joshua) (Entered: 09/05/2023)	
35	09/08/2023	ORDER granting 33 Unopposed Motion to Stay the Case Pending Inter Partes Review Proceedings; denying as moot 34 Time Sensitive Joint Motion to Stay All Case Deadlines. This case is stayed pending resolution of the inter partes review proceedings before the PTO. On or before March 6, 2024, and every 180 days thereafter, Defendant shall file a report as to the status of the review proceedings. The Clerk is directed to administratively close this case. Signed by Judge Wendy W. Berger on 9/8/2023. (MDJ) (Entered: 09/08/2023)	

Patents

Number	Title	Issued	Class	Subclass
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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End of Document

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User Name: Karen Ward
Date and Time: Monday, December 4, 2023 3:03:00PM EST
Job Number: 211856014

Document (1)

1. *1:22cv1044, Omega Patents, Llc V. Geotab Usa, Inc. Et Al*
   Client/Matter: -None-
   Search Terms: US PAT 8032278 or 8,032,278
   Search Type: Terms and Connectors
   Narrowed by:

Content Type	Narrowed by
Dockets	-None-

1:22cv1044, Omega Patents, Llc V. Geotab Usa, Inc. Et Al

US District Court Docket

United States District Court, Delaware

(Wilmington)

This case was retrieved on 12/04/2023

Header

Case Number: 1:22cv1044
Date Filed: 08/09/2022
Assigned To: Judge William C. Bryson
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: 1:21cv00030, 1:23cv00282
Jurisdiction: Federal Question

Class Code: Open
Statute: 35:271
Jury Demand: Plaintiff
Demand Amount: $0
NOS Description: Patent

Participants

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GeoTab, Inc.
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[Terminated: 03/10/2023]
Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	08/09/2022	COMPLAINT filed with Jury Demand against Geotab USA, Inc., Geotab, Inc. (Filing fee $ 402, receipt number ADEDC-3933226.) - filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A, # 2	

#	Date	Proceeding Text	Source
		Civil Cover Sheet)(apk) (Entered: 08/09/2022)	
2	08/09/2022	Notice, Consent and Referral forms re: U.S. Magistrate Judge jurisdiction. (apk) (Entered: 08/09/2022)	
3	08/09/2022	Report to the Commissioner of Patents and Trademarks for Patent/Trademark Number(s) 8,032,278 B2. (apk) (Entered: 08/09/2022)	
4	08/09/2022	Summons Issued as to Geotab USA, Inc. on 8/9/2022; Geotab, Inc. on 8/9/2022. (Attachments: # 1 Summons Issued)(apk) (Entered: 08/09/2022)	
5	08/12/2022	AFFIDAVIT of Service for Summons and Complaint served on The Corporation Trust Company as Registered Agent for Geotab USA, Inc. on August 12, 2022, filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 08/12/2022)	
	08/17/2022	Case Assigned to Judge Colm F. Connolly. Please include the initials of the Judge (CFC) after the case number on all documents filed. (rjb) (Entered: 08/17/2022)	
6	08/26/2022	STIPULATION TO EXTEND TIME for Defendant Geotab USA, Inc. to Answer, Move, or Otherwise Respond to the Complaint to October 3, 2022 - filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 08/26/2022)	
	08/26/2022	SO ORDERED, re 6 STIPULATION TO EXTEND TIME for Defendant Geotab USA, Inc. to Answer, Move, or Otherwise Respond to the Complaint to October 3, 2022, filed by Omega Patents, LLC. Reset Answer Deadlines: Geotab USA, Inc. answer due 10/3/2022. Ordered by Judge Colm F. Connolly on 8/26/2022. (kmd) (Entered: 08/26/2022)	
7	09/23/2022	MOTION for Extension of Time to File Answer to November 2, 2022 - filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 09/23/2022)	
	09/26/2022	SO ORDERED, re 7 MOTION for Extension of Time to File Answer to November 2, 2022, filed by Omega Patents, LLC. Reset Answer Deadlines: Geotab USA, Inc. answer due 11/2/2022. Ordered by Judge Colm F. Connolly on 9/26/2022. (kmd) (Entered: 09/26/2022)	
8	10/28/2022	MOTION for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre - filed by Geotab USA, Inc.. (Hoeschen, Nathan) (Entered: 10/28/2022)	
	10/28/2022	SO ORDERED, re 8 MOTION for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre, filed by Geotab USA, Inc. Ordered by Judge Colm F. Connolly on 10/28/2022. (kmd) (Entered: 10/28/2022)	
	10/31/2022	Pro Hac Vice Attorney Hunter D. Keeton, Susmita A. Gadre, and Michael A. Albert for Geotab USA, Inc. added for electronic noticing. Pursuant to Local Rule 83.5 (d)., Delaware counsel shall be the registered users of CM/ECF and shall be required to file all papers. (mpb) (Entered: 10/31/2022)	
9	11/02/2022	MOTION to Dismiss for Failure to State a Claim - filed by Geotab USA, Inc.. (Hoeschen, Nathan) (Additional attachment(s) added on 11/2/2022: # 1 Proposed Order) (kmd). (Entered: 11/02/2022)	
10	11/02/2022	OPENING BRIEF in Support re 9 MOTION to Dismiss for Failure to State a Claim filed by Geotab USA, Inc..Answering Brief/Response due date per Local Rules is 11/16/2022. (Hoeschen, Nathan) (Entered: 11/02/2022)	
11	11/02/2022	Disclosure Statement pursuant to Rule 7.1: identifying Other Affiliate Geotab, Inc. for Geotab USA, Inc. filed by Geotab USA, Inc.. (Hoeschen, Nathan) (Entered: 11/02/2022)	
12	11/03/2022	AFFIDAVIT of Service for Summons and Complaint served on GeoTab, Inc. on October 28, 2022, filed by Omega Patents, LLC.	

#	Date	Proceeding Text	Source
		(Golden, Ronald) (Entered: 11/03/2022)	
13	11/16/2022	MOTION for Pro Hac Vice Appearance of Attorney Ryan T. Santurri and Brian R. Gilchrist - filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 11/16/2022)	
14	11/16/2022	ANSWERING BRIEF in Opposition re 9 MOTION to Dismiss for Failure to State a Claim filed by Omega Patents, LLC.Reply Brief due date per Local Rules is 11/23/2022. (Golden, Ronald) (Entered: 11/16/2022)	
	11/16/2022	Remark re 13 MOTION for Pro Hac Vice Appearance of Attorney Ryan T. Santurri and Brian R. Gilchrist - filed by Omega Patents, LLC. Applicant's signature line must include the applicant's address (see form of motion on the Court's website). Local counsel shall file a corrected version of the Motion. (Motion terminated.) (kmd) (Entered: 11/16/2022)	
15	11/16/2022	MOTION for Pro Hac Vice Appearance of Attorney Ryan T. Santurri and Brian R. Gilchrist - filed by Omega Patents, LLC. (Attachments: # 1 Certification)(Golden, Ronald) (Entered: 11/16/2022)	
	11/17/2022	SO ORDERED, re 15 MOTION for Pro Hac Vice Appearance of Attorney Ryan T. Santurri and Brian R. Gilchrist, filed by Omega Patents, LLC. Ordered by Judge Colm F. Connolly on 11/17/2022. (kmd) (Entered: 11/17/2022)	
	11/17/2022	Pro Hac Vice Attorney Ryan T. Santurri for Omega Patents, LLC added for electronic noticing. Pursuant to Local Rule 83.5 (d)., Delaware counsel shall be the registered users of CM/ECF and shall be required to file all papers. (apk) (Entered: 11/17/2022)	
16	11/18/2022	MOTION to Dismiss for Insufficiency of Service of Process , MOTION to Dismiss for Failure to State a Claim - filed by Geotab, Inc.. (Attachments: # 1 Text of Proposed Order)(Russell, Andrew) (Entered: 11/18/2022)	
17	11/18/2022	OPENING BRIEF in Support re 16 MOTION to Dismiss for Insufficiency of Service of Process MOTION to Dismiss for Failure to State a Claim filed by Geotab, Inc..Answering Brief/Response due date per Local Rules is 12/2/2022. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C)(Russell, Andrew) (Entered: 11/18/2022)	
18	11/18/2022	DECLARATION re 17 Opening Brief in Support, (Declaration of Uju Orebajo) by Geotab, Inc.. (Russell, Andrew) (Entered: 11/18/2022)	
19	11/18/2022	Disclosure Statement pursuant to Rule 7.1: No Parents or Affiliates Listed filed by Geotab, Inc.. (Russell, Andrew) (Entered: 11/18/2022)	
20	11/23/2022	REPLY BRIEF re 9 MOTION to Dismiss for Failure to State a Claim filed by Geotab USA, Inc.. (Russell, Andrew) (Entered: 11/23/2022)	
21	11/30/2022	STIPULATION TO EXTEND TIME re Answering Brief in Opposition to 16 Motion to Dismiss and Reply Brief in Support of 16 Motion to Dismiss to December 16, 2022 and January 6, 2023 - filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 11/30/2022)	
22	12/02/2022	SO ORDERED, re 21 STIPULATION TO EXTEND TIME re Answering Brief in Opposition to 16 Motion to Dismiss and Reply Brief in Support of 16 Motion to Dismiss to December 16, 2022 and January 6, 2023, filed by Omega Patents, LLC. Reset Briefing Schedule: re 16 MOTION to Dismiss for Insufficiency of Service of Process, MOTION to Dismiss for Failure to State a Claim. Answering Brief due 12/16/2022. Reply Brief due 1/6/2023. Signed by Judge Colm F. Connolly on 12/2/2022. (kmd) (Entered: 12/02/2022)	

#	Date	Proceeding Text	Source
	12/05/2022	Pro Hac Vice Attorney Brian R. Gilchrist for Omega Patents, LLC added for electronic noticing. Pursuant to Local Rule 83.5 (d)., Delaware counsel shall be the registered users of CM/ECF and shall be required to file all papers. (mkr) (Entered: 12/05/2022)	
23	12/16/2022	ANSWERING BRIEF in Opposition re 16 MOTION to Dismiss for Insufficiency of Service of Process MOTION to Dismiss for Failure to State a Claim filed by Omega Patents, LLC.Reply Brief due date per Local Rules is 12/27/2022. (Golden, Ronald) (Entered: 12/16/2022)	
24	12/16/2022	DECLARATION re 23 Answering Brief in Opposition, Declaration of Lene Oest by Omega Patents, LLC. (Golden, Ronald) (Entered: 12/16/2022)	
25	01/06/2023	REPLY BRIEF re 16 MOTION to Dismiss for Insufficiency of Service of Process MOTION to Dismiss for Failure to State a Claim [Defendant Geotab, Inc.'s Reply Brief in Support of Its Motion to Dismiss] filed by Geotab, Inc.. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C)(Russell, Andrew) (Entered: 01/06/2023)	
26	01/06/2023	MOTION for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre - filed by Geotab USA, Inc., Geotab, Inc.. (Russell, Andrew) (Entered: 01/06/2023)	
	01/06/2023	SO ORDERED, re 26 MOTION for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre, filed by Geotab, Inc., Geotab USA, Inc. Ordered by Judge Colm F. Connolly on 1/6/2023. (kmd) (Entered: 01/06/2023)	
	02/22/2023	Case Reassigned to Judge William C. Bryson of the United States Court of Appeals for the Federal Circuit. Please include the initials of the Judge (WCB) after the case number on all documents filed. Associated Cases: 1:22-cv-01044-WCB, 1:21-cv-00030-WCB (rjb) (Entered: 02/22/2023)	
27	03/10/2023	MEMORANDUM OPINION AND ORDER, In summary, Geotab Canada's motion to dismiss is GRANTED because Omega has not effected proper service on Geotab Canada. Geotab USA's motion is DENIED because Omega has plausibly alleged direct and induced infringement of claims 1 and 12 of the '278 patent. Geotab Canada will be dismissed from this action without prejudice. (See Order for further details). Signed by Judge William C. Bryson on 3/10/2023. (twk) (Entered: 03/10/2023)	
28	03/15/2023	ORAL ORDER: The court will hold a telephonic Rule 16 scheduling conference on Friday, March 24, 2023, at 10:00am. The dial-in information and a form scheduling order will be distributed to the parties via email. The parties should jointly arrange for a court reporter to be present at the conference. Signed by Judge William C. Bryson on 3/15/2023. (dds) (Entered: 03/15/2023)	
29	03/22/2023	PROPOSED ORDER Scheduling Order by Omega Patents, LLC. (Golden, Ronald) (Entered: 03/22/2023)	
30	03/22/2023	Letter to The Honorable William C. Bryson from Andrew E. Russell regarding IPR. (Russell, Andrew) (Entered: 03/22/2023)	
31	03/24/2023	ANSWER to 1 Complaint with Jury Demand [Geotab USA, Inc.'s Answer to Complaint] by Geotab USA, Inc..(Russell, Andrew) (Entered: 03/24/2023)	
32	03/24/2023	SCHEDULING ORDER: Joinder of Parties due by 10/20/2023. Fact Discovery completed by 7/26/2024. Opening Expert Reports due by 8/30/2024. Rebuttal Expert Reports due by 9/27/2024. Claim Construction Opening Brief due by 4/19/2024. Claim Construction Answering Brief due by 5/3/2024. Claim Construction Reply Brief due by 5/10/2024. Claim Construction Surreply Brief due by 5/17/2024. A Final Pretrial Conference is set for 5/5/2025	

#	Date	Proceeding Text	Source
		at 09:00 AM in To Be Determined before Judge William C. Bryson. A 5-day Jury Trial is set for 6/9/2025 at 09:00 AM in To Be Determined before Judge William C. Bryson. (PLEASE SEE ORDER FOR FURTHER DETAILS) Signed by Judge William C. Bryson on 03/24/2023. (apk) Modified on 3/27/2023 (nmg). (Entered: 03/24/2023)	
	03/24/2023	Minute Entry for proceedings held before Judge William C. Bryson: Telephonic hearing held on 3/24/2023. Counsel for all parties appeared. Court reporter present. The Court conducted a Rule 16 scheduling conference. (Total Time in Court: 30 minutes) (Court reporter Stacy Ingraham). (dds) (Entered: 03/28/2023)	
33	03/29/2023	NOTICE OF SERVICE of Omega Patents, LLC's First Set of Interrogatories (Nos. 1-8) to Geotab USA, Inc., First Request for Production of Documents (Nos. 1-60) to Geotab USA, Inc., and this Notice of Service filed by Omega Patents, LLC.(Golden, Ronald) (Entered: 03/29/2023)	
34	04/04/2023	PROPOSED ORDER re Protective Order Regarding The Disclosure and Use of Discovery Materials by Omega Patents, LLC. (Golden, Ronald) (Entered: 04/04/2023)	
35	04/05/2023	PROTECTIVE ORDER Regarding Disclosure and Use of Discovery Materials. Signed by Judge William C. Bryson on 04/05/2023. (apk) (Entered: 04/05/2023)	
36	05/30/2023	NOTICE OF SERVICE of 1. Defendant Geotab USA, Inc.'s Responses to Plaintiff's First Set of Requests for Production of Documents (Nos. 1 - 60) 2. Defendant Geotab USA, Inc.'s Responses to Plaintiff's First Set of Interrogatories (Nos. 1 - 8) filed by Geotab USA, Inc..(Keller, Karen) (Entered: 05/30/2023)	
37	08/01/2023	Joint STIPULATION and [Proposed] Order to Stay pending Inter Partes Review by Geotab USA, Inc.. (Russell, Andrew) (Entered: 08/01/2023)	
38	08/01/2023	SO ORDERED, re 37 Joint STIPULATION and [Proposed] Order to Stay pending Inter Partes Review. (CASE STAYED) Signed by Judge William C. Bryson on 08/01/2023. (smg) (Entered: 08/01/2023)	

Patents

Number	Title	Issued	Class	Subclass
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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*** THIS DATA IS FOR INFORMATIONAL PURPOSES ONLY ***

End of Document

User Name: Karen Ward
Date and Time: Monday, December 4, 2023 3:05:00PM EST
Job Number: 211856212

Document (1)

1. *2:20cv1344, Omega Patents Llc V. Firstech Llc*
   Client/Matter: -None-
   Search Terms: US PAT 8032278 or 8,032,278
   Search Type: Terms and Connectors
   Narrowed by:

Content Type	Narrowed by
Dockets	-None-

2:20cv1344, Omega Patents Llc V. Firstech Llc

US District Court Docket

United States District Court, Washington Western

(Seattle)

This case was retrieved on 12/04/2023

Header

Case Number: 2:20cv1344
Date Filed: 09/10/2020
Assigned To: Judge Thomas S. Zilly
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: None
Jurisdiction: Federal Question

Class Code: Closed
Closed: 01/26/2022
Statute: 35:271
Jury Demand: Both
Demand Amount: $0
NOS Description: Patent

Participants

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Plaintiff

Firstech LLC
a Washington limited liability company |

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Proceedings

#	Date	Proceeding Text	Source
1	09/10/2020	COMPLAINT against defendant(s) Firstech, LLC with JURY DEMAND (Receipt # AWAWDC-6589464) Attorney John D Denkenberger added to party Omega Patents, LLC(pty:pla), filed by Omega Patents, LLC. (Attachments: # 1 Civil Cover Sheet, # 2 Summons, # 3 Report on Patents and Trademarks (AO Form 120), # 4 Exhibit A, # 5 Exhibit B, # 6 Exhibit C, # 7 Exhibit D)(Denkenberger, John) (Entered: 09/10/2020)	
2	09/10/2020	CORPORATE DISCLOSURE STATEMENT indicating Kenneth Flick no as a Corporate Parents and/or Affiliate. Filed pursuant to Fed.R.Civ.P 7.1. Filed by Omega Patents, LLC (Denkenberger, John) Modified on 9/16/2020 (KMC). (Entered: 09/10/2020)	
	09/11/2020	Judge J Richard Creatura added. (RE) (Entered: 09/11/2020)	
3	09/11/2020	REPORT on the filing or determination of an action. Emailed to the US Patent Office. (RE) (Entered: 09/11/2020)	
4	09/11/2020	Summons Electronically Issued as to defendant Firstech LLC. (RE) (Entered: 09/11/2020)	
5	09/24/2020	AFFIDAVIT of Service of Summons and Complaint on Firstech, LLC on 9/15/2020, filed by Plaintiff Omega Patents LLC. (Denkenberger, John) (Entered: 09/24/2020)	
6	09/25/2020	APPLICATION OF ATTORNEY Brian R. Gilchrist FOR LEAVE TO APPEAR PRO HAC VICE for Plaintiff Omega Patents LLC (Fee Paid) Receipt No. AWAWDC-6623706 (Denkenberger, John) (Entered: 09/25/2020)	
7	09/25/2020	APPLICATION OF ATTORNEY Ryan T. Santurri FOR LEAVE TO APPEAR PRO HAC VICE for Plaintiff Omega Patents LLC (Fee Paid) Receipt No. AWAWDC-6623720 (Denkenberger, John) (Entered: 09/25/2020)	
8	09/28/2020	ORDER re 6 Application for Leave to Appear Pro Hac Vice. The Court ADMITS Attorney Brian R Gilchrist for Plaintiff Omega Patents LLC, by Clerk William M McCool. No document associated with this docket entry, text only.NOTE TO COUNSEL: Local counsel agrees to sign all filings and to be prepared to handle the matter, including the trial thereof, in the event the applicant is unable to be present on any date scheduled by the court, pursuant to LCR 83.1(d).(DS) (Entered: 09/28/2020)	
9	09/28/2020	ORDER re 7 Application for Leave to Appear Pro Hac Vice. The Court ADMITS Attorney Ryan Santurri for Plaintiff Omega Patents	

#	Date	Proceeding Text	Source
		LLC, by Clerk William M McCool. No document associated with this docket entry, text only.NOTE TO COUNSEL: Local counsel agrees to sign all filings and to be prepared to handle the matter, including the trial thereof, in the event the applicant is unable to be present on any date scheduled by the court, pursuant to LCR 83.1(d).(DS) (Entered: 09/28/2020)	
10	10/29/2020	NOTICE of Appearance by attorney Lawrence D Graham on behalf of Defendant Firstech LLC. (Graham, Lawrence) (Entered: 10/29/2020)	
11	10/29/2020	MOTION TO DISMISS FOR FAILURE TO STATE A CLAIM , filed by Defendant Firstech LLC. (Attachments: # 1 Proposed Order) Noting Date 1/28/2022 11/20/2020, (Graham, Lawrence) Modified on 11/22/2021 (MW). (Entered: 10/29/2020)	
12	10/30/2020	NOTICE OF ASSIGNMENT TO A US MAGISTRATE JUDGE AND DECLINATION OF CONSENT FORM. Each party will be deemed to have knowingly and voluntarily consented to proceed before a Magistrate Judge if this form is not returned by 11/6/2020. Please Note: Forms must not be electronically filed with the Court. (KAM) (Entered: 10/30/2020)	
13	11/03/2020	CORPORATE DISCLOSURE STATEMENT indicating Jason Lee, Myungja Lee, Jessica Bissell, and Justin Lee no as Corporate Parents and/or Affiliates. Filed pursuant to Fed.R.Civ.P 7.1. Filed by Firstech LLC (Graham, Lawrence) Modified on 11/3/2020 (KMC). (Entered: 11/03/2020)	
14	11/06/2020	MINUTE ORDER REASSIGNING CASE. Case reassigned to Judge Thomas S. Zilly for all further proceedings, by Judge J Richard Creatura. (KAM) (Entered: 11/06/2020)	
15	11/10/2020	ORDER REGARDING INITIAL DISCLOSURES, JOINT STATUS REPORT, AND EARLY SETTLEMENT IN A PATENT CASE. FRCP 26(f) Conference Deadline is 12/28/2020, Initial Disclosure Deadline is 1/11/2021, Joint Status Report and Discovery Plan due by 1/11/2021. Signed by Judge Thomas S. Zilly. (PM) (Entered: 11/10/2020)	
16	11/16/2020	RESPONSE, by Plaintiff Omega Patents LLC, to 11 MOTION TO DISMISS FOR FAILURE TO STATE A CLAIM . (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C, # 4 Exhibit D)(Denkenberger, John) (Entered: 11/16/2020)	
17	11/20/2020	REPLY, filed by Defendant Firstech LLC, TO RESPONSE to 11 MOTION TO DISMISS FOR FAILURE TO STATE A CLAIM (Graham, Lawrence) (Entered: 11/20/2020)	
18	01/05/2021	JOINT STATUS REPORT signed by all parties. Estimated Trial Days: Five. (Denkenberger, John) (Entered: 01/05/2021)	
19	02/09/2021	NOTICE of Appearance by attorney John J Bamert on behalf of Defendant Firstech LLC. (Bamert, John) (Entered: 02/09/2021)	
20	02/10/2021	MINUTE ORDER: Defendant Firstech, LLC's motion to dismiss, docket no. 11 , is STRICKEN without prejudice to refiling after the United States Supreme Court issues a decision in Am. Axle & Mfg., Inc. v. Neapco Holdings LLC, No. 20-891. Having reviewed the parties' Joint Status Report, docket no. 18 , the Court SETS a five-day jury trial for June 6, 2022. A separate scheduling order will be entered. Authorized by Judge Thomas S. Zilly.(MW) (Entered: 02/10/2021)	
21	02/10/2021	MINUTE ORDER: JURY TRIAL DATE (5 days) June 6, 2022; Statement of asserted claims and preliminary infringement contentions due March 1, 2021; Statement of preliminary non-infringement and invalidity contentions due March 22, 2021; Deadline for joining additional parties March 29, 2021; Parties to exchange preliminary proposed constructions of disputed claim terms and provide list of proposed extrinsic evidence April 12,	

#	Date	Proceeding Text	Source
		2021; Joint Claim Chart and Prehearing Statement due June 30, 2021; Parties to disclose reports from expert witnesses, if any, regarding Markman issues June 30, 2021; Parties to disclose rebuttal expert reports, if any, regarding Markman issues July 30, 2021; Deadline for completion of claim construction discovery and for amending pleadings August 20, 2021; Opening claim construction briefs (24 pp. per side) filed by (and noted for the date that the responsive claim construction briefs are due) August 24, 2021; Responsive claim construction briefs (24 pp. per side) filed by September 10, 2021, If a claim construction (Markman) hearing is necessary, one will be set upon at least 20 days' notice to the parties; Reports from expert witnesses under FRCP 26(a)(2) due September 30, 2021; Rebuttal expert reports due November 1, 2021; All discovery motions must be filed by (and noted on the motion calendar no later than the third Friday thereafter) November 4, 2021; Discovery completed by January 18, 2022; All dispositive motions must be filed by (and noted on the motion calendar no later than the fourth Friday thereafter; see LCR 7(d)) February 10, 2022; All motions related to expert witnesses (e.g., Daubert motion) must be filed by and noted on the motion calendar no later than the third Friday thereafter (see LCR 7(d)) February 17, 2022; All motions in limine must be filed by (and noted on the motion calendar for the Friday before the Pretrial Conference) May 5, 2022; Agreed pretrial order due May 20, 2022; Trial briefs, proposed voir dire questions, and proposed jury instructions due May 20, 2022; Pretrial Conference at 10:00 a.m. on May 27, 2022. Authorized by Judge Thomas S. Zilly. (MW) (Entered: 02/10/2021)	
22	02/24/2021	ANSWER to 1 Complaint, with JURY DEMAND by Firstech LLC.(Graham, Lawrence) (Entered: 02/24/2021)	
23	03/10/2021	Stipulated MOTION for Protective Order, filed by Plaintiff Omega Patents LLC. (Attachments: # 1 Proposed Order Stipulated Protective Order, # 2 Exhibit A - Redline Stipulated Protective Order) Noting Date 3/10/2021, (Denkenberger, John) (Entered: 03/10/2021)	
24	03/12/2021	STIPULATED PROTECTIVE ORDER re Parties' 23 Stipulated MOTION for Protective Order. Signed by Judge Thomas S. Zilly. (MW) (Entered: 03/12/2021)	
25	04/07/2021	Stipulated MOTION to extend case deadlines, filed by Defendant Firstech LLC. Noting Date 4/7/2021, (Graham, Lawrence) (Entered: 04/07/2021)	
26	04/09/2021	MINUTE ORDER: Jury Trial DATE (5 days) is set for 9/26/2022 at 09:00 AM before Judge Thomas S. Zilly; Parties to exchange preliminary proposed constructions of disputed claim terms and provide lists of proposed extrinsic evidence by 5/17/2021; Joint claim chart and Prehearing Statement due 7/30/2021; Reports from expert witnesses regarding Markman issues due 7/30/2021; Rebuttal expert reports regarding Markman issues due 8/30/2021; Deadline for completion of claim construction discovery and for amending pleadings due by 9/20/2021; Opening claim construction briefs filed by (and noted for the date that the responsive claim construction briefs are due) due 9/30/2021; Responsive claim construction briefs due 10/15/2021, If a claim construction (Markman) hearing is necessary, one will be set upon at least 20 days' notice to the parties; Expert Witness Disclosure/Reports under FRCP 26(a) (2) due by 12/31/2021; Rebuttal Expert Disclosure/Reports due by 1/31/2022; Discovery Motions due by 2/10/2022; Discovery completed by 4/4/2022; Dispositive motions due by 5/5/2022 (and noted on the motion calendar no later than the fourth Friday thereafter; see LCR 7(d));	

#	Date	Proceeding Text	Source
		Motions related to expert witnesses due by 5/12/2022 (and noted on the motion calendar no later than the third Friday thereafter; see LCR 7(d)); 39.1 mediation to be completed by 6/10/2022; Motions in Limine due by 8/25/2022; Agreed Pretrial Order due by 9/9/2022; Voir dire/jury instructions/trial briefs due by 9/9/2022; Pretrial Conference set for 9/16/2022 at 10:00 AM before Judge Thomas S. Zilly. signed by Judge Thomas S. Zilly.(SR) (Entered: 04/09/2021)	
27	07/30/2021	STATEMENT Joint Claim Construction and Prehearing Statement by Plaintiff Omega Patents LLC (Attachments: # 1 Exhibit Appendix A - Joint Claim Construction Chart)(Denkenberger, John) (Entered: 07/30/2021)	
28	08/31/2021	NOTICE OF WITHDRAWAL OF COUNSEL: Attorney John J Bamert for Defendant Firstech LLC. (Attachments: # 1 Certificate of Service)(Bamert, John) (Entered: 08/31/2021)	
29	09/30/2021	OPENING BRIEF (Claim Construction) re 26 Order on Stipulated Motion,,,,,,, Set Deadlines/Hearings,,,,,, by Plaintiff Omega Patents LLC (Attachments: # 1 Exhibit A - US Patent 7,305,293, # 2 Exhibit B - US Patent 8,032,278, # 3 Exhibit C - US Patent RE47,225, # 4 Exhibit D - US Patent RE47,354, # 5 Exhibit E - OMEGA-1162 to 1172)(Santurri, Ryan) (Entered: 09/30/2021)	
30	09/30/2021	OPENING BRIEF by Defendant Firstech LLC (Attachments: # 1 Exhibit 1, # 2 Exhibit 2, # 3 Exhibit 3, # 4 Exhibit 4, # 5 Exhibit 5, # 6 Exhibit 6)(Graham, Lawrence) (Entered: 09/30/2021)	
31	10/15/2021	RESPONSIVE BRIEF re 29 Brief - Opening, by Defendant Firstech LLC. (Attachments: # 1 Exhibit 7)(Graham, Lawrence) (Entered: 10/15/2021)	
32	10/15/2021	RESPONSIVE BRIEF (Claim Construction) re 30 Brief - Opening by Plaintiff Omega Patents LLC. (Santurri, Ryan) (Entered: 10/15/2021)	
33	11/22/2021	Stipulated MOTION to Extend Deadlines, filed by Plaintiff Omega Patents LLC. Noting Date 11/22/2021, (Denkenberger, John) (Entered: 11/22/2021)	
34	11/22/2021	CLAIM CONSTRUCTION ORDER. Signed by Judge Thomas S. Zilly. (MW) (Entered: 11/22/2021)	
35	11/22/2021	MINUTE ORDER: The Court REINSTATES defendant Firstech, LLC's motion, docket no. 11 , challenging the patentability of U.S. Patent No. 7,305,293. Defendant's motion to dismiss, docket no. 11 , is NOTED for January 1/28/2022. Plaintiff may file a supplemental response, not to exceed twelve (12) pages in length, by 1/21/2022. Defendant may file a supplemental reply, not to exceed six (6) pages in length, by the noting date. Authorized by Judge Thomas S. Zilly. (MW) (Entered: 11/22/2021)	
	11/22/2021	The parties' stipulated motion, docket no. 33 , is GRANTED, and the deadline for Expert Witness Disclosure/Reports under FRCP 26(a)(2) is EXTENDED to January 31, 2022, and the deadline for Rebuttal Expert Disclosure/Reports is EXTENDED to February 28, 2022. (KK) (Entered: 11/22/2021)	
36	01/26/2022	ORDER: Plaintiff's counsel having telephonically advised the Court that this matter has been resolved, and it appearing that no issue remains for the Court's determination, NOW, THEREFORE, IT IS ORDERED that defendant's motion to dismiss, docket no. 11 , is STRICKEN as moot, and this case is DISMISSED with prejudice and without costs. In the event settlement is not perfected, either party may move to reopen and trial will be scheduled, provided such motion is filed within 60 days of the date of this Order. Signed by Judge Thomas S. Zilly. (MW) (Entered: 01/26/2022)	

#	Date	Proceeding Text	Source
37	01/26/2022	REPORT on the filing or determination of an action. Emailed to the US Patent Office (MW) (Entered: 01/26/2022)	

Patents

Number	Title	Issued	Class	Subclass
RE47,225	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	02/05/2019	1	1
RE47,354	Vehicle tracking unit for controlling operable vehicle devices using a vehicle data bus and related methods	04/16/2019	1	1
7,305,293	Vehicle tracker including input/output features and related methods	12/04/2007	701	45
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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User Name: Karen Ward
Date and Time: Monday, December 4, 2023 3:06:00PM EST
Job Number: 211856399

Document (1)

1. *1:23cv382, Omega Patents, Llc V. Geotab, Inc.*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

1:23cv382, Omega Patents, Llc V. Geotab, Inc.

US District Court Docket

United States District Court, Delaware

(Wilmington)

This case was retrieved on 12/04/2023

Header

Case Number: 1:23cv382
Date Filed: 04/04/2023
Assigned To: Judge William C. Bryson
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: 1:21cv00030, 1:22cv01044
Jurisdiction: Federal Question

Class Code: Open
Statute: 35:271
Jury Demand: Plaintiff
Demand Amount: $0
NOS Description: Patent

Participants

Litigants

Omega Patents, LLC
a Georgia limited liability company |
Plaintiff

GeoTab, Inc.
a Canadian corporation |
Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	04/04/2023	COMPLAINT for PATENT INFRINGEMENT filed with Jury Demand against Geotab, Inc. (Filing fee $ 402, receipt number ADEDC-4104744.) - filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A, # 2 Civil Cover Sheet) (vfm) (Entered: 04/04/2023)	
2	04/04/2023	Notice, Consent and Referral forms re: U.S. Magistrate Judge jurisdiction. (vfm) (Entered: 04/04/2023)	
3	04/04/2023	Report to the Commissioner of Patents and Trademarks for Patent/Trademark Number(s) 8,032,278 B2. (vfm) (Entered: 04/04/2023)	
4	04/04/2023	Summons Issued as to Geotab, Inc. on 4/4/2023. (vfm) (Entered: 04/04/2023)	
	04/05/2023	Case Assigned to Judge William C. Bryson of the United States Court of Appeals for the Federal Circuit (due to related cases). Please include the initials of the Judge (WCB) after the case number on all documents filed. (rjb) (Entered: 04/05/2023)	
5	05/31/2023	AFFIDAVIT of Service for Complaint, Summons and District of Delaware, Local Rule 73.1 served on Geotab, Inc. c/o Neil Cawse, Chief Executive Officer, Director and President on May 15,2023, filed by Omega Patents, LLC. (Golden, Ronald) (Entered: 05/31/2023)	
6	06/05/2023	MOTION for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre - filed by Geotab, Inc.. (Russell, Andrew) (Entered: 06/05/2023)	
7	06/05/2023	Disclosure Statement pursuant to Rule 7.1: No Parents or Affiliates Listed filed by Geotab, Inc.. (Russell, Andrew) (Entered: 06/05/2023)	
8	06/05/2023	ANSWER to 1 Complaint with Jury Demand by Geotab, Inc..(Russell, Andrew) (Entered: 06/05/2023)	
9	06/05/2023	ORDER granting 6 Motion for Pro Hac Vice Appearance of Attorney Michael A. Albert, Hunter D. Keeton and Susmita A. Gadre. Signed by Judge William C. Bryson on 6/5/2023. (mpb) (Entered: 06/05/2023)	
	06/06/2023	Pro Hac Vice Attorney Michael A. Albert, Susmita A. Gadre, and Hunter D. Keeton for Geotab, Inc. added for electronic noticing.	

#	Date	Proceeding Text	Source
		Pursuant to Local Rule 83.5 (d)., Delaware counsel shall be the registered users of CM/ECF and shall be required to file all papers. (mpb) (Entered: 06/06/2023)	
10	08/01/2023	Joint STIPULATION and [Proposed] Order to Stay pending Inter Partes Review by Geotab, Inc.. (Russell, Andrew) (Entered: 08/01/2023)	
11	08/01/2023	SO ORDERED, re 10 Joint STIPULATION and [Proposed] Order to Stay pending Inter Partes Review. (CASE STAYED) Signed by Judge William C. Bryson on 08/01/2023. (smg) (Entered: 08/01/2023)	

Patents

Number	Title	Issued	Class	Subclass
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36

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User Name: Karen Ward
Date and Time: Monday, December 4, 2023 3:07:00PM EST
Job Number: 211856565

Document (1)

1. *IPR2023-01162, Verizon Connect Inc. Vs. Omega Patents, LLC*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

IPR2023-01162, Verizon Connect Inc. Vs. Omega Patents, LLC

US Patent Trial and Appeals Board - Alexandria

Alexandria

This case was retrieved on 12/04/2023

Header

Case Number: IPR2023-01162
Date Filed: 06/30/2023
Date Full Case Retrieved: 12/04/2023
Status: Open
Misc: (0) Unknown; Civil

Summary

Court Case Status: Corrected
Case Type: IPR: Inter partes review
Technical Center Number: 3600
Patent Application Number: 11773272
Patent Number: 8032278

Participants

Litigants	Attorneys
Verizon Connect Inc. **Petitioner** Omega Patents, LLC **PatentOwner**	

Proceedings

Date	#	Proceeding Text	Details
06/30/2023	1	In Ex Parte A. James Smith, Jr., 2010 WL 3269939 (BPAI August 17, 2010)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1029 Public? Yes
06/30/2023	2	02-20-2015 Order on Claim Construction, 6:13-cv-1950-ORL- 40-DAB	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1028 Public? Yes
06/30/2023	3	10-03-2014 Plaintiff???s Opposition to CalAmp???s Motion for Claim Construction	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1027 Public? Yes
06/30/2023	4	Application No. 60/205,178 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1026 Public? Yes
06/30/2023	5	Application No. 60/222,777 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1025 Public? Yes
06/30/2023	6	Application No. 60/246,463 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1024 Public? Yes
06/30/2023	7	Application No. 60/236,890 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1023 Public? Yes
06/30/2023	8	Application No. 60/252,125 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1022 Public? Yes
06/30/2023	9	Application No. 60/251,552 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1021 Public? Yes
06/30/2023	10	Application No. 60/258,005 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1020 Public? Yes

Date	#	Proceeding Text	Details
06/30/2023	11	Application No. 60/264,811 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1019 Public? Yes
06/30/2023	12	Application No. 09/859,972 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1018 Public? Yes
06/30/2023	13	Application No. 10/383,496 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1017 Public? Yes
06/30/2023	14	Application No. 11/076,259 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1016 Public? Yes
06/30/2023	15	12-01-2022 Decision on Appeal (Appl. No. 90/014,675)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1015 Public? Yes
06/30/2023	16	04-01-2022 Patent Owner???s Appeal Brief (Appl. No. 90/014,675)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1014 Public? Yes
06/30/2023	17	08-23-2021 Response to Non-Final Office Action (Appl. No. 90/014,675)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1013 Public? Yes
06/30/2023	18	08-21-2021 Declaration of Joseph C. McAlexander, III	Filed By: PETITIONER Document Type: EXHIBIT

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 1012 Public? Yes
06/30/2023	19	06-21-2021 Examiner???s Non-Final Office Action (Appl. No. 90/014,675)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1011 Public? Yes
06/30/2023	20	03-25-2021 Order Granting the Reexamination (Appl. No. 90/014,675)	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1010 Public? Yes
06/30/2023	21	File History of Application No. 11/773,272, which issued as U.S. Patent No.	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1009 Public? Yes
06/30/2023	22	U.S. Patent No. 6,812,829 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1008 Public? Yes
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06/30/2023	24	U.S. Patent Application Publication No. 2003/0182003 to Underdahl	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1006 Public? Yes
06/30/2023	25	U.S. Patent Application Publication No. 2006/0161315 to Lewis	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1005 Public? Yes

Date	#	Proceeding Text	Details
06/30/2023	26	U.S. Patent No. 6,606,561 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1004 Public? Yes
06/30/2023	27	U.S. Patent No. 6,756,885 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1003 Public? Yes
06/30/2023	28	Declaration of Dr. Azim Eskandarian	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1002 Public? Yes
08/24/2023	29	Declaration of Dr. Azim Eskandarian	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1002 Public? Yes
06/30/2023	30	U.S. Patent No. 8,032,278 to Flick	Filed By: PETITIONER Document Type: EXHIBIT Paper/Exhibit No: 1001 Public? Yes
09/08/2023	31	Errata	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 6 Public? Yes
09/08/2023	32	Notice: acceptance corrected petition	Filed By: BOARD Document Type: PAPER Paper/Exhibit No: 5 Public? Yes
08/24/2023	33	Notice: defective petition	Filed By: BOARD Document Type: PAPER

Date	#	Proceeding Text	Details
			Paper/Exhibit No: 4 Public? Yes
07/21/2023	34	Notice : Mandatory Notice	Filed By: PATENT OWNER Document Type: PAPER Paper/Exhibit No: 3 Public? Yes
06/30/2023	35	Petition : as filed	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 2 Public? Yes
06/30/2023	36	Notice : Power of Attorney	Filed By: PETITIONER Document Type: PAPER Paper/Exhibit No: 1 Public? Yes

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Document (1)

1. *1:13cv646, Omega Patents, Llc V. Enfora, Inc.*

Client/Matter: -None-
Search Terms: US PAT 8032278 or 8,032,278
Search Type: Terms and Connectors
Narrowed by:

Content Type	Narrowed by
Dockets	-None-

1:13cv646, Omega Patents, Llc V. Enfora, Inc.

US District Court Docket

United States District Court, Georgia Northern

(Atlanta)

This case was retrieved on 12/04/2023

Header

Case Number: 1:13cv646
Date Filed: 02/28/2013
Assigned To: Judge Thomas W. Thrash, Jr
Nature of Suit: Patent (830)
Cause: Patent Infringement
Lead Docket: None
Other Docket: None
Jurisdiction: Federal Question

Class Code: Closed
Closed: 06/20/2013
Statute: 28:1338
Jury Demand: Plaintiff
Demand Amount: $0
NOS Description: Patent

Participants

Litigants

Omega Patents, LLC
a Georgia limited liability company |
Plaintiff

Enfora, Inc.
a Delaware Corporation |
Defendant

Novatel Wireless, Inc.
Defendant

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Proceedings

#	Date	Proceeding Text	Source
1	02/28/2013	COMPLAINT with Jury Demand, filed by Omega Patents, LLC. Consent form to proceed before U.S. Magistrate and pretrial instructions provided. (Filing fee $ 350.00 receipt number 113E-4436675.) (Attachments: # 1 Exhibit A - '876, # 2 Exhibit B - '727,	

#	Date	Proceeding Text	Source
		# 3 Exhibit C -'278, # 4 Exhibit D - '886, # 5 Civil Cover Sheet)(eop) Please visit our website at http://www.gand.uscourts.gov to obtain Pretrial Instructions. (Entered: 02/28/2013)	
2	02/28/2013	Electronic Summons Issued as to Enfora, Inc.. (eop) (Entered: 02/28/2013)	
3	02/28/2013	Certificate of Interested Persons by Omega Patents, LLC. (eop) (Entered: 02/28/2013)	
4	02/28/2013	AO Form 120 forwarded to Commissioner. (eop) (Entered: 02/28/2013)	
	03/01/2013	Clerks Notation re 3 Certificate of Interested Persons, OK per TWT. (ss) (Entered: 03/01/2013)	
5	03/07/2013	First AMENDED COMPLAINT against Enfora, Inc., Novatel Wireless, Inc.with Jury Demand, filed by Omega Patents, LLC. (Attachments: # 1 Exhibit A - '876 Patent, # 2 Exhibit B - '727 Patent, # 3 Exhibit C - '278 Patent, # 4 Exhibit D - '886 Patent, # 5 Summons Novatel Wireless, Inc.)(Gresham, Dan) Please visit our website at http://www.gand.uscourts.gov to obtain Pretrial Instructions. (Entered: 03/07/2013)	
6	03/07/2013	Supplemental Certificate of Interested Persons and Corporate Disclosure Statement by Omega Patents, LLC identifying Other Affiliate Kenneth Flick for Omega Patents, LLC. (Gresham, Dan) (Entered: 03/07/2013)	
7	06/19/2013	NOTICE of Voluntary Dismissal Without Prejudice filed by Omega Patents, LLC (Gresham, Dan) (Entered: 06/19/2013)	
	06/20/2013	Clerk's Entry of Dismissal APPROVING 7 Notice of Voluntary Dismissal pursuant to Fed.R.Civ.P.41(a)(1)(i) (dr) (Entered: 06/20/2013)	
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8	06/20/2013	AO Form 120 forwarded to Commissioner. (dr) (Entered: 06/20/2013)	

Patents

Number	Title	Issued	Class	Subclass
6,346,876	Multi-vehicle compatible control system generating command signals on a data bus and associated methods	02/12/2002	340	426.13
7,671,727	Speed exceeded notification device for vehicle having a data bus and associated methods	03/02/2010	340	466
8,032,278	Vehicle tracking unit with downloadable codes and associated methods	10/04/2011	701	36
8,362,886	Multi-controller data bus adaptor and associated methods	01/29/2013	340	426.17

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Doc code: IDS
Doc description: Information Disclosure Statement (IDS) Filed

PTO/SB/08a (01-22)
Approved for use through 05/31/2024. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	90014419
Filing Date	2019-12-16
First Named Inventor	FLICK
Art Unit	3992
Examiner Name	WASSUM, LUKE S
Attorney Docket Number	CAAMP-001X

U.S.PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
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	2	5333177	A	1994-07-26	Michael F. Braitberg	
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	Attorney Docket Number	CAAMP-001X

	9	6011460	A	2000-01-04	Kenneth E. Flick	
	10	6028537	A	2000-02-22	Michael J. Suman	
	11	6330499	B1	2001-12-11	Paul Bao-Luo Chou	
	12	6346876	B1	2002-02-12	Kenneth E. Flick	
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	20	7209813	B2	2007-04-24	Hamid Namaky	
	21	7484008	B1	2009-01-27	David C. Gelvin	
	22	7617727	B2	2009-11-17	William S. Watson	
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	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	31	9892568	B2	2018-02-13	Ieon C. Chen	
	32	D558621	S1	2008-01-01	David Rich	
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	Art Unit	3992
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	Attorney Docket Number	CAAMP-001X

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If you wish to add additional U.S. Patent citation information please click the Add button.

U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
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	First Named Inventor	FLICK
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	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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	3	20040136790	A1	2004-07-15	Michael Kapolka	
	4	20050032511	A1	2005-02-10	Jason Malone	
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Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1							☐

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NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	1	Declaration of Mr. Joseph C. McAlexander, III in Support of Response to Petition of Inter Partes Review"; pgs. 77. ***SEE IPR NO. IPR2023-00504	☐
	2	ISO 15765-4:2005(E) "Road vehicles-Diagnostics on Controller Area Networks (CAN)-Part 4: Requirements for emissions-related systems" (1st ed. ISO January 15, 2005); pgs 27 ***SEE IPR NO. IPR2023-00504	☐

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	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	3	ISO 14230-4 Road vehicles-Diagnostic systems-Keyword Protocol 2000; Part 4: Requirements for emission-related systems (ISO 1st ed. June 1, 2000); pgs. 8. ***SEE IPR NO. IPR2023-00504	☐
	4	Pages from Title 40 Code of Federal Regulations, Part 86, Subpart S—General Compliance Provisions for Control of Air Pollution From New and In-Use Light Duty Vehicles, Light-Duty Trucks, and Complete Otto-Cycle Heavy-Duty Vehicles (July 1, 2014); pgs. 604 - 838. ***SEE IPR NO. IPR2023-00504	☐
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	7	ISO 14230-2 Road vehicles—Diagnostic systems—Keyword Protocol 2000 – Part 2: data link layer (1st ed. Mar. 15, 1999) pgs. 28 ***SEE IPR NO. IPR2023-00504	☐
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	9	SAE On-Board Diagnostics for Light and Medium Duty Vehicles Standards Manual, SAE HS-3000, Society of Automotive Engineers, Inc., 1994 Edition; pgs. 253. ***SEE REEXAMINATION SERIAL NO. 90/013,851	☐
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	14	SAE J2178-1 Class B Data Communication Network Messages—Detailed Header Formats and Physical Address Assignments (reaffirmed July 2004). pgs. 21***SEE IPR NO. IPR2023-00504	☐
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	21	Pages from IEEE 100 The Authoritative Dictionary of IEEE Standard Terms (7th Ed. 2000); pgs. 3. ***SEE IPR NO. IPR2023-00504	☐
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

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	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	25	SAE J1708 Serial Data Communications Between Microcomputer Systems in Heavy-Duty Vehicle Applications (rev. AUG2004); pgs. 16. ***SEE IPR NO. IPR2023-00504	☐
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EXAMINER SIGNATURE

Examiner Signature	/LUKE S WASSUM/	Date Considered	12/18/2023

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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	Attorney Docket Number	CAAMP-001X

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

☐ See attached certification statement.

☐ The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/JACK G. ABID/	Date (YYYY-MM-DD)	10-5-23
Name/Print	JACK G. ABID	Registration Number	58237

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

EFS Web 2.1.18

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

Bibliographic Data

Application No: 90/014,419

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☑ No ☐ Met After Allowance

Verified and Acknowledged: /LUKE S WASSUM/ Examiner's Signature | Initials

Title: Vehicle Tracking Unit with Downloadable Codes and Associated Methods

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
12/16/2019	701	3992	CAAMP-001X
RULE			

APPLICANTS

INVENTORS

8032278,

OMEGA PATENTS, LLC, DOUGLASVILLE, GA, UNITED STATES

INNOVA ELECTRONICS CORPORATION (3RD PTY REQ.), ALISO VIEJO, CA, UNITED STATES

CONTINUING DATA

This application is a REX of 11773272 07/03/2007 PAT 8032278

11773272 is a CIP of 11076259 03/09/2005 PAT 7720597

11076259 is a CON of 10383496 03/07/2003 PAT 7149623

10383496 is a CON of 09859972 05/17/2001 PAT 6606561

09859972 has PRO of 60264811 01/29/2001

09859972 has PRO of 60258005 12/22/2000

09859972 has PRO of 60251552 12/06/2000

09859972 has PRO of 60252125 11/20/2000

09859972 has PRO of 60246463 11/07/2000

09859972 has PRO of 60236890 09/29/2000

09859972 has PRO of 60222777 08/03/2000

09859972 has PRO of 60205178 05/17/2000

FOREIGN APPLICATIONS

IF REQUIRED, FOREIGN LICENSE GRANTED**

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STATE OR COUNTRY

ADDRESS

ADD+G - 27975
1135 East State Road 434, Suite 3001
Winter Springs, FL 32708
UNITED STATES

FILING FEE RECEIVED

$6,000

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

CPC						
Symbol					Type	Version
B60R	/	25	/	33	F	2013-01-01
G07C	/	5	/	008	I	2013-01-01
B60R	/	25	/	04	I	2013-01-01
G08G	/	1	/	205	I	2013-01-01
B60R	/	25	/	102	I	2013-01-01
G08G	/	1	/	20	I	2013-01-01
B60R	/	25	/	104	I	2013-01-01
G08G	/	1	/	127	I	2013-01-01
B60R	/	25	/	045	I	2013-01-01
B60W	/	2556	/	50	A	2020-02-01
B60R	/	2325	/	205	A	2013-01-01
B60R	/	2325	/	202	A	2013-01-01

CPC Combination Sets							
Symbol					Type	Set	Ranking	Version
	/		/					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	13 December 2023	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office

Part of Paper No.: 20231212

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	**Art Unit**
	Luke S Wassum	3992

INTERNATIONAL CLASSIFICATION					
CLAIMED					
G01C	/	21	/	00	
NON-CLAIMED					
	/		/		

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**
1	1

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	13 December 2023	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office

Part of Paper No.: 20231212

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	**Art Unit**
	Luke S Wassum	3992

☑ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIMS

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1	10	10	19	19										
2	2	11	11	20	20										
3	3	12	12	21	21										
4	4	13	13	22	22										
5	5	14	14												
6	6	15	15												
7	7	16	16												
8	8	17	17												
9	9	18	18												

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	13 December 2023	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office Part of Paper No.: 20231212

Reexamination	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Certificate Date	Certificate Number
		C5

Requester Correspondence Address: ☐ **Patent Owner** ☑ **Third Party**

STETINA BRUNDA GARRED & BRUCKER
75 ENTERPRISE, SUITE 250
ALISO VIEJO, CA 92656

LITIGATION REVIEW ☑	lsw (examiner initials)	04 December 2023 (date)
Case Name		Director Initials
Omega Patents, LLC v. Calamp Corp, 6:13cv1950 (closed)		
Omega Patents, LLC v. Dei Holdings, Inc., 6:20cv693 (closed)		
Omega Patents, LLC v. Enfora, Inc., 1:17cv2769 (closed)		
Omega Patents, LLC v. Verizon Connect, Inc., 6:22cv2371 (open)		
Omega Patents, LLC v. Geotab USA, Inc. et al., 1:22cv1044 (open)		
Omega Patents, LLC v. Firstech LLC, 2:20cv1344 (closed)		
Omega Patents, LLC v. Geotab, Inc., 1:23cv382 (open)		

COPENDING OFFICE PROCEEDINGS	
TYPE OF PROCEEDING	**NUMBER**
Inter Partes Review	IPR2023-00504 (open)
Inter Partes Review	IPR2023-01162 (open)

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
90/014,419	12/16/2019	8032278	CAAMP-001X	8770

27975 7590 01/02/2024

ADD+G - 27975
1135 East State Road 434, Suite 3001
Winter Springs, FL 32708

EXAMINER
WASSUM, LUKE S

ART UNIT	PAPER NUMBER
3992	

MAIL DATE	DELIVERY MODE
01/02/2024	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Commissioner for Patents
United States Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450
www.uspto.gov

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(THIRD PARTY REQUESTER'S CORRESPONDENCE ADDRESS)

STETINA BRUNDA GARRED & BRUCKER
75 ENTERPRISE
SUITE 250
ALISO VIEJO, CA 92656

EX PARTE REEXAMINATION COMMUNICATION TRANSMITTAL FORM

REEXAMINATION CONTROL NO. *90/014,419* .

PATENT UNDER REEXAMINATION *8032278* .

ART UNIT *3992* .

Enclosed is a copy of the latest communication from the United States Patent and Trademark Office in the above identified *ex parte* reexamination proceeding (37 CFR 1.550(f)).

Where this copy is supplied after the reply by requester, 37 CFR 1.535, or the time for filing a reply has passed, no submission on behalf of the *ex parte* reexamination requester will be acknowledged or considered (37 CFR 1.550(g)).

Notice of Intent to Issue Ex Parte Reexamination Certificate	**Control No.** 90/014,419	**Patent Under Reexamination** 8032278	
	Examiner Luke S Wassum	**Art Unit** 3992	**AIA Status** No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

1. ☑ Prosecution on the merits is (or remains) closed in this *ex parte* reexamination proceeding. This proceeding is subject to reopening at the initiative of the Office or upon petition. *Cf.* 37 CFR 1.313(a). A Certificate will be issued in view of
   (a) ☑ Patent owner's communication(s) filed: 27 September 2023.
   (b) ☐ Patent owner's failure to file an appropriate timely response to the Office action mailed: _____.
   (c) ☐ Patent owner's failure to timely file an Appeal Brief (37 CFR 41.31).
   (d) ☐ The decision on appeal by the ☐ Board of Patent Appeals and Interferences ☐ Court dated _____
   (e) ☐ Other: _____.
2. The Reexamination Certificate will indicate the following:
   (a) Change in the Specification: ☐ Yes ☑ No
   (b) Change in the Drawing(s): ☐ Yes ☑ No
   (c) Status of the Claim(s):
      (1) Patent claim(s) confirmed: 1-22.
      (2) Patent claim(s) amended (including dependent on amended claim(s)): _____
      (3) Patent claim(s) canceled: _____.
      (4) Newly presented claim(s) patentable: _____.
      (5) Newly presented canceled claims: _____.
      (6) Patent claim(s) ☐ previously ☐ currently disclaimed: _____
      (7) Patent claim(s) not subject to reexamination: _____.
3. ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.
4. ☑ Note the attached statement of reasons for patentability and/or confirmation. Any comments considered necessary by patent owner regarding reasons for patentability and/or confirmation must be submitted promptly to avoid processing delays. Such submission(s) should be labeled: "Comments On Statement of Reasons for Patentability and/or Confirmation."
5. ☐ Note attached NOTICE OF REFERENCES CITED (PTO-892).
6. ☑ Note attached LIST OF REFERENCES CITED (PTO/SB/08 or PTO/SB/08 substitute).
7. ☐ The drawing correction request filed on _____ is: ☐approved ☐disapproved.
8. ☐ Acknowledgment is made of the priority claim under 35 U.S.C. § 119(a)-(d) or (f).
   a) ☐ All b) ☐ Some* c) ☐None of the certified copies have
   ☐been received.
   ☐not been received.
   ☐been filed in Application No. _____.
   ☐been filed in reexamination Control No. _____.
   ☐been received by the International Bureau in PCT Application No. _____.

   * Certified copies not received: _____.
9. ☐ Note attached Examiner's Amendment.
10. ☐ Note attached Interview Summary (PTO-474).
11. ☐ Other: _____.

All correspondence relating to this reexamination proceeding should be directed to the **Central Reexamination Unit** at the mail, FAX, or hand-carry addresses given at the end of this Office action.

/LUKE S WASSUM/
Primary Examiner, Art Unit 3992

cc: Requester (if third party requester)

Ex Parte Reexamination

A request for *Ex Parte* Reexamination of claims 1-22 of U.S. Patent Number 8,032,278 ("the '278 patent") was filed 11 December 2019 ("the Request"). The '278 patent issued to **Kenneth E. Flick** on 4 October 2011, from application 11/773,272 ("the '272 application"), filed 3 July 2007.

The Office mailed a Decision denying the request for reexamination on 27 January 2020.

The Requester filed a petition for review of the examiner's decision to deny reexamination on 25 February 2000.

The Office mailed a response to the petition on 27 July 2023. The petition was granted-in-part, denying the request for reexamination based on double patenting, but granting the request for reexamination based upon obviousness over U.S. Patent 5,719,551 to Flick ("**Flick '551**") and other references.

A Patent Owner's Response to Order was filed on 27 September 2023.

Claims 1-22 are subject to reexamination.

Related Proceedings

The application which issued as the '278 patent was application no. 11/773,272 ("the '272 application"), filed 3 July 2007.

The '278 patent was the subject of three previous and one subsequent *Ex Parte* Reexamination proceedings; 90/013,587, filed 14 September 2014 ("**First Reexamination**"); 90/013,851, filed 28 October 2016 ("**Second Reexamination**"); 90/014,309, filed 24 May 2019 ("**Third Reexamination**"); and 90/014,675, filed 10 February 2021 ("**Fifth Reexamination**"). The instant reexamination proceeding is the **Fourth Reexamination**.

Priority

The '278 patent is a continuation-in-part of application 11/076,259, filed 9 March 2005, now U.S. Patent 7,720,597, which is a continuation of application 10/383,496, filed 7 March 2003, now U.S. Patent 7,149,623, which is a continuation of application 09/859,972 ("'**972 application**"), filed 17 May 2001, now U.S. Patent 6,606,561.

The '278 patent also claimed priority under 35 U.S.C. § 119(e) to the following provisional applications:

60/264,811, filed 29 January 2001;
60/258,005, filed 22 December 2000;
60/251,552, filed 6 December 2000;
60/252,125, filed 20 November 2000;
60/246,463[1], filed 7 November 2000;

[1] The Office notes that the serial number of this provisional application contains a typographical error; the provisional application presumably intended in the priority claim was actually 60/246,436.

60/236,890, filed 29 September 2000;

60/222,777, filed 3 August 2000; and

60/205,178, filed 17 May 2000.

As a continuation-in-part, the '278 patent is entitled to a priority date earlier than the actual filing date of the '272 application only for those claims that are fully supported by the earlier cited applications.

The Office notes that each of the independent claims of the '278 patent includes several features that were not disclosed in the earlier cited applications, including the fact that the tracking unit and its components are *multi-vehicle compatible*, that the vehicle includes a *vehicle data bus* that extends throughout the vehicle to facilitate communication between the controller and *at least one vehicle device* using at least one corresponding *vehicle device code*, and that the tracking unit includes *a downloading interface* for permitting *downloading of enabling data* related to the at least one corresponding vehicle device code.

Since each of the independent claims of the '278 patent includes subject matter not supported by its parent application, the patent is entitled only to a priority date of 3 July 2007, the actual application date of the '272 application.

Because the effective filing date of the '272 application is presumed to be *not* on or after March 16, 2013, the AIA First Inventor to File ("AIA-FITF") provisions do not apply. Instead, the earlier 'First to Invent' provisions will apply.

In the event the determination of the status of the '366 application as subject to AIA 35 U.S.C. §§ 102 and 103 (or as subject to pre-AIA 35 U.S.C. §§ 102 and 103) is incorrect, any correction of the statutory basis for the rejection will not be considered a new ground of rejection if the prior art relied upon, and the rationale supporting the rejection, would be the same under either status.

Claim Construction

During reexamination, claims are given the broadest reasonable interpretation consistent with the specification and limitations in the specification are not read into the claims (*In re Yamamoto*, 740 F.2d 1569, 222 USPQ 934 (Fed. Cir. 1984)).

Upon review of the original specification and prosecution history, the examiner has found no instance of lexicographic definitions, either express or implied, that are inconsistent with the ordinary and customary meaning of the respective terms. Therefore, for the purposes of claim interpretation, the examiner concludes that there

are no claim terms for which Patent Owner is acting as their own lexicographer. See MPEP § 2111.01(IV).

The Office notes that there were several claim terms construed by the Patent Trial and Appeal Board (PTAB) in a decision[2] on appeal in the **Second Reexamination**. In the Decision, the PTAB also considered the construction of claim terms ordered in related District Court litigation[3] involving several patents by inventor Kenneth E. Flick, including the '278 patent.

The construed claim terms are as follows:

Multi-Vehicle Compatible Controller, construed as "electronic circuitry that performs one or more control functions, and can operate with more than one vehicle."

Different Vehicles, construed as "vehicles from different manufacturers, different models, or different trim levels of the same make or model, but having different electronics."

Enabling Data, construed as "data related to the at least one corresponding vehicle device code for use by said multi-vehicle compatible controller, and which enables the controller to use a *particular* vehicle device code from among plural such

[2] Reexamination Proceeding 90/013,851, Decision on Appeal, 13 November 2018.
[3] *Omega Patents, LLC v. CalAmp Corp.*, No. 6:13-cv-1950-Orl-40DAB (M.D. Fla.), Claim Construction Order, 20 February 2015.

codes for different vehicles by providing either (1) the code itself to the controller, or (2) data that otherwise enables the controller to select or generate the code."

The Court's construction of these claim terms is consistent with the broadest reasonable interpretation and is adopted for the purposes of the instant reexamination proceeding.

The Office also notes that the PTAB construed the claimed Vehicle Device Codes as "signal from a vehicle device". However, in light of the disclosure at col. 23, line 67 through col. 24, line 3, that "[t]he corresponding vehicle [device] code may be for reading from the vehicle device **121**. Similarly, the corresponding vehicle [device] code may be additionally or alternatively for writing to the vehicle device **121**", for the purposes of the instant reexamination proceeding, the term Vehicle Device Codes will be construed as "signal *to or* from a vehicle device."

Additionally, upon review of the pending claims, the examiner finds no instances where the claim term explicitly includes functional language which would invoke 35 U.S.C. § 112(f).

The Claimed Invention

Independent Claim 1 is directed to a multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle. The multi-vehicle compatible tracking unit may comprise a vehicle position determining device, a wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles. The multi-vehicle compatible tracking unit may comprise a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller.

Independent Claims 13 and 18 are directed to multivehicle compatible tracking units similar to that of Claim 1, but further recite the downloading interface comprising a connector for temporary connection to a downloading device and a wireless receiver for temporary connection to a downloading device, respectively.

Patent Owner's Statement

The Patent Owner's Statement included a number of arguments. Among them, the Patent Owner argued that in view of Secondary Considerations, claims 1-22 are confirmable over the prior art cited in the Request. The Patent Owner cited the PTAB's decisions reversing the examiner's obviousness claim rejections in the **Second Reexamination** and the **Fifth Reexamination**, based upon evidence of Secondary Considerations made of record in the respective reexamination proceedings.

These arguments are persuasive.

Information Disclosure Statement

Applicants' Information Disclosure Statement (IDS), filed 5 October 2023, has been received and entered into the record. Since the IDS complies with the provisions of MPEP § 2280, the references cited therein have been considered by the examiner.

See attached form PTO-1449.

With respect to the Information Disclosure Statement considered with this action, the information cited has been considered as described in the MPEP. Note that MPEP §§ 2256 and 2656 indicate that the degree of consideration to be given to such

information will be normally limited by the degree to which the party filing the information citation has explained the content and relevance of the information. Information that does not appear to be "patents or printed publications" as identified in 35 U.S.C. 301 have been considered to the same extent.

Allowable Subject Matter

Claims 1-22 are confirmed.

STATEMENT OF REASONS FOR PATENTABILITY AND/OR CONFIRMATION

The following is an examiner's statement of reasons for patentability and/or confirmation of the claims found patentable in this reexamination proceeding:

Regarding claims 1-22, the prior art of record fails to render the claims obvious in light of secondary considerations, for the reasons set forth in the **Fifth Reexamination** by the PTAB in the Decision on Appeal mailed 1 December 2022.

Any comments considered necessary by PATENT OWNER regarding the above statement must be submitted promptly to avoid processing delays. Such submission by

the patent owner should be labeled: "Comments on Statement of Reasons for Patentability and/or Confirmation" and will be placed in the reexamination file.

Conclusion

The Patent Owner is reminded of the continuing responsibility under 37 CFR 1.565(a), to apprise the Office of any litigation activity, or other prior or concurrent proceeding, involving U.S. Patent No. 8,032,278 throughout the course of this reexamination proceeding. The third party requester is also reminded of the ability to similarly apprise the Office of any such activity or proceeding throughout the course of this reexamination proceeding. See MPEP §§ 2207, 2282 and 2286.

The Patent Owner is reminded that any proposed amendment to the specification and/or claims in the reexamination proceeding must comply with the provisions of 37 C.F.R. § 1.530(d)-(j), must be formally presented pursuant to 37 C.F.R. § 1.52(a) and (b), and must include any fees required by 37 C.F.R. § 1.20(c). See MPEP § 2250(IV) for examples to assist in the preparation of proper amendments in reexamination proceedings.

Any document filed by the Patent Owner must be served on the third party requester (or requesters in a merged proceeding) in the reexamination proceeding in the manner provided by 37 C.F.R. § 1.248. See 37 C.F.R. § 1.550(f) and MPEP § 2266.03.

All correspondence relating to this *ex parte* reexamination proceeding should be directed:

By Patent Center:	Patent Center (patentcenter.uspto.gov) has 100% of the functionality of EFS-Web, Public and Private PAIR, and is available to all users for electronic filing and management of patent applications. For more information, please visit the Patent Center information page at uspto.gov/patents/apply/patent-center.
By Mail to:	Mail Stop *Ex Parte* Reexam Central Reexamination Unit Commissioner for Patents United States Patent & Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450
By FAX to:	(571) 273-9900 Central Reexamination Unit
By hand:	Customer Service Window Randolph Building 401 Dulany Street Alexandria, VA 22314

Any inquiry concerning this communication should be directed to the Central Reexamination Unit at telephone number 571-272-7705.

/LUKE S WASSUM/
Primary Examiner, Art Unit 3992

Conferees:

/Stephen J. Ralis/
Primary Examiner, Art Unit 3992

/Michael Fuelling/
Supervisory Patent Examiner
Art Unit 3992

5 lsw
12 December 2023

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

CPC - Searched*		
Symbol	Date	Examiner

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
Reviewed prosecution history of US Pat No 8,032,278	01/07/2020	cmt
Reviewed related ex parte reexaminations: 90013587, 90013851, 90014309	01/08/2020	cmt
Reviewed prosecution history of appn 11/773,272	12/12/2023	lsw
Reviewed prosecution history of appns 90/013,587; 90/013,851; 90/014,309; 90/014,675	12/12/2023	lsw
Updated Litigation Search	12/04/2023	lsw
Patent Data Portal (PDP) for continuity data	12/12/2023	lsw
P-TACTS for AIA proceedings	12/12/2023	lsw
Reviewed IPR2023-00504	12/12/2023	lsw
Reviewed IPR2023-01162	12/12/2023	lsw

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

Doc code: IDS
Doc description: Information Disclosure Statement (IDS) Filed

PTO/SB/08a (01-22)
Approved for use through 05/31/2024. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	90014419
Filing Date	2019-12-16
First Named Inventor	FLICK
Art Unit	3992
Examiner Name	WASSUM, LUKE S
Attorney Docket Number	CAAMP-001X

U.S.PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	5208756	A	1993-05-04	Han L. Song	
	2	5333177	A	1994-07-26	Michael F. Braitberg	
	3	5555498	A	1996-09-10	Charles J. Berra	
	4	5557254	A	1996-09-17	Sam Johnson	
	5	5732074	A	1998-03-24	Charles W. Spaur	
	6	5794164	A	1998-08-11	Richard D. Beckert	
	7	5877724	A	1999-03-02	Paul M. Davis	
	8	6009363	A	1999-12-28	Richard D. Beckert	

EFS Web 2.1.18

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	90014419
	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	9	6011460	A	2000-01-04	Kenneth E. Flick	
	10	6028537	A	2000-02-22	Michael J. Suman	
	11	6330499	B1	2001-12-11	Paul Bao-Luo Chou	
	12	6346876	B1	2002-02-12	Kenneth E. Flick	
	13	6430164	B1	2002-08-06	Marc T. Jones	
	14	6606561	B2	2003-08-12	Kenneth E. Flick	
	15	6611740	B2	2003-08-26	Larkin Hill Lowrey	
	16	6636790	B1	2003-10-21	Bruce Lightner	
	17	6756885	B1	2004-06-29	Kenneth E. Flick	
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	90014419
	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

	20	7209813	B2	2007-04-24	Hamid Namaky	
	21	7484008	B1	2009-01-27	David C. Gelvin	
	22	7617727	B2	2009-11-17	William S. Watson	
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	Attorney Docket Number	CAAMP-001X

	31	9892568	B2	2018-02-13	Ieon C. Chen	
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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	Filing Date	2019-12-16
	First Named Inventor	FLICK
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	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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If you wish to add additional U.S. Patent citation information please click the Add button.

U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20010033225	A1	2001-10-25	Behfar Razavi	

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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

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	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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If you wish to add additional U.S. Published Application citation information please click the Add button.

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1							☐

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NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	1	Declaration of Mr. Joseph C. McAlexander, III in Support of Response to Petition of Inter Partes Review"; pgs. 77. ***SEE IPR NO. IPR2023-00504	☐
	2	ISO 15765-4:2005(E) "Road vehicles-Diagnostics on Controller Area Networks (CAN)-Part 4: Requirements for emissions-related systems" (1st ed. ISO January 15, 2005); pgs 27 ***SEE IPR NO. IPR2023-00504	☐

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	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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	Application Number	90014419
	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

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If you wish to add additional non-patent literature document citation information please click the Add button

EXAMINER SIGNATURE

Examiner Signature	/LUKE S WASSUM/	Date Considered	01/11/2024

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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	Filing Date	2019-12-16
	First Named Inventor	FLICK
	Art Unit	3992
	Examiner Name	WASSUM, LUKE S
	Attorney Docket Number	CAAMP-001X

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

☐ See attached certification statement.

☐ The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/JACK G. ABID/	Date (YYYY-MM-DD)	10-5-23
Name/Print	JACK G. ABID	Registration Number	58237

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /L.S.W/

Bibliographic Data

Application No: 90/014,419

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☑ No ☐ Met After Allowance

Verified and Acknowledged: /LUKE S WASSUM/ Examiner's Signature | Initials

Title: Vehicle Tracking Unit with Downloadable Codes and Associated Methods

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
12/16/2019	701	3992	CAAMP-001X
RULE			

APPLICANTS

INVENTORS

8032278,

OMEGA PATENTS, LLC, DOUGLASVILLE, GA, UNITED STATES

INNOVA ELECTRONICS CORPORATION (3RD PTY REQ.), ALISO VIEJO, CA, UNITED STATES

CONTINUING DATA

This application is a REX of 11773272 07/03/2007 PAT 8032278

11773272 is a CIP of 11076259 03/09/2005 PAT 7720597

11076259 is a CON of 10383496 03/07/2003 PAT 7149623

10383496 is a CON of 09859972 05/17/2001 PAT 6606561

09859972 has PRO of 60264811 01/29/2001

09859972 has PRO of 60258005 12/22/2000

09859972 has PRO of 60251552 12/06/2000

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09859972 has PRO of 60246463 11/07/2000

09859972 has PRO of 60236890 09/29/2000

09859972 has PRO of 60222777 08/03/2000

09859972 has PRO of 60205178 05/17/2000

FOREIGN APPLICATIONS

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Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

CPC						
Symbol					Type	Version
B60R	/	25	/	33	F	2013-01-01
G07C	/	5	/	008	I	2013-01-01
B60R	/	25	/	04	I	2013-01-01
G08G	/	1	/	205	I	2013-01-01
B60R	/	25	/	102	I	2013-01-01
G08G	/	1	/	20	I	2013-01-01
B60R	/	25	/	104	I	2013-01-01
G08G	/	1	/	127	I	2013-01-01
B60R	/	25	/	045	I	2013-01-01
B60W	/	2556	/	50	A	2020-02-01
B60R	/	2325	/	205	A	2013-01-01
B60R	/	2325	/	202	A	2013-01-01

CPC Combination Sets							
Symbol					Type	Set	Ranking	Version
	/		/					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	12 January 2024	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office — Part of Paper No.: 20240111

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	**Art Unit**
	Luke S Wassum	3992

INTERNATIONAL CLASSIFICATION					
CLAIMED					
G01C	/	21	/	00	
NON-CLAIMED					
	/		/		

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**
1	1

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	12 January 2024	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office

Part of Paper No.: 20240111

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	**Art Unit**
	Luke S Wassum	3992

☑ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIMS

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1	10	10	19	19										
2	2	11	11	20	20										
3	3	12	12	21	21										
4	4	13	13	22	22										
5	5	14	14												
6	6	15	15												
7	7	16	16												
8	8	17	17												
9	9	18	18												

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/LUKE S WASSUM/ Primary Examiner, Art Unit 3992	12 January 2024	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	2

U.S. Patent and Trademark Office Part of Paper No.: 20240111

Reexamination	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Certificate Date	Certificate Number
		C5

Requester Correspondence Address: ☐ **Patent Owner** ☑ **Third Party**

STETINA BRUNDA GARRED & BRUCKER
75 ENTERPRISE, SUITE 250
ALISO VIEJO, CA 92656

LITIGATION REVIEW ☑	lsw (examiner initials)	04 December 2023 (date)
Case Name		Director Initials
Omega Patents, LLC v. Calamp Corp, 6:13cv1950 (closed)		
Omega Patents, LLC v. Dei Holdings, Inc., 6:20cv693 (closed)		
Omega Patents, LLC v. Enfora, Inc., 1:17cv2769 (closed)		
Omega Patents, LLC v. Verizon Connect, Inc., 6:22cv2371 (open)		
Omega Patents, LLC v. Geotab USA, Inc. et al., 1:22cv1044 (open)		
Omega Patents, LLC v. Firstech LLC, 2:20cv1344 (closed)		
Omega Patents, LLC v. Geotab, Inc., 1:23cv382 (open)		

COPENDING OFFICE PROCEEDINGS	
TYPE OF PROCEEDING	**NUMBER**
Inter Partes Review	IPR2023-00504 (open)
Inter Partes Review	IPR2023-01162 (open)

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
90/014,419	12/16/2019	8032278	CAAMP-001X	8770

27975 7590 01/17/2024

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1135 East State Road 434, Suite 3001
Winter Springs, FL 32708

EXAMINER
WASSUM, LUKE S

ART UNIT	PAPER NUMBER
3992	

MAIL DATE	DELIVERY MODE
01/17/2024	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

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EX PARTE REEXAMINATION COMMUNICATION TRANSMITTAL FORM

REEXAMINATION CONTROL NO. *90/014,419* .

PATENT UNDER REEXAMINATION *8032278* .

ART UNIT *3992* .

Enclosed is a copy of the latest communication from the United States Patent and Trademark Office in the above identified *ex parte* reexamination proceeding (37 CFR 1.550(f)).

Where this copy is supplied after the reply by requester, 37 CFR 1.535, or the time for filing a reply has passed, no submission on behalf of the *ex parte* reexamination requester will be acknowledged or considered (37 CFR 1.550(g)).

Notice of Intent to Issue Ex Parte Reexamination Certificate	**Control No.** 90/014,419	**Patent Under Reexamination** 8032278	
	Examiner Luke S Wassum	**Art Unit** 3992	**AIA Status** No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

1. ☑ Prosecution on the merits is (or remains) closed in this *ex parte* reexamination proceeding. This proceeding is subject to reopening at the initiative of the Office or upon petition. *Cf.* 37 CFR 1.313(a). A Certificate will be issued in view of
   (a) ☑ Patent owner's communication(s) filed: 27 September 2023.
   (b) ☐ Patent owner's failure to file an appropriate timely response to the Office action mailed: _____.
   (c) ☐ Patent owner's failure to timely file an Appeal Brief (37 CFR 41.31).
   (d) ☐ The decision on appeal by the ☐ Board of Patent Appeals and Interferences ☐ Court dated _____
   (e) ☐ Other: _____.
2. The Reexamination Certificate will indicate the following:
   (a) Change in the Specification: ☐ Yes ☑ No
   (b) Change in the Drawing(s): ☐ Yes ☑ No
   (c) Status of the Claim(s):
      (1) Patent claim(s) confirmed: 1-22.
      (2) Patent claim(s) amended (including dependent on amended claim(s)): _____
      (3) Patent claim(s) canceled: _____.
      (4) Newly presented claim(s) patentable: _____.
      (5) Newly presented canceled claims: _____.
      (6) Patent claim(s) ☐ previously ☐ currently disclaimed: _____
      (7) Patent claim(s) not subject to reexamination: _____.
3. ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.
4. ☑ Note the attached statement of reasons for patentability and/or confirmation. Any comments considered necessary by patent owner regarding reasons for patentability and/or confirmation must be submitted promptly to avoid processing delays. Such submission(s) should be labeled: "Comments On Statement of Reasons for Patentability and/or Confirmation."
5. ☐ Note attached NOTICE OF REFERENCES CITED (PTO-892).
6. ☑ Note attached LIST OF REFERENCES CITED (PTO/SB/08 or PTO/SB/08 substitute).
7. ☐ The drawing correction request filed on _____ is: ☐approved ☐disapproved.
8. ☐ Acknowledgment is made of the priority claim under 35 U.S.C. § 119(a)-(d) or (f).
   a) ☐ All b) ☐ Some* c) ☐None of the certified copies have
   ☐been received.
   ☐not been received.
   ☐been filed in Application No. _____.
   ☐been filed in reexamination Control No. _____.
   ☐been received by the International Bureau in PCT Application No. _____.

   * Certified copies not received: _____.
9. ☐ Note attached Examiner's Amendment.
10. ☐ Note attached Interview Summary (PTO-474).
11. ☐ Other: _____.

All correspondence relating to this reexamination proceeding should be directed to the **Central Reexamination Unit** at the mail, FAX, or hand-carry addresses given at the end of this Office action.

cc: Requester (if third party requester)

Ex Parte Reexamination

A request for *Ex Parte* Reexamination of claims 1-22 of U.S. Patent Number 8,032,278 ("the '278 patent") was filed 11 December 2019 ("the Request"). The '278 patent issued to **Kenneth E. Flick** on 4 October 2011, from application 11/773,272 ("the '272 application"), filed 3 July 2007.

The Office mailed a Decision denying the request for reexamination on 27 January 2020.

The Requester filed a petition for review of the examiner's decision to deny reexamination on 25 February 2000.

The Office mailed a response to the petition on 27 July 2023. The petition was granted-in-part, denying the request for reexamination based on double patenting, but granting the request for reexamination based upon obviousness over U.S. Patent 5,719,551 to Flick ("**Flick '551**") and other references.

A Patent Owner's Response to Order was filed on 27 September 2023.

Claims 1-22 are subject to reexamination.

Related Proceedings

The application which issued as the '278 patent was application no. 11/773,272 ("the '272 application"), filed 3 July 2007.

The '278 patent was the subject of three previous and one subsequent *Ex Parte* Reexamination proceedings; 90/013,587, filed 14 September 2014 ("**First Reexamination**"); 90/013,851, filed 28 October 2016 ("**Second Reexamination**"); 90/014,309, filed 24 May 2019 ("**Third Reexamination**"); and 90/014,675, filed 10 February 2021 ("**Fifth Reexamination**"). The instant reexamination proceeding is the **Fourth Reexamination**.

Priority

The '278 patent is a continuation-in-part of application 11/076,259, filed 9 March 2005, now U.S. Patent 7,720,597, which is a continuation of application 10/383,496, filed 7 March 2003, now U.S. Patent 7,149,623, which is a continuation of application 09/859,972 ("'**972 application**"), filed 17 May 2001, now U.S. Patent 6,606,561.

The '278 patent also claimed priority under 35 U.S.C. § 119(e) to the following provisional applications:

60/264,811, filed 29 January 2001;

60/258,005, filed 22 December 2000;

60/251,552, filed 6 December 2000;

60/252,125, filed 20 November 2000;

60/246,463[1], filed 7 November 2000;

60/236,890, filed 29 September 2000;

[1] The Office notes that the serial number of this provisional application contains a typographical error; the provisional application presumably intended in the priority claim was actually 60/246,436.

60/222,777, filed 3 August 2000; and

60/205,178, filed 17 May 2000.

As a continuation-in-part, the '278 patent is entitled to a priority date earlier than the actual filing date of the '272 application only for those claims that are fully supported by the earlier cited applications.

The Office notes that each of the independent claims of the '278 patent includes several features that were not disclosed in the earlier cited applications, including the fact that the tracking unit and its components are *multi-vehicle compatible*, that the vehicle includes a *vehicle data bus* that extends throughout the vehicle to facilitate communication between the controller and *at least one vehicle device* using at least one corresponding *vehicle device code*, and that the tracking unit includes *a downloading interface* for permitting *downloading of enabling data* related to the at least one corresponding vehicle device code.

Since each of the independent claims of the '278 patent includes subject matter not supported by its parent application, the patent is entitled only to a priority date of 3 July 2007, the actual application date of the '272 application.

Because the effective filing date of the '272 application is presumed to be *not* on or after March 16, 2013, the AIA First Inventor to File ("AIA-FITF") provisions do not apply. Instead, the earlier 'First to Invent' provisions will apply.

In the event the determination of the status of the '366 application as subject to AIA 35 U.S.C. §§ 102 and 103 (or as subject to pre-AIA 35 U.S.C. §§ 102 and 103) is incorrect, any correction of the statutory basis for the rejection will not be considered a new ground of rejection if the prior art relied upon, and the rationale supporting the rejection, would be the same under either status.

Claim Construction

During reexamination, claims are given the broadest reasonable interpretation consistent with the specification and limitations in the specification are not read into the claims (*In re Yamamoto*, 740 F.2d 1569, 222 USPQ 934 (Fed. Cir. 1984)).

Upon review of the original specification and prosecution history, the examiner has found no instance of lexicographic definitions, either express or implied, that are inconsistent with the ordinary and customary meaning of the respective terms. Therefore, for the purposes of claim interpretation, the examiner concludes that there are no claim terms for which Patent Owner is acting as their own lexicographer. See MPEP § 2111.01(IV).

The Office notes that there were several claim terms construed by the Patent Trial and Appeal Board (PTAB) in a decision[2] on appeal in the **Second Reexamination**. In the Decision, the PTAB also considered the construction of claim terms ordered in related District Court litigation[3] involving several patents by inventor Kenneth E. Flick, including the '278 patent.

The construed claim terms are as follows:

Multi-Vehicle Compatible Controller, construed as "electronic circuitry that performs one or more control functions, and can operate with more than one vehicle."

Different Vehicles, construed as "vehicles from different manufacturers, different models, or different trim levels of the same make or model, but having different electronics."

Enabling Data, construed as "data related to the at least one corresponding vehicle device code for use by said multi-vehicle compatible controller, and which enables the controller to use a *particular* vehicle device code from among plural such codes for different vehicles by providing either (1) the code itself to the controller, or (2) data that otherwise enables the controller to select or generate the code."

[2] Reexamination Proceeding 90/013,851, Decision on Appeal, 13 November 2018.
[3] *Omega Patents, LLC v. CalAmp Corp.*, No. 6:13-cv-1950-Orl-40DAB (M.D. Fla.), Claim Construction Order, 20 February 2015.

The Court's construction of these claim terms is consistent with the broadest reasonable interpretation and is adopted for the purposes of the instant reexamination proceeding.

The Office also notes that the PTAB construed the claimed Vehicle Device Codes as "signal from a vehicle device". However, in light of the disclosure at col. 23, line 67 through col. 24, line 3, that "[t]he corresponding vehicle [device] code may be for reading from the vehicle device **121**. Similarly, the corresponding vehicle [device] code may be additionally or alternatively for writing to the vehicle device **121**", for the purposes of the instant reexamination proceeding, the term Vehicle Device Codes will be construed as "signal *to or* from a vehicle device."

Additionally, upon review of the pending claims, the examiner finds no instances where the claim term explicitly includes functional language which would invoke 35 U.S.C. § 112(f).

The Claimed Invention

Independent Claim 1 is directed to a multi-vehicle compatible tracking unit for a vehicle comprising a vehicle data bus extending throughout the vehicle. The multi-vehicle compatible tracking unit may comprise a vehicle position determining device, a

wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles. The multi-vehicle compatible tracking unit may comprise a downloading interface for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller.

Independent Claims 13 and 18 are directed to multivehicle compatible tracking units similar to that of Claim 1, but further recite the downloading interface comprising a connector for temporary connection to a downloading device and a wireless receiver for temporary connection to a downloading device, respectively.

Patent Owner's Statement

The Patent Owner's Statement included a number of arguments. Among them, the Patent Owner argued that in view of Secondary Considerations, claims 1-22 are confirmable over the prior art cited in the Request. The Patent Owner cited the PTAB's decisions reversing the examiner's obviousness claim rejections in the **Second**

Reexamination and the **Fifth Reexamination**, based upon evidence of Secondary Considerations made of record in the respective reexamination proceedings.

These arguments are persuasive.

Information Disclosure Statement

Applicants' Information Disclosure Statement (IDS), filed 5 October 2023, has been received and entered into the record. Since the IDS complies with the provisions of MPEP § 2280, the references cited therein have been considered by the examiner.

The examiner notes that Patent Application Publication document number 2, indicated as PgPub 20030182003, should actually be PgPub 20030182033. The document number, as well as the name of the Applicant, have been corrected.

See attached form PTO-1449.

With respect to the Information Disclosure Statement considered with this action, the information cited has been considered as described in the MPEP. Note that MPEP §§ 2256 and 2656 indicate that the degree of consideration to be given to such information will be normally limited by the degree to which the party filing the information citation has explained the content and relevance of the information. Information that does not appear to be "patents or printed publications" as identified in 35 U.S.C. 301 have been considered to the same extent.

Allowable Subject Matter

Claims 1-22 are confirmed.

STATEMENT OF REASONS FOR PATENTABILITY AND/OR CONFIRMATION

The following is an examiner's statement of reasons for patentability and/or confirmation of the claims found patentable in this reexamination proceeding:

Regarding claims 1-22, the prior art of record fails to render the claims obvious in light of secondary considerations, for the reasons set forth in the **Fifth Reexamination** by the PTAB in the Decision on Appeal mailed 1 December 2022.

Any comments considered necessary by PATENT OWNER regarding the above statement must be submitted promptly to avoid processing delays. Such submission by the patent owner should be labeled: "Comments on Statement of Reasons for Patentability and/or Confirmation" and will be placed in the reexamination file.

Conclusion

The Patent Owner is reminded of the continuing responsibility under 37 CFR 1.565(a), to apprise the Office of any litigation activity, or other prior or concurrent proceeding, involving U.S. Patent No. 8,032,278 throughout the course of this reexamination proceeding. The third party requester is also reminded of the ability to similarly apprise the Office of any such activity or proceeding throughout the course of this reexamination proceeding. See MPEP §§ 2207, 2282 and 2286.

The Patent Owner is reminded that any proposed amendment to the specification and/or claims in the reexamination proceeding must comply with the provisions of 37 C.F.R. § 1.530(d)-(j), must be formally presented pursuant to 37 C.F.R. § 1.52(a) and (b), and must include any fees required by 37 C.F.R. § 1.20(c). See MPEP § 2250(IV) for examples to assist in the preparation of proper amendments in reexamination proceedings.

Any document filed by the Patent Owner must be served on the third party requester (or requesters in a merged proceeding) in the reexamination proceeding in the manner provided by 37 C.F.R. § 1.248. See 37 C.F.R. § 1.550(f) and MPEP § 2266.03.

All correspondence relating to this *ex parte* reexamination proceeding should be directed:

By Patent Center:	Patent Center (patentcenter.uspto.gov) has 100% of the functionality of EFS-Web, Public and Private PAIR, and is available to all users for electronic filing and management of patent applications. For more information, please visit the Patent Center information page at uspto.gov/patents/apply/patent-center.
By Mail to:	Mail Stop *Ex Parte* Reexam Central Reexamination Unit Commissioner for Patents United States Patent & Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450
By FAX to:	(571) 273-9900 Central Reexamination Unit
By hand:	Customer Service Window Randolph Building 401 Dulany Street Alexandria, VA 22314

Any inquiry concerning this communication should be directed to the Central Reexamination Unit at telephone number 571-272-7705.

/LUKE S WASSUM/
Primary Examiner, Art Unit 3992

Conferees:

/Stephen J. Ralis/
Primary Examiner, Art Unit 3992

/Michael Fuelling/
Supervisory Patent Examiner
Art Unit 3992

lsw
12 January 2024

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

CPC - Searched*		
Symbol	Date	Examiner

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
Reviewed prosecution history of US Pat No 8,032,278	01/07/2020	cmt
Reviewed related ex parte reexaminations: 90013587, 90013851, 90014309	01/08/2020	cmt
Reviewed prosecution history of appn 11/773,272	12/12/2023	lsw
Reviewed prosecution history of appns 90/013,587; 90/013,851; 90/014,309; 90/014,675	12/12/2023	lsw
Updated Litigation Search	12/04/2023	lsw
Patent Data Portal (PDP) for continuity data	12/12/2023	lsw
P-TACTS for AIA proceedings	12/12/2023	lsw
Reviewed IPR2023-00504	12/12/2023	lsw
Reviewed IPR2023-01162	12/12/2023	lsw

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	90/014,419	8032278
	Examiner	Art Unit
	Luke S Wassum	3992

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
www.uspto.gov

ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
90/014,419	**01/23/2024 12:03:41 PM Z ET**	**CAAMP-001X**

Title of Invention

Vehicle Tracking Unit with Downloadable Codes and Associated Methods

Application Information

APPLICATION TYPE	Utility / ex parte reexam	PATENT #	8032278
CONFIRMATION #	8770	FILED BY	Sheryl Scheibe
PATENT CENTER #	64050330	FILING DATE	12/16/2019
CUSTOMER #	27975	FIRST NAMED INVENTOR	- 8032278
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Jack Abid

Documents

TOTAL DOCUMENTS: 1

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
INTERVIEW SUMMARY.pdf	4	Reexam Miscellaneous Incoming Letter	103 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
INTERVIEW SUMMARY.pdf	0EE87EB68F755C0C7605CF2C929BB34912405C3C37CF06D99 DF9CC6618616CCA21D21A7137C51FCC419FD013C554FE7E1 8F87748476BF1C5BA1922C97F484795

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as

described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of: **KENNETH FLICK**	)	
Serial No. **90/014,419**	)	Examiner: **L. WASSUM**
Confirmation No. **8770**	)	Art Unit: **3992**
Filing Date: **12/16/2019**	)	Attorney Docket No. **CAAMP-001X (0058106CIP1_REX4)**
For: **VEHICLE TRACKING UNIT WITH DOWNLOADABLE CODES AND ASSOCIATED METHODS**	)	

INTERVIEW SUMMARY FOR TELEPHONIC INTERVIEW OF JANUARY 11, 2024

EFILE

Commissioner for Patents

The Patent Owner thanks the U.S. Patent and Trademark Office and the Examiner for extending all courtesies to the Patent Owner's Representative during the telephonic interview of January 11, 2024.

During the telephonic interview, Examiner Luke Wasssum was present on behalf of the U.S. Patent and Trademark Office, and Attorney Jack G. Abid (Reg. No. 58,237) was present on behalf of the Patent Owner.

The Patent Owner noted that in the Information Disclosure Statement filed on October 5, 2023, U.S. Patent Application Publication No. 20030182003 to Takashima was cited in error and should have been U.S. Patent Application Publication No. 20030182033 to Underdahl et al. In particular,

the Patent Owner noted that the error was sourced from the related petition for *Inter Partes* review, Case No. IPR2023-001162.

The Examiner agreed to fully consider the correct prior art reference, U.S. Patent Application Publication No. 20030182033A1 to Underdahl et al., and take appropriate action thereafter.

Respectfully submitted,

/JACK G. ABID/

_____
JACK GEORGE ABID
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In re Patent Application of:
Kenneth E. FLICK
Reexamination Control No. **90/014,419**
Filed: **12/16/2019**
_____/

US008032278C5

(12) EX PARTE REEXAMINATION CERTIFICATE (12512th)
United States Patent
Flick

(10) Number: US 8,032,278 C5
(45) Certificate Issued: Feb. 7, 2024

(54) **VEHICLE TRACKING UNIT WITH DOWNLOADABLE CODES AND ASSOCIATED METHODS**

(75) Inventor: **Kenneth E. Flick**, Douglasville, GA (US)

(73) Assignee: **OMEGA PATENTS, L.L.C.**, Douglasville, GA (US)

Reexamination Request:
No. 90/014,419, Dec. 16, 2019

Reexamination Certificate for:
Patent No.: **8,032,278**
Issued: **Oct. 4, 2011**
Appl. No.: **11/773,272**
Filed: **Jul. 3, 2007**

Reexamination Certificate C1 8,032,278 issued Dec. 28, 2016

Reexamination Certificate C2 8,032,278 issued Feb. 6, 2019

Reexamination Certificate C3 8,032,278 issued Jan. 8, 2020

Reexamination Certificate C4 8,032,278 issued May 17, 2023

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/076,259, filed on Mar. 9, 2005, now Pat. No. 7,720,597, which is a continuation of application No. 10/383,496, filed on Mar. 7, 2003, now Pat. No. 7,149,623, which is a continuation of application No. 09/859,972, filed on May 17, 2001, now Pat. No. 6,606,561.
(Continued)

(51) **Int. Cl.**

G01C 21/00	(2006.01)
B60R 25/04	(2013.01)
B60R 25/045	(2013.01)
B60R 25/102	(2013.01)
B60R 25/104	(2013.01)
B60R 25/33	(2013.01)
G07C 5/00	(2006.01)
G08G 1/00	(2006.01)
G08G 1/127	(2006.01)

(52) **U.S. Cl.**
CPC ***B60R 25/33*** (2013.01); ***B60R 25/04*** (2013.01); ***B60R 25/045*** (2013.01); ***B60R 25/102*** (2013.01); ***B60R 25/104*** (2013.01); ***G07C 5/008*** (2013.01); ***G08G 1/127*** (2013.01); ***G08G 1/20*** (2013.01); ***G08G 1/205*** (2013.01); *B60R 2325/202* (2013.01); *B60R 2325/205* (2013.01); *B60W 2556/50* (2020.02)

(58) **Field of Classification Search**
None
See application file for complete search history.

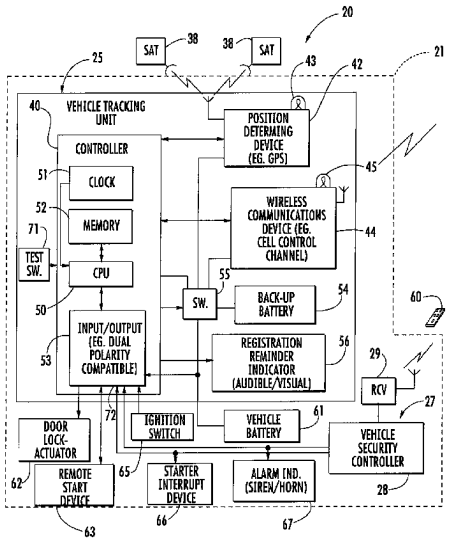
(56) **References Cited**

To view the complete listing of prior art documents cited during the proceeding for Reexamination Control Number 90/014,419, please refer to the USPTO's Patent Electronic System.

Primary Examiner — Luke S Wassum

(57) **ABSTRACT**

A multi-vehicle compatible tracking unit is for a vehicle including a vehicle data bus extending throughout the vehicle. The vehicle tracking unit may include a vehicle position determining device, a wireless communications device, and a multi-vehicle compatible controller for cooperating with the vehicle position determining device and the wireless communications device to send vehicle position information. The multi-vehicle compatible controller may be coupled to the vehicle data bus for communication thereover with at least one vehicle device using at least one corresponding vehicle device code from among a plurality thereof for different vehicles. A downloading interface may be included for permitting downloading of enabling data related to the at least one corresponding vehicle device code for use by the multi-vehicle compatible controller.



Related U.S. Application Data

(60) Provisional application No. 60/264,811, filed on Jan. 29, 2001, provisional application No. 60/258,005, filed on Dec. 22, 2000, provisional application No. 60/251,552, filed on Dec. 6, 2000, provisional application No. 60/252,125, filed on Nov. 20, 2000, provisional application No. 60/246,463, filed on Nov. 7, 2000, provisional application No. 60/236,890, filed on Sep. 29, 2000, provisional application No. 60/222,777, filed on Aug. 3, 2000, provisional application No. 60/205,178, filed on May 17, 2000.

EX PARTE REEXAMINATION CERTIFICATE

NO AMENDMENTS HAVE BEEN MADE TO THE PATENT

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1-22** is confirmed.

* * * * *

In re Patent Application of:
Kenneth E. FLICK
Reexamination Control No. **90/014,419**
Filed: **12/16/2019**
_____/

CERTIFICATE OF SERVICE

Certificate of Service in compliance with 37 C.F.R. §1.530(c)

Pursuant to 37 C.F.R. §§1.530(c), 1.248, I hereby certify that on January 23, 2024, a complete copy of this Patent Owner's Statement is being served via First Class U.S. Mail upon Third Party Requester at the correspondence address as shown in PAIR:

Mark B. Garred
STETINA BRUNDA GARRED & BRUCKER
75 Enterprise, Suite 250
Aliso Viejo, California 92656

Respectfully submitted,

/JACK ABID/

_____
Jack G. Abid