Table 9.1 2.4 GHz Channel Assignment

Channel ID	Center frequency	High-density channel set (802.11b does not coexist)	802.11b coexistence channel set
1	2.412 GHz	X	X
2	2.428 GHz	X	
3	2.437 GHz		X
4	2.445 GHz	X	
5	2.461 GHz	X	X

The DEVs can discover information about the services and capabilities of other DEVs in the piconet. This information can be collected in several ways: the PNC information request command, the probe command, and the piconet services information element within the beacon. In addition, the PNC can ask a DEV in its piconet to evaluate the wireless media conditions either in the current channel or in an alternate channel using the remote scan request command. A DEV can ask another DEV in the piconet about the status of the current channel using the channel status request command. The PNC information request command is used to obtain information from the PNC about either a specific DEV or all of the DEVs in the piconet. The PNC reply includes the ID and address of the DEV, its supported data rates, an indication whether this DEV is PNC capable, an indication whether it is a PNC of another piconet, and other information.

The PHY supports various data rates corresponding to the modulation and coding used such as 11 Mbps (QPSK[Quadrature Phase Shift Keying]-TCM), 22 Mbps (QPSK), and 33, 44, 55 (16-32-64 QAM-TCM, respectively).

Recently, IEEE 802.15.3 established the 802.15.3a study group with the charter to investigate alternate PHY to support very high data rate applications (more than 100 Mbps). Examples of such applications are: 1394a/USB 2.0 high-speed cable replacement, high-density DVD, high-resolution printer and scanner, and digital camera. Ultra Wide Band (UWB) is a potential PHY candidate for such very high data rate applications.

9.4 IEEE 802.15.3 Media Access Control

IEEE 802.15.3 MAC includes several functions. In this subsection we will describe only some key mechanisms such the channel access and the creation of a piconet.

9.4.1 Channel Definition and Channel Access

The MAC is based on a time-slotted superframe structure that consists of three periods: Beacon, Contention Access Period (CAP), and Contention-Free Period (CFP) (see Figure 9.5). Within a CFP, there are two types of time slots: *management time slot (MTS)* reserved for command exchange between PNC and DEVs, and *guaranteed time slot (GTS)* reserved for data exchange among DEVs. The length of each period or time slot is determined by the PNC via beacons. At the beginning of each superframe, the PNC broadcasts beacons to specify the control, resource allocation, and time synchronization to the entire piconet.

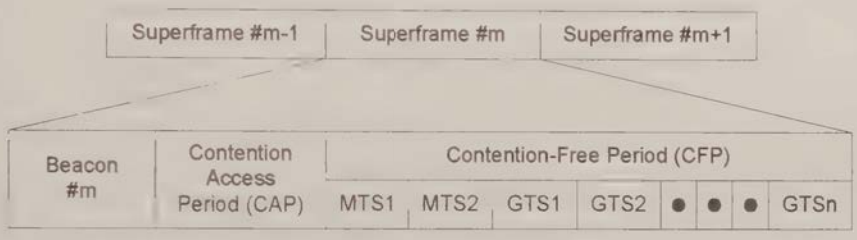


Figure 9.5 Superframe Structure

9.4.1.1 Contention Access Period (CAP)

In the CAP, contention is allowed via the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism. The DEVs can send small amounts of pending data without requesting reserved time slots. Because of the unpredictable channel access delay of the contention scheme, CAP is suitable for asynchronous data traffic such as file transfer, MP3 download files, etc. Moreover, CAP can be used for command exchange between the PNC and the DEVs. CAP starts after the end of beacon and terminates at a time specified by piconet synchronization parameters information element in a beacon. Figure 9.6 shows the CAP within the superframe.

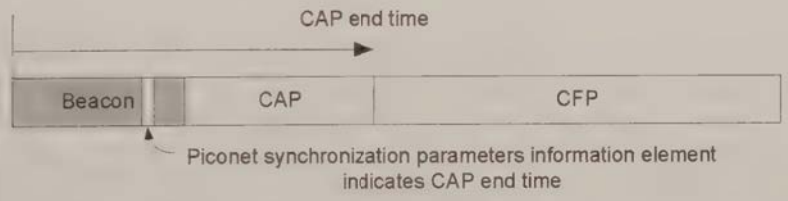


Figure 9.6 CAP Structure in the Superframe

The draft standard defines two interframe spacings (IFSs) used in CSMA/CA mechanism: *short interframe space (SIFS)* and *retransmission interframe space (RIFS)* with RIFS = SIFS + aBackoffSlot. Both SIFS and aBackoffSlot duration are PHY dependent. The CSMA/CA mechanism

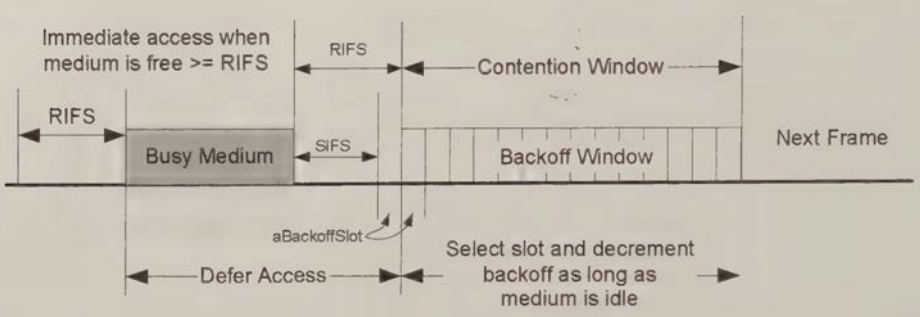


Figure 9.7 CSMA/CA in CAP

and backoff procedure are similar to the IEEE 802.11 MAC introduced in Chapter 4 except for the different IFSs (i.e., RIFS is analogous to DIFS in IEEE 802.11). Figure 9.7 shows the CSMA/CA mechanism in CAP.

A DEV transmits a data packet after it senses the channel idle for a time duration equal to RIFS. Acknowledgment packets are transmitted immediately after SIFS time. When a collision occurs (i.e., multiple DEVs transmit packets at the same time), the exponential backoff algorithm (i.e., doubling the contention window) is applied.

9.4.1.2 Contention-Free Period (CFP)

The CFP is based on time division multiple access (TDMA) in which the PNC guarantees the starting time and reserved duration of time slots for traffic streams that require certain amounts of bandwidth. Time slot allocation is specified by the *channel time allocation (CTA)* information element (IE) in a beacon. As shown in Figure 9.8, the CTA information element includes source and destination addresses of the DEVs that transmit and receive the traffic stream, the stream index that identifies the traffic stream, and the starting time and duration of the reserved time slots (MTS or GTS).

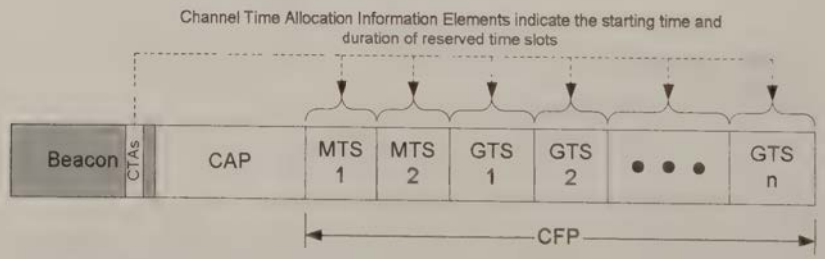


Figure 9.8 Channel Time Allocation (CTA)

Since the bandwidth is allocated using a TDMA scheme, the channel is fully controlled by the PNC and can provide QoS support. Therefore, CFP is suitable for isochronous data traffic such as video streaming, audio streaming, and video/audio broadcast. We will discuss QoS aspects in

Section 9.5. As mentioned earlier, CFP includes two types of time slots: MTS and GTS. MTS is used for command exchange while GTS is used for data exchange. GTS can accommodate not only isochronous data traffic but also asynchronous data traffic. However, the ways to request and allocate time slots are slightly different between the two types of slots.

The PNC allocates time slots through the CTA mechanism. A source DEV, which has pending data traffic and is seeking reserved time slots for transmitting the data, first sends the *channel time request (CTR) command* to the PNC to indicate the recurring duration and the number of required time slots. For isochronous data traffic, the CTR command contains 1) the number of time slots needed (i.e., the number of time slots per superframe) and 2) the duration of each time slot (i.e., the minimum duration and desired duration). If there are available resources or time slots to accommodate the new request, the PNC allocates GTSs to the requesting DEV by including them in the CTA information element. On the other hand, for asynchronous data traffic, the CTR command contains the total amount of time needed to transmit the data instead of the recurring channel time. The PNC will schedule such time based on the channel availability. The source DEV, destination DEV, and PNC are all allowed to terminate the data connection whenever they want for both isochronous and asynchronous data traffic.

Each GTS is actually one time slot reserved for a specific DEV. This DEV may or may not make use of all the allocated time slots. Each DEV is responsible for determining how to use its reserved slot—that is, it can determine what command, stream, and asynchronous data will be transmitted.

There are two types of GTSs: dynamic GTS and pseudostatic GTS (see Figure 9.9). The type of GTS is also indicated in the CTR command. The PNC may dynamically change the location of the dynamic GTSs within the superframe, on a superframe-by-superframe basis. This provides a tool for the PNC to reassign GTS locations to optimize channel utilization. Pseudostatic GTSs, which are allocated only for isochronous data traffic, have fixed location (referenced to the beginning of the beacon) within the CTA. The channel time location of the pseudostatic GTS can be changed (but less frequently than dynamic GTS) to optimize the channel utilization. To carry out this change, the PNC has to go through a series of processes to notify the involved DEVs (both transmitting and receiving DEVs). The PNC notifies the DEVs by sending a special command (probe command) with the new location. After all involved DEVs have been confirmed, the new CTA is included in the beacon.

Management Time Slots (MTSs) are identical to GTSs. MTSs are used for exchanging commands between the PNC and the DEVs. There are two ways to deploy MTSs: an MTS for the command service of an individual DEV or an MTS for command service of multiple DEVs. In the latter case, the MTS is denoted as open MTS in which any DEV can transmit the command messages. The PNC determines the number of MTSs per superframe. Since multiple DEVs can send command messages in the same MTS, collisions can occur. Therefore, in open

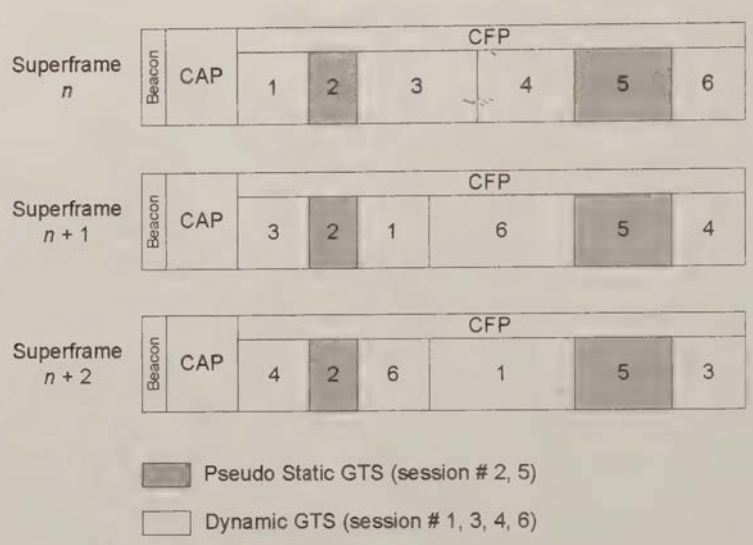


Figure 9.9 Dynamic GTS and Pseudostatic GTS

MTS the slotted Aloha protocol is used for channel access and contention resolution. Each DEV maintains its own contention window (CW) and a counter. The contention window is based on the number of retransmission attempts of a DEV. The contention window is defined as follows:

$$CW = \begin{cases} 256 & for\ 2^{a+1} \geq 256 \\ 2^{a+1} & for\ 2^{a+1} \leq 256 \end{cases}$$

$$where \quad a = number\ of\ retransmission\ attempts$$

Each DEV assigns the counter value by randomly selecting an integer in the interval [1,CW]. The DEV counts down in each open MTS continuously across superframes. When the counter reaches 1, the DEV will transmit the command message in the current open MTS as shown in Figure 9.10. An acknowledgment (ACK) is required to indicate the success of the command transmission. An open MTS that is used for the association process is called association MTS.

9.4.2 Starting a Piconet

The creation of a piconet begins with a DEV that is capable of being a PNC. This DEV scans the channel and selects the channel that has the least interference and is not being used by other piconets. If the channel is available, the DEV becomes a PNC and starts sending beacons. Thus a piconet is established. If no channels are available, the DEV can try to establish a child or neighbor piconet instead.

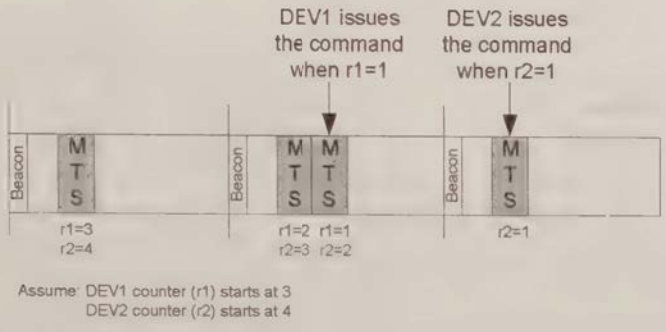


Figure 9.10 MTS Channel Access

9.4.2.1 Creating a Child Piconet

A PNC capable DEV establishes a child piconet to extend the coverage area of the existing piconet, which eventually becomes the parent piconet. The DEV sends the channel request command to the parent's PNC to request the special GTS (called private GTS) for the child piconet. If a time slot is available, the parent's PNC will assign a private GTS to the child piconet. The DEV becomes the child's PNC and starts transmitting beacons. All communication of the child piconet takes place within the assigned private GTS as shown in Figure 9.11. Because the child's PNC is also a member of the parent piconet, the parent's PNC may allocate GTS of the parent piconet (which is also in unassigned GTS duration of the child piconet) to the child's PNC to enable interpiconet communication between the child's PNC and any DEVs (including a PNC) of the parent's piconet.

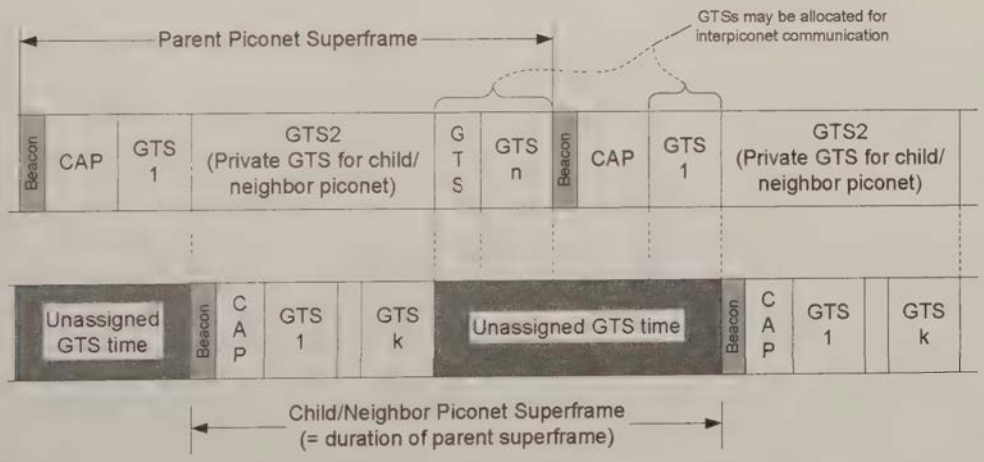


Figure 9.11 Parent Piconet and Child/Neighbor Piconet Superframe Relationship

9.4.2.2 Creating a Neighbor Piconet

If no channels are available during the piconet creation procedure, a PNC capable DEV can establish a neighbor piconet on the existing piconet, which eventually becomes the parent piconet. First the DEV sends an association request to the parent's PNC. If the neighbor association request is accepted, the DEV sends the channel request command to the parent's PNC to request private GTS for the neighbor piconet. Then the parent's PNC will assign a private GTS to the neighbor piconet. The DEV becomes the neighbor's PNC and starts transmitting beacons. The superframe relationship between the parent piconet and the neighbor piconet is the same as the relationship between the parent piconet and the child piconet as shown in Figure 9.11. Even though the neighbor's PNC is not a member of the parent piconet, the parent's PNC may allocate GTSs of the parent piconet (which is also in unassigned GTS duration of the neighbor piconet). This enables the neighbor's PNC to have limited communication between the neighbor's PNC and the parent's PNC such as association requests, disassociation requests, channel time request (CTR), and authentication requests.

9.5 IEEE 802.15.3 QoS Support

IEEE 802.15.3 aims to support both asynchronous and isochronous data services. The draft standard defines some QoS mechanisms to facilitate those services. IEEE 802.15.3 MAC focuses on channel access mechanisms. It leaves QoS negotiation and traffic handling to the upper protocol layers. As we know, isochronous data is time sensitive and requires certain bandwidth and delay commitment. As described in the previous section, IEEE 802.15.3 MAC has two modes of operation: Contention Access Period (CAP) and Contention-Free Period (CFP).

9.5.1 QoS in Contention Access Period

A DEV with pending data is not required to establish any connection or request any resource. A DEV accesses the channel and competes for bandwidth with other DEVs using the CSMA/CA mechanism. Therefore, CAP does not provide any service assurance—that is, it offers best effort service. CAP is suitable for asynchronous data services.

9.5.2 QoS in Contention-Free Period

Using TDMA, the PNC has full control over the channel by allowing a DEV to access the channel in a specific time for a specific duration. CFP provides certain QoS assurances in terms of bandwidth and delay. It aims to support high-bandwidth asynchronous data and isochronous data. A priori to transmission, a connection needs to be established between the DEV and the PNC. Such a connection is established by sending the PNC a channel time request (CTR) command. In case there are available resources, the PNC allocates GTSs. The connection establishment process is shown in Figure 9.12.

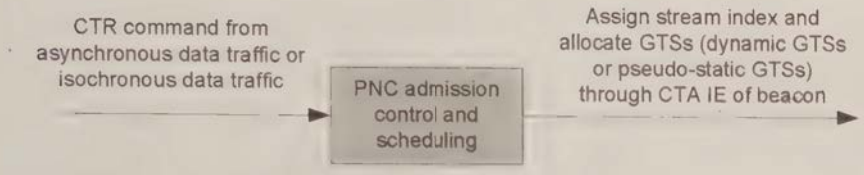


Figure 9.12 Connection Establishment Process

In establishing isochronous connections, the DEV must first determine the bandwidth and delay requirements of its isochronous connection in terms of the following parameters: the required number of time slots (GTSs) per superframe, the minimum and desired duration of each time slot, priority (based on eight priority values of IEEE 802.1p traffic types, see Table 9.2, and the desired GTS type (i.e., dynamic GTS or pseudostatic GTS). These parameters are included in the CTR command. The mapping process between the QoS requirements of an isochronous connection and the CTR parameters is the task of each DEV and it is not specified by the draft standard. The PNC admits and allocates GTSs based on the CTR information.

Table 9.2 IEEE 802.1p Priorities and Traffic Types

User priority	Traffic type	Used for	Comments
0 (default)	Best effort (BE)	Asynchronous data	Default piconet traffic
1	Background (BK)	Asynchronous data	
2	-	A spare	Currently not assigned
3	Excellent effort (EE)	Isochronous data	For valued customer
4	Controlled load (CL)	Isochronous data	
5	Video (VI)	Isochronous data	< 100 ms delay and jitter
6	Video (VO)	Isochronous data	< 10 ms delay and jitter
7	Network control (NC)		

In establishing asynchronous connections, the parameters included in the CTR command are slightly different from those in the isochronous connections. The DEV requests the total amount of time for the connection (i.e., total file transfer time) and the priority.

After receiving the CTR command, the PNC performs admission control to check if there are available resources. When there are available resources, the PNC allocates GTSs to the requesting DEV. The admission control and scheduling algorithms are not specified in the draft standard.

9.5.2.1 Classification

The draft standard specifies the stream index used to identify the connection or traffic stream (see Figure 9.13). The stream index is assigned by the PNC during the connection establishment procedure. There are two reserved stream indices: 0x00 for unassigned streams and 0xFE for all asynchronous streams. A stream index, except these two reserved stream indices, is uniquely assigned for each isochronous stream in the piconet. The classification process uses the stream index to identify the traffic and forward it to the appropriate queue. Due to the fact that there is only a single stream index for asynchronous streams, multiple asynchronous connections within a DEV will be aggregated to a single queue and wait for scheduling. Therefore, there is no service differentiation among asynchronous connections residing in the same DEV. On the other hand, each isochronous stream is assigned a unique stream index. This enables per-flow classification.

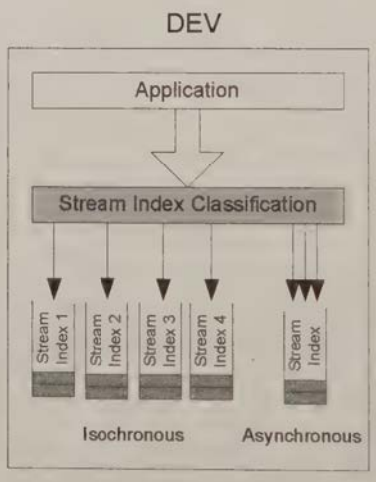


Figure 9.13 Classification

In summary, the TDMA channel access scheme combined with flow classification will enable a certain level of QoS support for isochronous traffic streams. However, there are a number of QoS mechanisms (i.e., admission control, packet scheduling) which are still undefined. The network designer may implement per-flow QoS solutions for which the standard defines some necessary QoS mechanisms such as per-flow (stream index) classification, CTA IE, and CTR command. The draft standard also provides optional priority which may be used to implement differential services. Figure 9.14 shows the simplified diagram of the IEEE 802.15.3 QoS architecture.

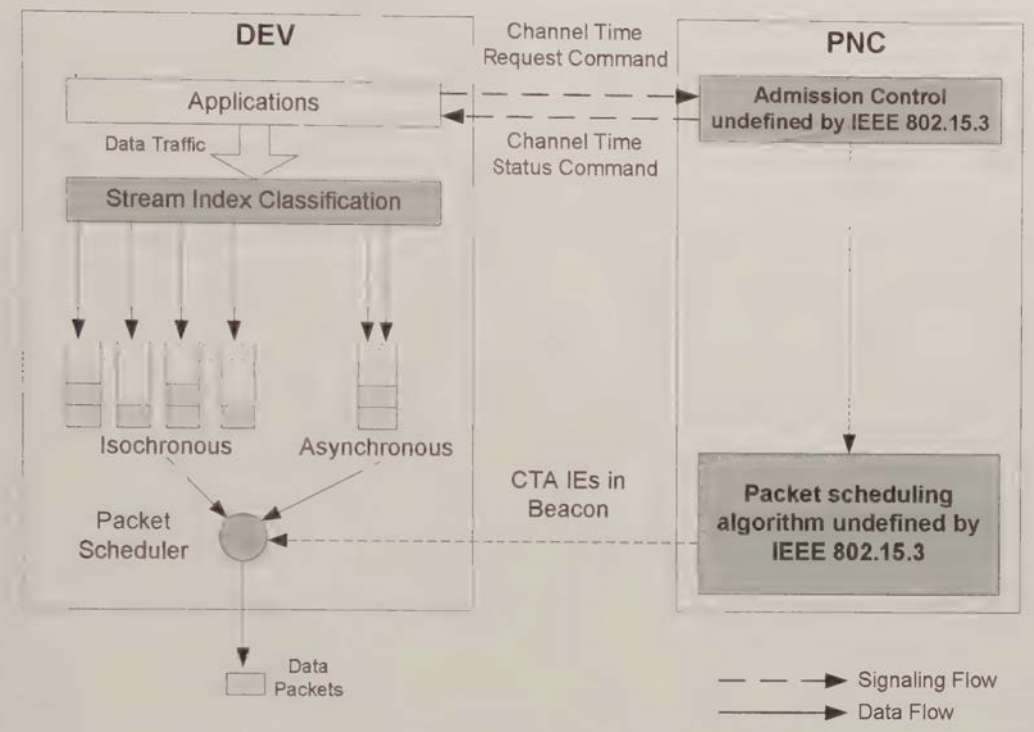


Figure 9.14 IEEE 802.15.3 QoS Architecture

9.6 IEEE 802.15.4

The IEEE 802.15.4 focuses on the development of a standard that details the wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for a Low-Rate Wireless Personal Area Network (LR-WPAN). The goal is to introduce a low-rate WPAN that is simple and low-cost that supports wireless network connectivity in applications that require minimal throughput as well as low power consumption. In this section we present some of the discussions and proposals in the group regarding the future standard. However, the future standard may be completely different.

The group may also address location tracking capabilities that can be applied within smart tags and badges. Other applications of the IEEE 802.15.4 standard may include personal networks, home networks, automotive networks, industrial networks, interactive toys, remote sensing, and cable replacement for the last meter connectivity. Sensor networks may include hundreds or thousands of wireless sensors. Examples of sensor networks include wearable personal health monitoring devices, home automation networks, and industrial control networks.

9.6.1 IEEE 802.15.4 Architecture

9.6.1.1 Network Topology

LR-WPAN consists of two or more interconnected devices (DEVs) that form a personal area network, which sometimes is called a personal operating space (POS). In the draft standard, the DEVs are categorized into two types: a Full Function Device (FFD) and a Reduced Function Device (RFD). The FFD can serve either as a network coordinator or as a simple network node. A network node (which typically runs the applications) operates as either a source or a destination of data traffic, whereas the network coordinator not only has the network node's functionality but also has the ability to route the data traffic, to control the channel access of other devices, and to provide basic timing within the POS. An FFD can communicate with other RFDs or FFDs and can control the network if it operates as a network coordinator. An RFD can only be a network node and can communicate only with a network coordinator (there is no direct connection between RFDs). The RFD is geared for devices that are extremely simple and do not need to send large amounts of data. Examples of such devices are light switches, actuators, smart badges, and passive infrared sensors. DEVs can be organized in three network topologies: star topology, peer-to-peer topology, and cluster tree topology (see Figures 9.15 and 9.16). FFDs can be part of any topology; however RFDs are limited to a star topology.

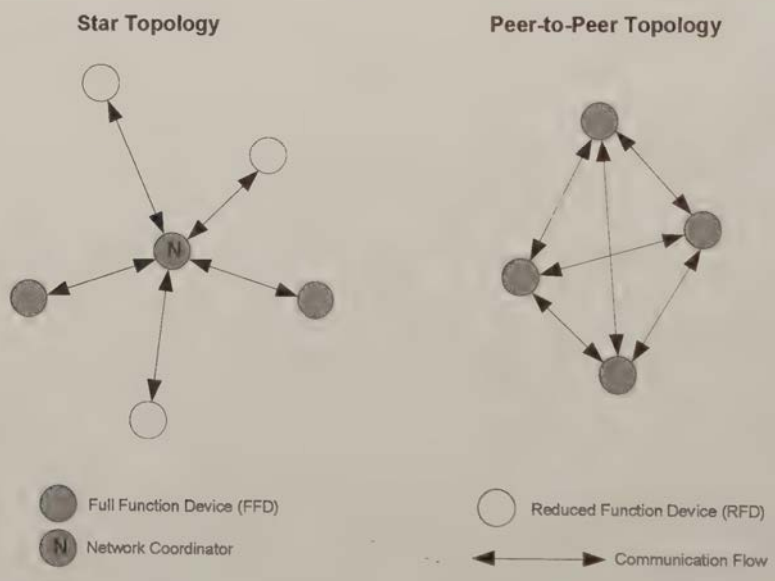


Figure 9.15 Star and Peer-to-Peer Topologies

In a star topology data may be exchanged only between the network coordinator and the DEVs or network nodes (no direct communication between DEVs). There are two types of communication: uplink, from the DEVs to the network coordinator; and downlink, from the network coordinator to the DEVs.

In a peer-to-peer topology, each DEV can communicate with others within its radio range. There is no network coordinator. However, a DEV can become such a coordinator if it is the first device to communicate on the channel. A basic peer-to-peer network can be formed when a new DEV searches for another DEV with which it can communicate. If no such DEVs are found, the new DEV can become the network coordinator and wait for other DEVs to join.

A more complex topology that can be constructed out of the peer-to-peer topology is a cluster tree topology (Figure 9.16). In the figure, the circle area represents a cluster. Multiple clusters interconnect with each other, forming a multi-cluster network. Each cluster contains network nodes and a network node designated to be a cluster head (CH). A cluster head controls its cluster. All network nodes in a cluster are only FFDs (there are no RFDs in a cluster tree network). The cluster head of the first established cluster is called a designated device (DD). Therefore, the entire multi-cluster network will have only one DD. At the cluster formation phase, a DD forms the first cluster by assigning the cluster identifier zero and transmitting the beacon. A new network node that is not associated with any cluster receives the beacon and starts making the connection request to the cluster head (or DD in the case of the first cluster). The cluster head or DD will accept the new network node to become a member of the cluster. Several network nodes join the cluster and the cluster becomes bigger and bigger. The DD may promote a network node to be the cluster head and partition a big cluster into small clusters resulting in a multi-cluster network. A unique cluster ID (CID) is assigned to each cluster.

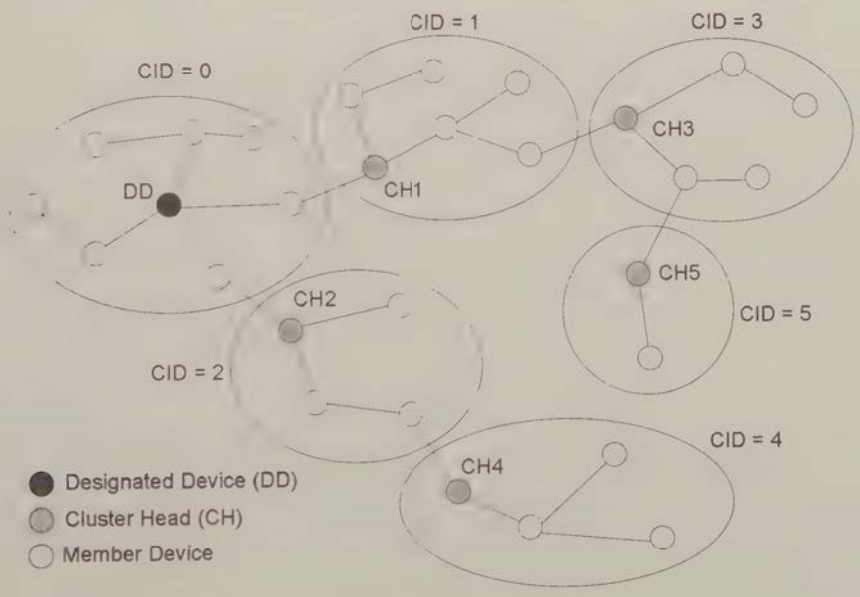


Figure 9.16 Cluster Tree Topology

9.6.1.2 Protocol Stack

The proposed standard is divided into the Link Layer Control (LLC), MAC, and its physical layer (PHY) (see Figure 9.17).

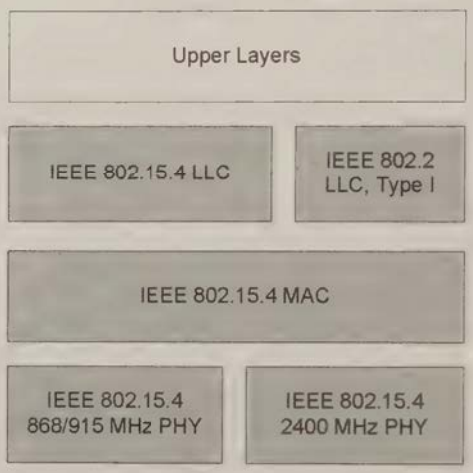


Figure 9.17 IEEE 802.15.4 Protocol Stack

9.7 IEEE 802.15.4 Physical Layer

The radio can operate at the following frequencies: the 868 MHz band (e.g., in Europe), the 915 MHz band (e.g., in the U.S.), and the 2.4 GHz band (worldwide) (Figure 9.18). At 868 MHz and 915 MHz, the transmission speed is 20 kbps using DSSS. 868 MHz band allows one channel while in the 915 MHz band there are 10 non-overlapping channels—that is, up to 10 networks can coexist in the same area. The 2.4 GHz band supports 250 kbps using DSSS, allowing 16 non-overlapping channels—that is, up to 16 networks can coexist in the same area.

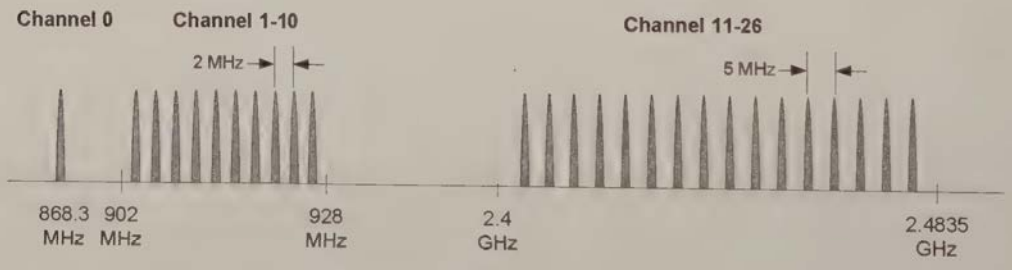


Figure 9.18 IEEE 802.15.4 Frequency Band

9.8 IEEE 802.15.4 Media Access Control

IEEE 802.15.4 focuses on low-cost, low power consumption devices. This focus constrains the MAC protocol design to be rather simple with adequate functionalities to support the low rate applications mentioned earlier. Sophisticated functions (i.e., QoS mechanisms) reside in the upper layers (above IEEE 802.15.4 MAC) which are not included in the draft standard. Several techniques are proposed to minimize the amount of overhead in maintaining the communication link. The packet structure is designed to be simple. IEEE 802.15.4 has three packet structures: beacon packet, data packet, and handshake packet (acknowledgment packet). Besides the beacon, there is no explicit message or command originated from the MAC layer that provides peer communication between the MAC layers of the two devices. The draft standard also defines several service primitives (i.e., primitives between the LLC and MAC sublayers and primitives between the MAC sublayer and the PHY) via the service access point (SAP) as shown in Figure 9.19. For more details on the concept of service primitives, please refer to IEEE 802.2. The MAC sublayer PAN information base (MAC PIB) is the MAC's database which maintains the network configuration. The peer communication between the MAC sublayers of the two devices takes place indirectly through the upper layers and the service primitives as shown in Figure 9.20.

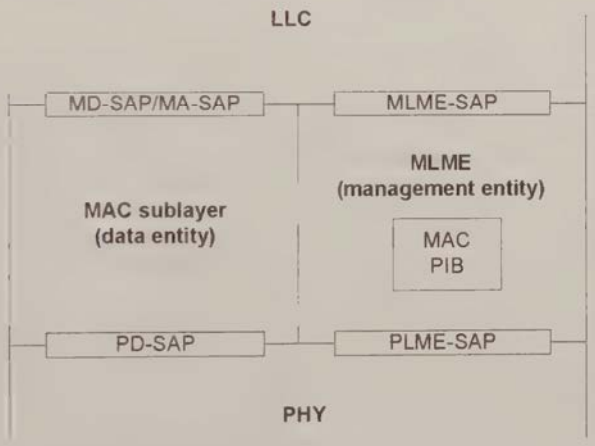


Figure 9.19 MAC Sublayer Reference Model

The proposed MAC utilizes either CSMA/CA or TDMA protocols, or a combination of both. As shown in Figure 9.21, the channel is organized into superframes. Each superframe starts with a network beacon, sent by the network coordinator. The superframe includes a beacon, a contention period, and guaranteed time slots (GTSs). The superframe duration varies depending on the active applications. If there are no low-latency applications, the superframe consists of only the beacon and the contention period. On the other hand, if there are low-latency applications, GTSs are present.

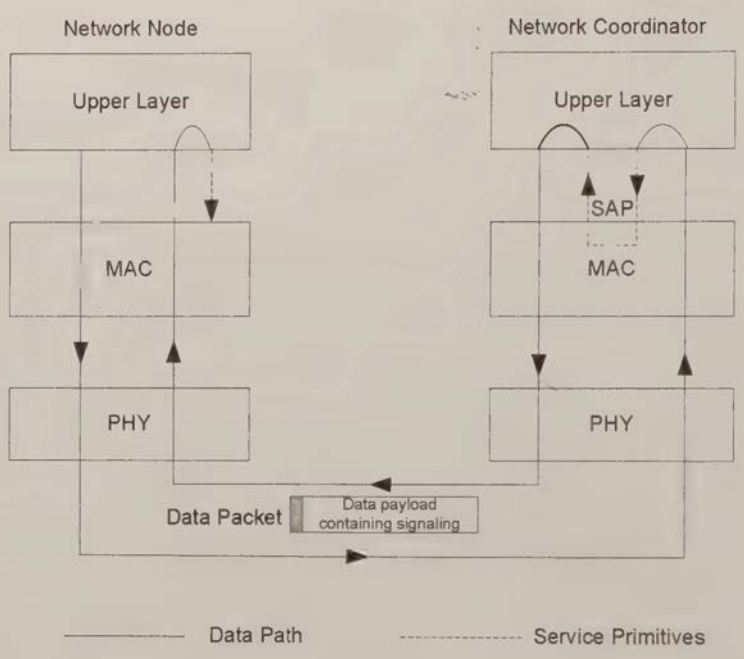


Figure 9.20 Example of Signaling Flow

In the beacon, the network coordinator 1) synchronizes the DEVs, 2) describes the structure of the superframe, and 3) notifies the pending node messages.

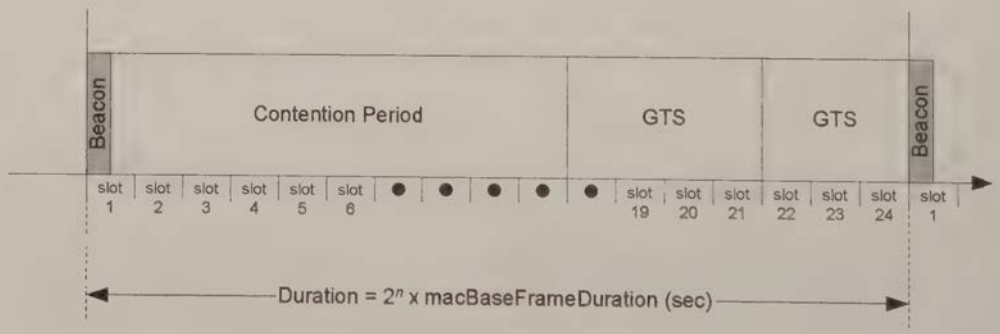


Figure 9.21 IEEE 802.15.4 Frame Structure

In the contention period, the DEVs can access the wireless media using the CSMA/CA mechanism. The CSMA/CA mechanism is similar to the one presented for the IEEE 802.11 standard (see Chapter 4). Each time a DEV wishes to transmit packets, it needs to determine if the wireless medium is free. For this process, the MAC sends a clear channel assessment (CCA) request

to the physical layer. If the wireless medium is free, the packet is transmitted. If the wireless medium is busy, the DEV will back off for a random period before trying again. All data transmissions require a handshake or acknowledgment by the receiving DEV. If an acknowledgment is not received at the sender within a pre-determined time, the sender will retransmit the packet. The DEVs must stop competing for channel access at the end of the contention period.

The GTS is reserved for specific DEVs that need guaranteed bandwidth. The network coordinator may decide not to allocate a GTS to a requesting DEV or to de-allocate an existing GTS at any time.

The proposal also defines the following services required for LR-WPAN operation: network discovery by the network coordinator and DEV, network initiation by the network coordinator, network synchronization by the DEV, and network searching by the DEV. Network discovery is the process of finding out which networks exist close to the network administrator in order to be able to choose a unique network identifier and channel. Network initiation is the process of establishing the network and its operation. Network synchronization is the process of listening to the network beacon to find out the availability of communication opportunities. Network searching is the process of finding the network beacon when network synchronization has been lost.

9.9 IEEE 802.15.4 QoS Support

IEEE 802.15.4 envisions three traffic types in the LR-WPAN:

- *Periodic data:* The traffic is generated in a regular fashion. The amount of data is defined by the application itself and mostly is low data rate. An example is sensor traffic.
- *Intermittent data:* The traffic is generated once in a while, not continuously. The data generation is activated by external stimulus. An example is the light switch traffic.
- *Repetitive low-latency data:* The traffic is generated continuously and requires low-latency data transfer. An example is the mouse device traffic.

As described in the previous section, IEEE 802.15.4 includes two channel access schemes: CSMA/CA and TDMA (via GTS). CSMA/CA provides best effort service while TDMA provides quantitative service in terms of bandwidth and delay assurance. Therefore, CSMA/CA adequately supports periodic and intermittent data while TDMA is applied to repetitive low-latency data.

Repetitive low-latency data traffic requires GTSs from the network coordinator. The network coordinator checks the available network resources. If resources are available, the network coordinator reserves GTSs as well as assigns unique IDs to each GTS. The negotiation process is accomplished through the upper layers and GTS primitives (i.e., MLME-GTS.request, MLME-GTS.confirm). Figure 9.22 shows an example of GTS primitives.

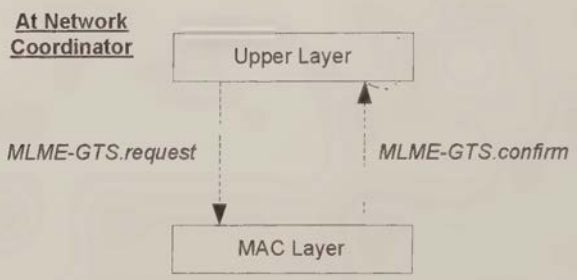


Figure 9.22 Examples of GTS Primitives

Figure 9.23 shows the GTS establishment procedure between a network node and the network coordinator. The network node's upper layer initiates the GTS request to the network coordinator. The upper layer of the network coordinator retrieves the GTS request and signals the MAC layer through the MLME-GTS.request. The MAC layer checks the available network resources. If resources are available, the request is granted, and the MAC layer replies with MLME-GTS.confirm which contains the granted GTS information (i.e., GTS ID, GTS starting time,

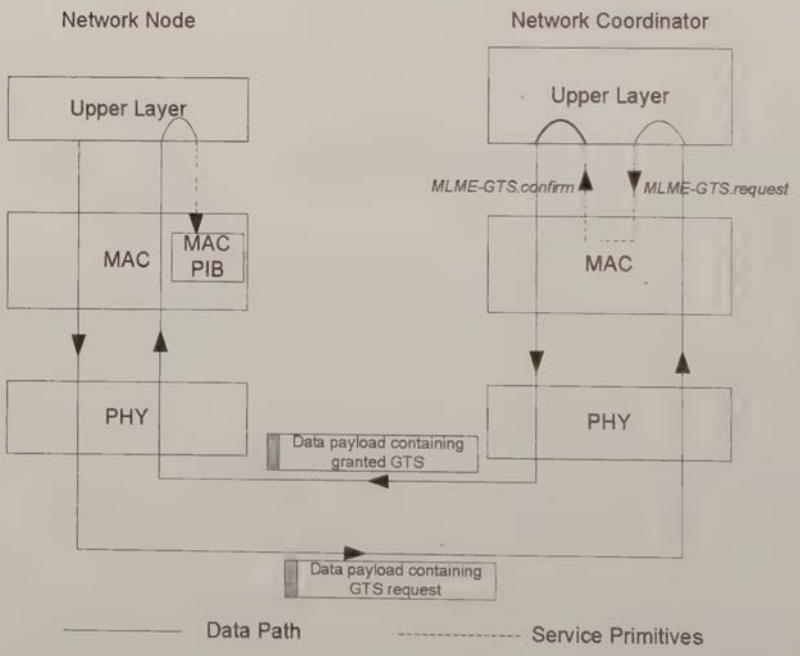


Figure 9.23 GTS Establishment Procedure

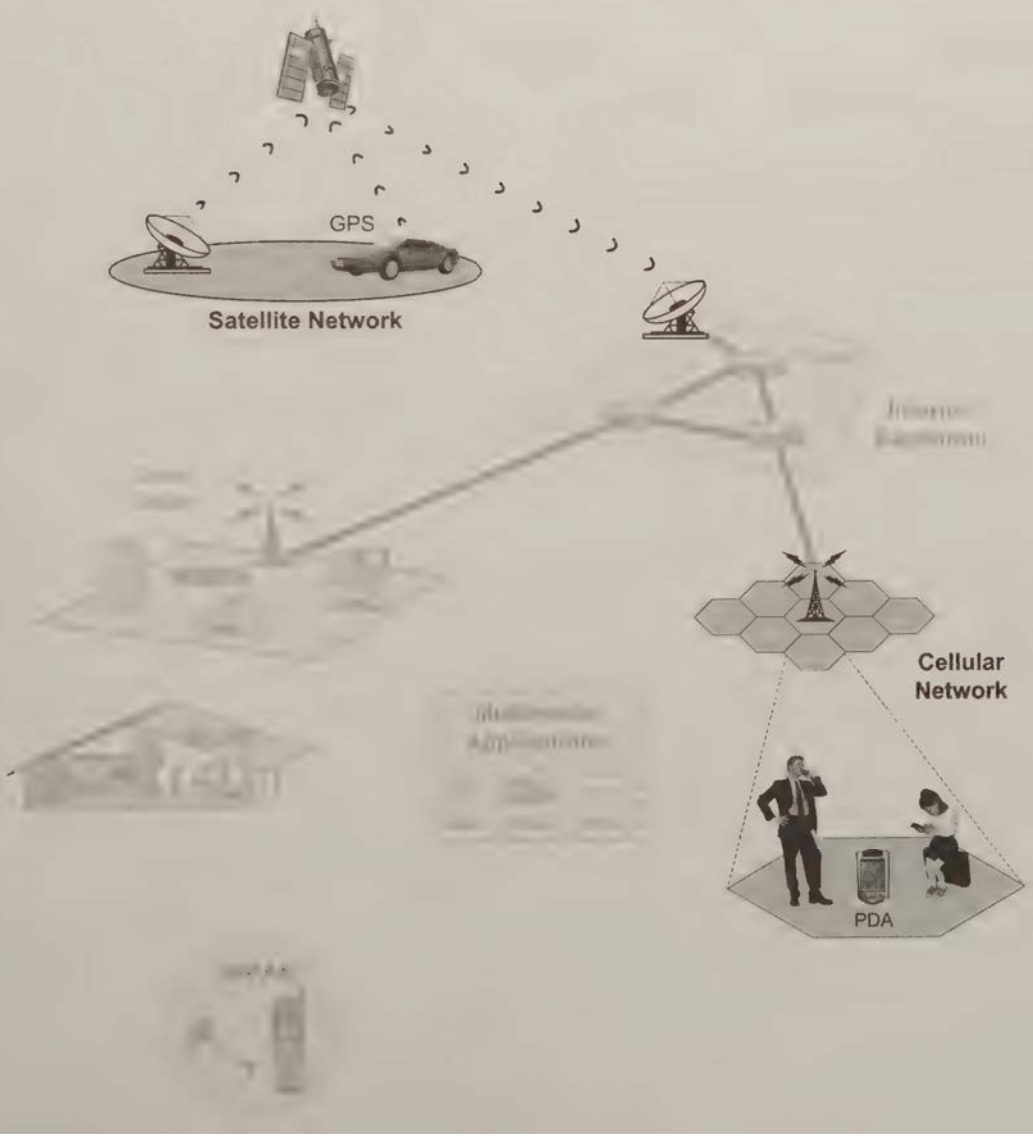
GTS length). The network coordinator's upper layer includes granted GTS information in the data payload and sends it to the network node. MLME-GTS.confirm contains GTSId, GTSStartSlot, and GTSLength. GTSStartSlot indicates the starting slot of the allocated GTS. After receiving the granted GTS information, the network node's upper layer updates its MAC PIB with GTS information. The network node accesses the channel during a GTS based on the information provided in the MAC PIB. The upper layers' mechanisms are not specified by IEEE 802.15.4.

In summary, IEEE 802.15.4 provides basic QoS mechanisms to support low-rate applications. However, the sophisticated QoS mechanisms and QoS algorithms reside in the upper layer and are not within the scope of the standard.



PART 5

2.5G and 3G Networks





CHAPTER 10

GPRS

10.1 Introduction

General Packet Radio Service (GPRS) is referred to by many as a 2.5G technology—an evolution from 2G Global System for Mobile Communications (GSM) technology and an interim phase toward 3G high-speed services including multimedia traffic with different QoS requirements.

GPRS standardization efforts were conducted by the European Telecommunications Standards Institute (ETSI) during the mid and late 1990s and then transferred to the 3G Partnership Project (3GPP) organization. 3GPP includes many organizations such as the Association of Radio Industries and Businesses (ARIB) in Japan, the China Wireless Telecommunication Standard Group (CWTS), the European Telecommunication Standard Group (ETSI), Standard Committee T1 Telecommunications (T1) in the U.S., and Telecommunication Technology Association (TTA) in Korea.

ETSI, and later 3GPP, introduced several releases of GPRS. In each release new features as well as increased speeds have been specified. Each release also has several versions in which problems are clarified. Each release and version is detailed in several documents that provide the release overview as well as detailed specifications of its various modules and parts. 3GPP started to harmonize later releases of GPRS to enable easy migration to the anticipated 3G Universal Mobile Telecommunications System (UMTS) technology (described in Chapter 11), which is provisioned by Wide Code Division Multiple Access (WCDMA) technology. The evolution of these standards is presented in Figure 10.1. It is expected that most of the telephone carriers will take this migration path, or part of it, toward 3G. This includes both carriers that currently support GSM and carriers that support alternative technologies such as CDMA. Such CDMA carriers are located mainly in the U.S. and Korea.

GSM, which was introduced in the early 1990s, is available in more than 100 countries and is the de facto standard in Asia and Europe. GSM is based on narrowband Time Division Multiple Access (TDMA), which can accommodate eight simultaneous calls on the same frequency for circuit switching services. Its standards are specified by ETSI and the TIA/EIA (Telecommunications Industry Alliance/Electronics Industries Alliance) IS-136 standards. GSM charges are based on the connection time and not on the volume of traffic delivered. This cost model is not suitable for certain data applications that are characterized by bursty transmissions.

GSM Phase 1 included common services such as basic telephony, emergency calls, up to 9.6 kbps data rate services, ciphering, authentication, and features such as call forwarding and SMS (Short Message Service). GSM Phase 2 included additional features such as identification, call waiting, call hold, advice of charge, and multi-party call. A half-rate speech coding was introduced in this phase in addition to full-rate speech coding. These two phases provided the basis for work toward 3G, referred to also as Phase 2+, which includes GPRS specifications.

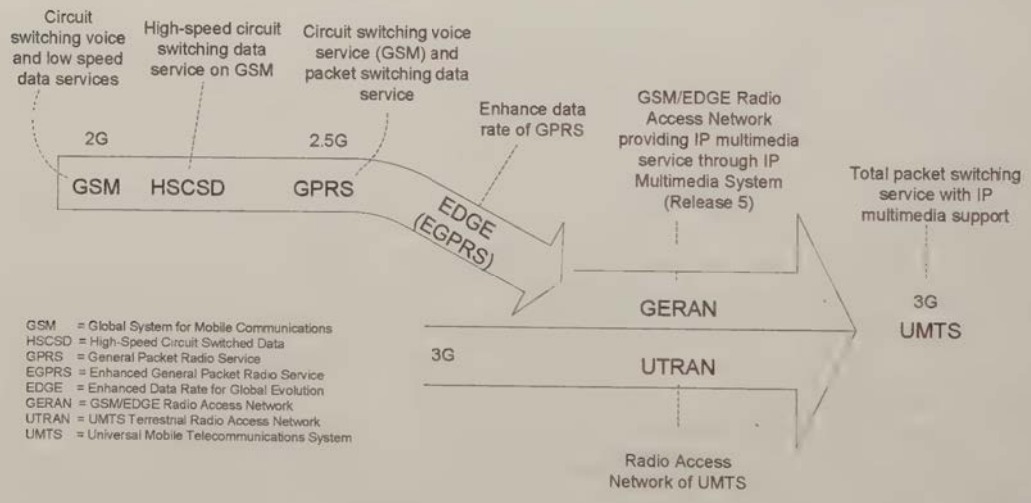


Figure 10.1 Evolution toward 3G/UMTS

The first work under Phase 2+, referred to as Release 96 (Rel-96), specified HSCSD (High-Speed Circuit Switched Data). HSCSD increased the 9.6 kbps data rate services provided in GSM Phases 1 and 2 to a maximum of 115 kbps. This data rate is achieved through a relatively simple combination of multiple GSM time slot allocations. However, due to various implementations and interfaces, the practical data rate is up to 64 kbps. In HSCSD, the dedicated time slots that are reserved for data connections cause inefficient bandwidth utilization in cases where the data traffic is bursty. GPRS releases continued to support HSCSD, which is currently deployed only in a few locations.

GPRS evolves on top of GSM's TDMA approach. The first release of GPRS was detailed in Release 97 (R97). R97 introduced the concept of packet switching in addition to GSM's circuit switching. The packet switching allows carriers to charge users based on actual traffic transmitted rather than on the duration of the circuit. GPRS also allows users to access other public networks via protocols such as IP. R97 provides speeds of up to 171 kbps with average speeds of 28.8 kbps. R97 allows support for QoS considering service priority, reliability, time delay, throughput, QoS profile, and other parameters. Release 98 (R98) included Adaptive Multi Rate (AMR) technology, which provides the ability to select either full-rate (FR) or half-rate (HR) speech coding. These releases are being deployed globally despite their relatively low data rates.

Release 99 (R99) includes Enhanced Data rate for Global Evolution (EDGE), sometimes referred to as Enhanced Data GSM Environment and as Enhanced GPRS (EGPRS). EDGE provided a number of additional radio modulation and coding techniques that enhanced speeds of up to 384 kbps with average speeds of 64 kbps. This release includes EDGE Compact, which is a variant of EGPRS that was designed to be deployed in narrow frequency band allocations. EDGE Compact requires less than 1MHz of spectrum, compared to more than 2.4 MHz for EDGE, reducing EDGE bandwidth to up to 250 kbps with averages of up to 56 kbps.

R99 also included support for UMTS traffic. This inclusion of UMTS traffic has been continuously improved and enhanced through the Release 4 (Rel-4), temporarily referred to as Release 2000, and Release 5 (Rel-5), known also as GSM/EDGE Radio Access Network (GERAN). In GERAN a new radio access technology was introduced that is fully harmonized with UMTS Terrestrial Radio Access Network (UTRAN), which details speeds of up to 2 Mbps. Rel-5 includes an optional Enhanced GPRS (EGPRS) radio that allows enhanced speeds compared to GPRS. Rel-5 also includes a new set of multimedia services, referred to as Internet Multimedia Subsystem (IMS), including multimedia interactive communications.

3GPP continues to work on a newer release, referred to as Release 6 (Rel-6). Rel-6 may include improved radio technology for increased data rates and other improvements. In this book we focus on Rel-5 while, when possible, we provide some pointers to previous releases. These intermediate releases receive interest from various carriers that may deploy them as an intermediate step toward 3G technology.

GPRS Release 5 is specified in several 3GPP documents including:

- TS 22.060 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; General Packet Radio Service (GPRS); Service description, Stage 1 (Release 5)
- TR 22.941 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; IP Based Multimedia Services Framework; Stage 0 (Release 5)
- TS 22.228 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Service requirements for the IP Multimedia Core Network Subsystem (Stage 1) (Release 5)

- TS 43.051 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Overall description (Stage 2) (Release 5)
- TS 44.118 3rd Generation Partnership Project; Technical Specification Group GSM EDGE Radio Access Network; Mobile radio interface layer 3 specification, Radio Resource Control (RRC) Protocol, Iu Mode (Release 5)
- TS 44.018 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Mobile radio interface layer 3 specification; Radio Resource Control Protocol (Release 5)
- TS 44.060 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; General Packet Radio Service (GPRS); Mobile Station (MS)—Base Station System (BSS) interface; Radio Link Control/Medium Access Control (RLC/MAC) protocol (Release 5)
- TS 44.160 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Mobile Station (MS)—Base Station System (BSS) interface; Radio Link Control/Medium Access Control (RLC/MAC) protocol; Iu mode (Release 5)
- TS 43.064 3rd Generation Partnership Project; Technical Specification Group GERAN; Digital cellular telecommunications system (Phase 2+); General Packet Radio Service (GPRS); Overall description of the GPRS radio interface (Stage 2) (Release 5)
- TS 45.005 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Radio transmission and reception (Release 5)

Several other documents detail various aspects of the standards. They can be found at www.3gpp.org and www.etsi.org.

10.2 GPRS (Rel-5) Architecture

As shown in Figure 10.2, the GPRS mobile system consists of three main entities: Mobile Station (MS), Radio Access Network (RAN), and Core Network (CN). A mobile station refers to the mobile equipment on which a user executes mobile services and applications (i.e., voice services, SMS). A mobile station communicates with the base station that controls the radio channel within its coverage area (or a cell, so to speak). Multiple base station systems interconnect and form the network called RAN. RAN is responsible for providing the communication path between the Mobile Station and the Core Network. Furthermore, RAN also provides several key functions to support communication such as channel access, mobility management, and radio resource management. GERAN (GSM/EDGE Radio Access Network) is the RAN entity of GPRS (Rel-5).

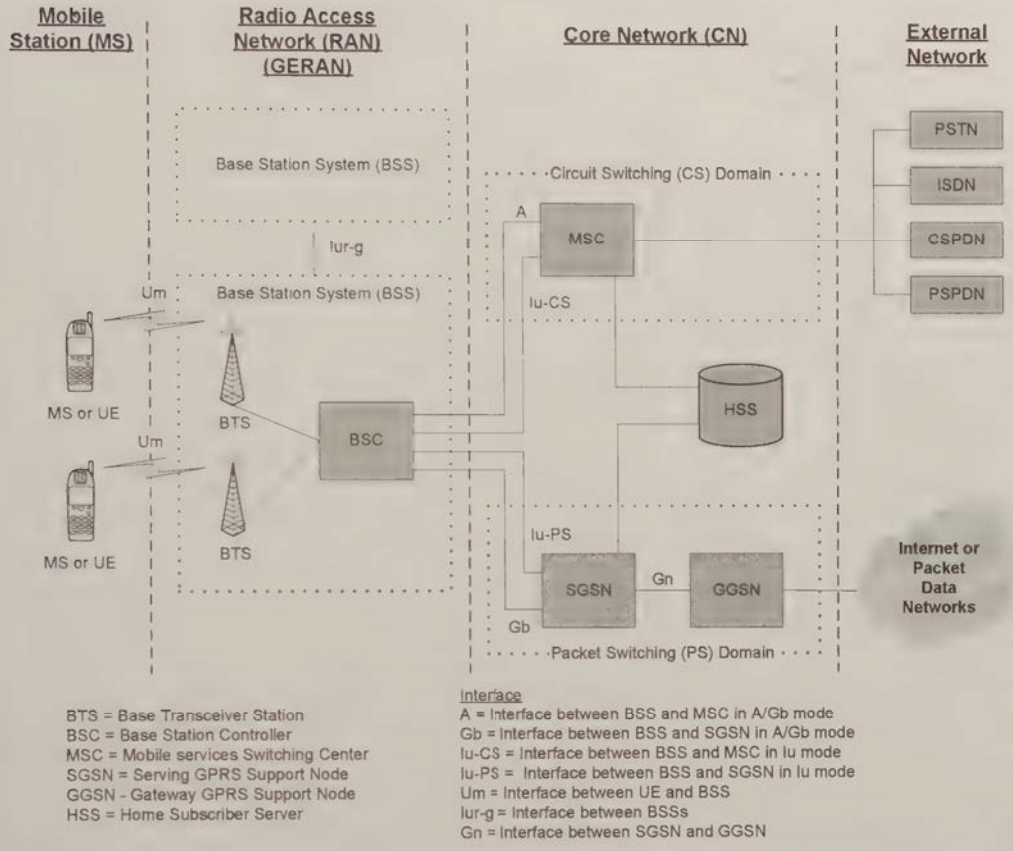


Figure 10.2 GPRS Architecture

The Core Network connects the mobile network to the external network (i.e., [PSTN], Integrated Services Digital Network [ISDN], Internet). The core network comprises two domains: Circuit Switching (CS) domain and Packet Switching (PS) domain. The CS domain contains modules that support circuit switching services. As shown in Figure 10.2, the Mobile Switching Center (MSC) resides in the CS domain. The PS domain contains the following main modules that support packet switching services: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). A voice signal (circuit switching traffic) travels between a mobile station and an external voice network (i.e., PSTN) through the Base Station System (BSS) and MSC. On the other hand, a data signal (packet switching traffic) travels between a mobile station and an external data network (i.e., Internet) through the BSS, SGSN, and GGSN. Home Subscriber Server (HSS) is a supporting module providing subscription-related information for both the CS and PS domains.

GERAN consists of multiple interconnected BSSs. Each BSS serves the mobile stations within its coverage area. The BSS connects to the CS domain of the core network through A and Iu-CS interfaces while the BSS connects to the PS domain of the core network through Gb and Iu-PS interfaces. Iu-CS and Iu-PS can be simply called Iu interface. The mobile station connects to the BSS through the Um interface. Each interface has its own protocol architecture that handles the communication between the pair systems.

Prior to Release 5, the BSS connects to the core network only via the A and Gb interfaces (no Iu interface). This core network is considered to be the second generation core network. 3GPP realizes a smooth migration from the second generation mobile system toward 3G's UMTS (Universal Mobile Telecommunications System). In UMTS, UTRAN (UMTS Terrestrial Radio Access Network) connects to the third generation core network through the Iu interface. Therefore, in order to align with UMTS, GPRS Release 5 includes Iu interface in addition to the existing A/Gb interfaces. Figure 10.3 illustrates the GPRS architecture for 2G and 3G core networks.

The mobile station can be in one of two modes: A/Gb mode and Iu mode. The mode is determined by the generation of the core network (i.e., 2G or 3G) with which the mobile station associates (see Figure 10.3).

The standard allows three domains of operation for the mobile station in A/Gb mode:

- *Class A domain of operation:* The MS can operate both packet switching services and circuit switching services simultaneously.
- *Class B domain of operation:* The MS can operate either packet switching services or circuit switching service at one time.
- *Class C domain of operation:* The MS can only operate packet switching services.

Furthermore, the standard also defines three domains of operation for the mobile station in Iu mode:

- *CS/PS domain of operation:* The MS can operate both packet switching services and circuit switching services simultaneously. This domain is analogous to Class A of the A/Gb mode.
- *PS domain of operation:* The MS can only operate packet switching services. This domain is analogous to Class C of the A/Gb mode
- *CS domain of operation:* The MS can only operate circuit switching services.

GPRS supports both Point-to-Point (PTP) and Point-to-Multipoint (PTM) services while supporting roaming of GPRS users between different carriers. The PTP can be used for accessing information on the Internet, messaging services, and conferencing applications. PTM can be used for delivering information, such as news and weather, to multiple locations or interactive conferencing applications.

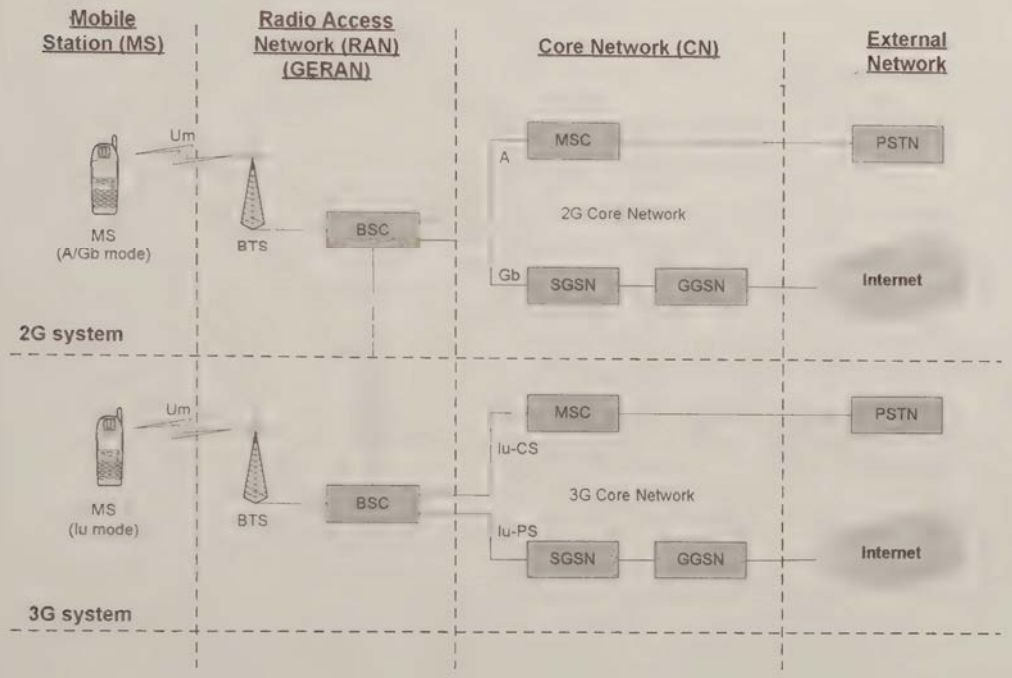


Figure 10.3 GPRS Architecture for 2G and 3G Systems

GPRS Rel-5 added a new component as compared to previous GPRS releases, the Internet Multimedia Subsystem (IMS). IMS allows simultaneous access to multiple different types of real-time and non-real-time traffic. Real-time traffic includes voice, text, and video, and non-real-time traffic includes data, audio and video files, audio and voice streaming, text and multimedia messaging, emails, and Internet browsing.

IMS provides synchronization between the multiple components of a multimedia communication session. For example, a user can receive calls while continuing with web browsing. IMS lists key requirements for multimedia services. These requirements pertain to the user perspective. In addition, IMS lists requirements for security, addressing, support for roaming, emergency calls, mobile number portability, messaging, and Virtual Private Network (VPN) support.

10.2.1 Radio Interface Protocol Architecture

Figure 10.4 illustrates the BSS's radio interface protocol stack, which includes the protocol modules for Iu and A/Gb modes. The protocol architecture is divided into 1) user plane for user data transfer and the associated user data transfer control and 2) control plane for the transfer of control information that supports the user plane.

A logical channel that represents a traffic stream of a specific type of information (i.e., data message, control message) contains a specific structure of the information block (or packet) which is mapped to the physical layer. The logical channel will be described in a later section. The radio interface protocol is divided into three layers: Layer 1 or physical layer (PHY); Layer 2, which includes the Data Link, Media Access Control (MAC), Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP); and Layer 3, which contains the Radio Resource Control (RRC) for Iu mode and Radio Resource (RR) for A/Gb mode.

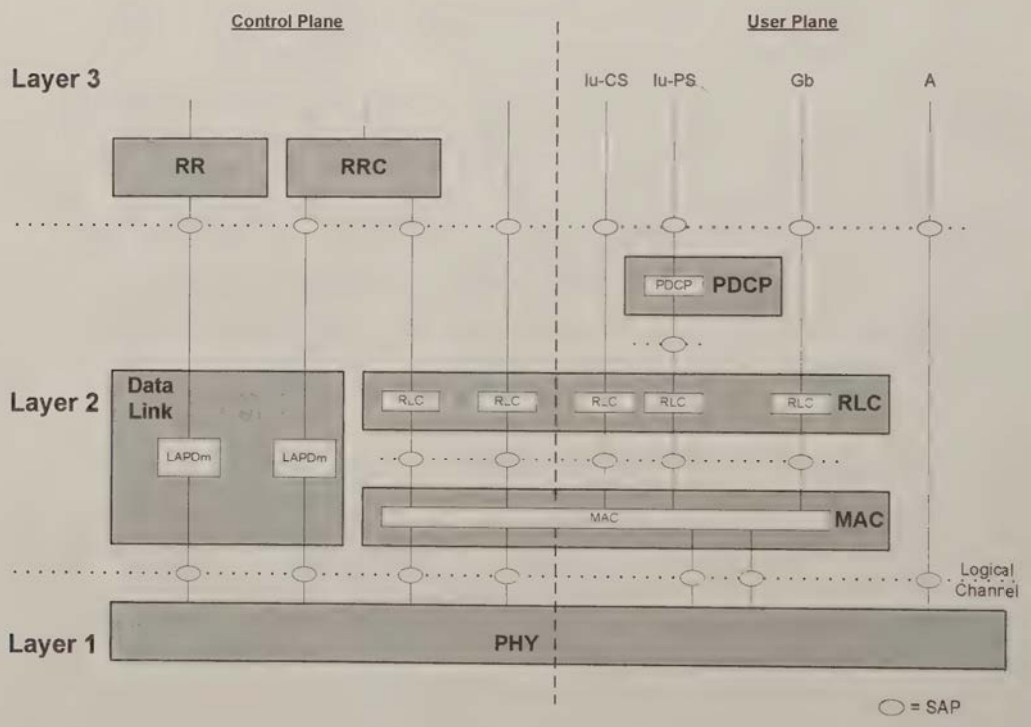


Figure 10.4 BSS's Radio Interface Protocol Stack

10.2.1.1 RRC

The Radio Resource Control (RRC), introduced in Rel-5, is responsible for radio resource management in the Iu mode. In these matters it shares similar responsibilities with the MAC. The RRC will carry the resource management responsibilities when dedicated resources are provided to the mobile station, where as the MAC will be responsible when shared resources are provided to the mobile station. The RRC broadcasts system information to the mobile stations. The system information may be cell specific (such as location services in cells) or not cell specific. The RRC is also responsible to establish, maintain, reconfigure, and release connections between the mobile stations and the GERAN. This includes cell reselection, admission control, and link

establishment. The RRC selects the connection parameters considering both control and applications needs. This allocation is then communicated to the mobile station. The RRC also handles mobility related activities such as evaluation, decision, and execution handovers. The RRC handover procedures follow the mobility of the mobile station and include procedures to modify the channels allocated to the mobile station. While executing these functions, the RRC considers the requested QoS. In addition, the RRC executes a variety of monitoring, reporting, ciphering, and mediating between GERAN and the mobile stations.

10.2.1.2 RR

The Radio Resource (RR) is responsible for the resource management in A/Gb mode. The RR is located in a plane parallel to the RRC.

10.2.1.3 PDCP

The Packet Data Convergence Protocol (PDCP) is located above the RLC layer in the user plane of the Iu mode. PDCP includes the following functions:

- Header compression and decompression of the IP data stream: PDCP receives the packet from the upper layer, performs header compression, and forwards the packet to the RLC layer. In the opposite direction, PDCP receives the packet from the RLC layer, decompresses the header, and forwards the packet to the upper layer.
- Passage of the data between the upper and lower layers.
- Maintenance of the PDCP sequence numbers: PDCP assigns a sequence number to the packet that arrives from the upper layer. At the receiving end, PDCP receives the packet with the sequence number from the RLC layer. Based on the sequence number it decides its action.

10.2.1.4 RLC

The RLC transmits data from the higher layers to the MAC. It can work in either transparent or non-transparent mode. In transparent mode the RLC has no functionality. Packets are transferred to the MAC without being altered and without adding any RLC protocol information. In non-transparent mode, the RLC provides reliability to the MAC data transmission. To achieve this, the RLC appends protocol information (RLC packet header) to the data packet and performs functions such as 1) segmentation of upper layer packets into RLC data blocks, 2) reassembly of RLC data blocks and transfer of the blocks back to the upper layer, 3) concatenation of upper layer packets into RLC data blocks, 4) padding to fill RLC data blocks, 5) backward Error Correction (BEC) procedures enabling selective retransmission of RLC data blocks, 6) discarding of RLC packets according to delay requirements, 7) in-sequence delivery of upper layer packets, 8) Link Adaptation, 9) Ciphering, and 10) validating Acknowledgments (if desired by upper layers). The non-transparent mode can be divided into Acknowledged mode and Unacknowledged mode. Acknowledgment mode provides a mechanism for guaranteed delivery since the addressee needs to acknowledge the receipt of the packet. The RLC can notify the upper layers

when errors cannot be resolved as well as when packets are discarded. For unacknowledged mode, RLC does not provide guaranteed delivery of packets.

10.2.1.5 MAC

The Medium Access Control (MAC) executes the functions of managing the shared transmission resources. In these matters it shares similar responsibilities with the RLC. The MAC responsibilities include 1) configuring and mapping logical channels, defined by the type of data which is transferred, to the appropriate physical subchannels; 2) assigning and configuring the shared radio resources; and 3) scheduling, multiplexing data, and controlling packets to be delivered on the shared physical channels. The MAC supports various logical Channels: traffic channels (TCH), control channels, and broadcast channels. The MAC supports both Iu and Gb traffic.

10.2.1.6 Data Link

The LAPDm delivers information between Layer 3 and Layer 1 across the GSM network. The term Dm channel is used to represent the collection of all the various signaling channels required in the GSM system.

10.2.1.7 Physical Layer

The physical channel interfaces with the Medium Access Control (MAC) and the Radio Resource Control (RRC). It uses a combination of frequency and Time Division Multiple Access (TDMA) methods. Each frequency channel is separated by 200 kHz. In each frequency channel, the channel is structured into time slots and defines eight basic physical channels per carrier. The physical channel is defined as a sequence of time slots and a frequency hopping sequence. Several frequencies are defined for usage in different countries. According to 3GPP TS 45.001 document, the frequencies and channel arrangements are as follows:

1. GSM 450 Band: the system is required to operate in the following band:
   a. 450.4 MHz to 457.6 MHz: mobile transmit, base receive
   b. 460.4 MHz to 467.6 MHz: base transmit, mobile receive
2. GSM 480 Band: the system is required to operate in the following band:
   a. 478.8 MHz to 486 MHz: mobile transmit, base receive
   b. 488.8 MHz to 496 MHz: base transmit, mobile receive
3. GSM 750 Band: the system is required to operate in the following band:
   a. 777 MHz to 792 MHz: mobile transmit, base receive
   b. 747 MHz to 762 MHz: base transmit, mobile receive
4. GSM 850 Band: the system is required to operate in the following band:
   a. 824 MHz to 849 MHz: mobile transmit, base receive
   b. 869 MHz to 894 MHz: base transmit, mobile receive

5. Standard or primary GSM 900 Band, P-GSM: the system is required to operate in the following frequency band:

   a. 890 MHz to 915 MHz: mobile transmit, base receive
   b. 935 MHz to 960 MHz: base transmit, mobile receive

6. Extended GSM 900 Band, E-GSM (includes Standard GSM 900 band): the system is required to operate in the following frequency band:

   a. 880 MHz to 915 MHz: mobile transmit, base receive
   b. 925 MHz to 960 MHz: base transmit, mobile receive

7. Railways GSM 900 Band, R-GSM (includes Standard and Extended GSM 900 Band): the system is required to operate in the following frequency band:

   a. 876 MHz to 915 MHz: mobile transmit, base receive
   b. 921 MHz to 960 MHz: base transmit, mobile receive

8. DCS 1800 Band: the system is required to operate in the following band:

   a. 1710 MHz to 1785 MHz: mobile transmit, base receive
   b. 1805 MHz to 1880 MHz: base transmit, mobile receive

9. PCS 1900 Band: the system is required to operate in the following band:

   a. 1850 MHz to 1910 MHz: mobile transmit, base receive
   b. 1930 MHz to 1990 MHz base transmit, mobile receive

To carry its transmission responsibilities successfully, the physical layer is also responsible for power control. The physical layer adjusts the mobile station power output level such that the desired quality is achieved with the minimum possible power. It synchronizes the receiving station with regard to frequency and time. It also carries handover functionality when a mobile station moves from one cell to another as well as quality monitoring that may result in a station changing its assigned physical channel.

The channel modulation can be either GMSK or 8-PSK. Each modulation can achieve a different data rate. The four channel coding schemes, CS-1 to CS-4, are defined for GPRS, while nine channel coding schemes, MCS-1 to MCS-9, are defined for EGPRS (EDGE). The bandwidth allocated for speech or data transmission is provided by a combination of modulation, block size, half or full rate, code rate, and other radio parameters. The potential speed of speech, control, and data varies significantly. Speech varies up to around 24 kbps, data varies up to around 480 kbps.

10.2.2 GPRS (Rel-5) Protocol Architecture

Figures 10.5 and 10.6 show the user and control plane protocols, respectively, in the PS domain (both A/Gb mode and Iu mode). Figures 10.7 and 10.8 show the user and control plane protocols, respectively, in the CS domain (both A/Gb mode and Iu mode). In these figures we do not intend to include all the protocols' components and connections, but rather to provide the big picture of the GPRS (Rel-5) protocol architecture.

As shown in Figure 10.5, the functions between A/Gb mode and Iu mode are slightly different. Iu RLC includes the transparent mode in addition to the acknowledged mode and unacknowledged mode in A/Gb RLC. The PDCP used in Iu mode and the Sub-Network Dependent Convergence Protocol (SNDCP) used in A/Gb mode provide the logical link control between the MS and the BSS. In Figure 10.5, the RR operates the radio resource management in A/Gb mode while the RRC operates the radio resource management in Iu mode. Other modules include the Radio Access Network Application Part (RANAP), the Signaling Connection Control Part (SCCP), and the Base Station System GPRS Protocol (BSSGP). These modules are not discussed in this book.

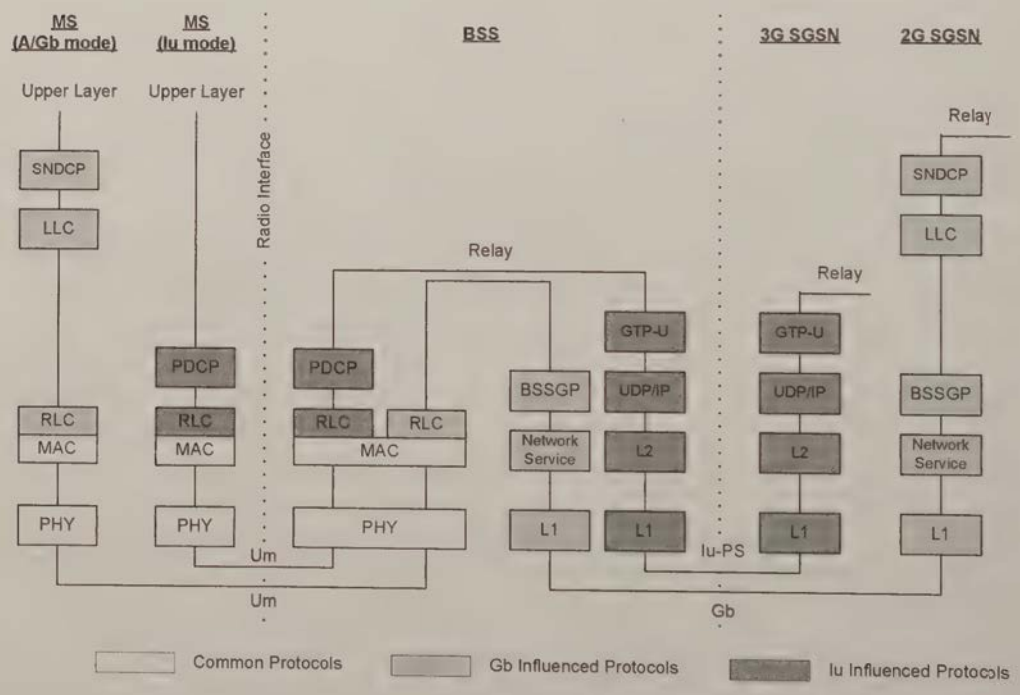


Figure 10.5 User Plane Protocol Architecture in PS Domain (A/Gb mode and Iu mode)

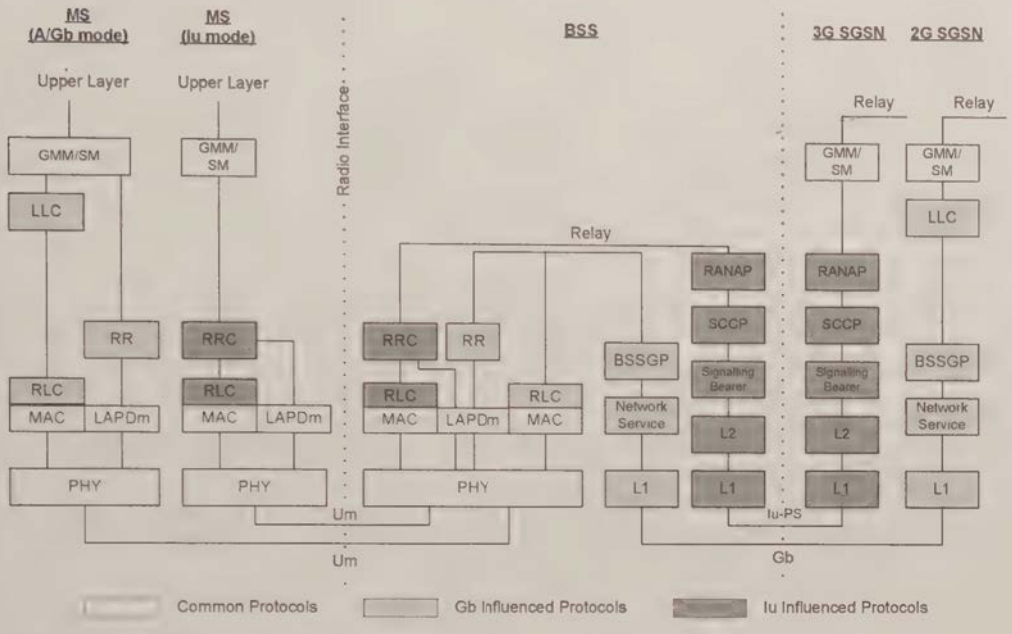


Figure 10.6 Control Plane Protocol Architecture in PS Domain (A/Gb mode and Iu mode)

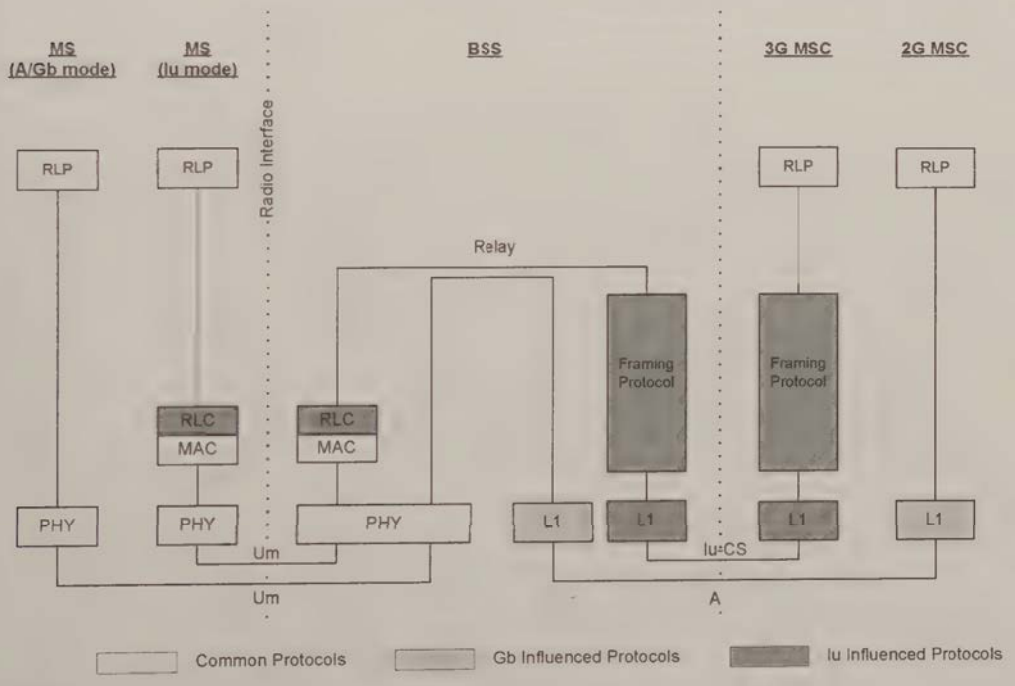


Figure 10.7 User Plane Protocol Architecture in CS Domain (A/Gb mode and Iu mode)

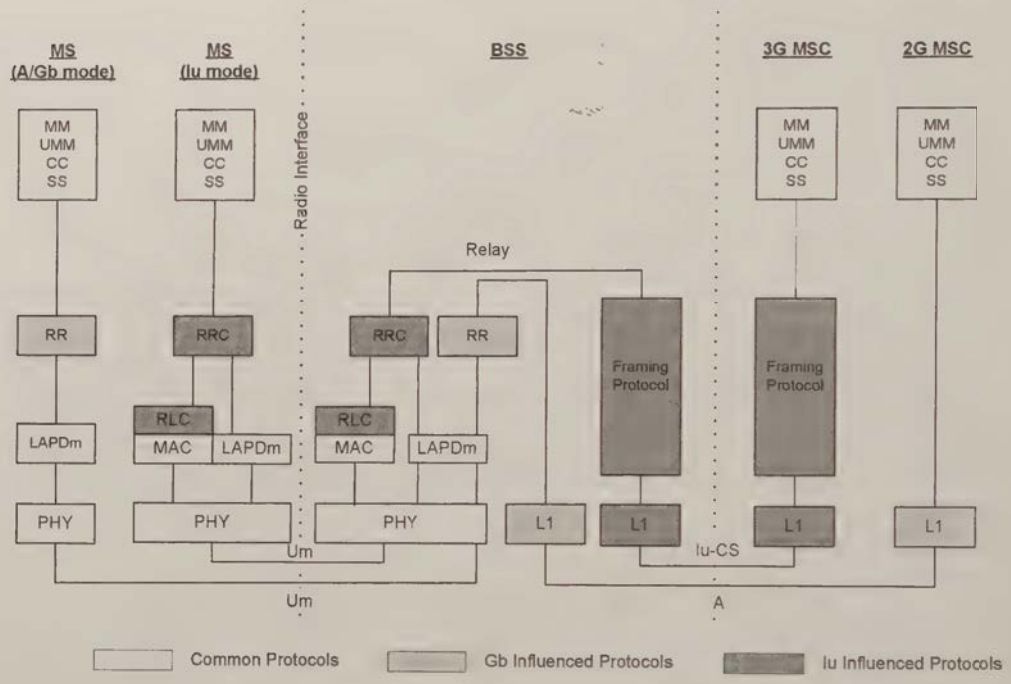


Figure 10.8 Control Plane Protocol Architecture in CS Domain (A/Gb mode and Iu mode)

10.3 Physical Channel

The physical channel is defined by a combination of a radio frequency channel and a time slot number. Within the frequency band, a radio frequency channel (seperated by 200 kHz) is structured into time slots (TSs) as shown in Figure 10.9. Eight consecutive time slots form a TDMA frame. A time slot in a TDMA frame is numbered from 0 to 7. A physical channel is defined by a radio frequency channel and a time slot number (TN) in every TDMA frame. All downlink and uplink TDMA frames are aligned. At the BSS, an uplink TDMA frame is delayed by three time slots from a downlink TDMA frame. At the mobile station, this delay is a function of the distance (the propagation delay) between the mobile station and the base station.

A physical channel can be categorized as a Shared Basic Physical Sub Channel (SBPSCH) or a Dedicated Basic Physical Sub Channel (DBPSCH). A DBPSCH is dedicated to only one user. In contrast, SBPSCH can be shared by up to eight users. Uplink Stage Flag (USF) is deployed to control the multiple access of users on SBPSCH. We will describe the USF mechanism in Section 10.5.2. Figure 10.10 shows an example of the physical channel assignment.

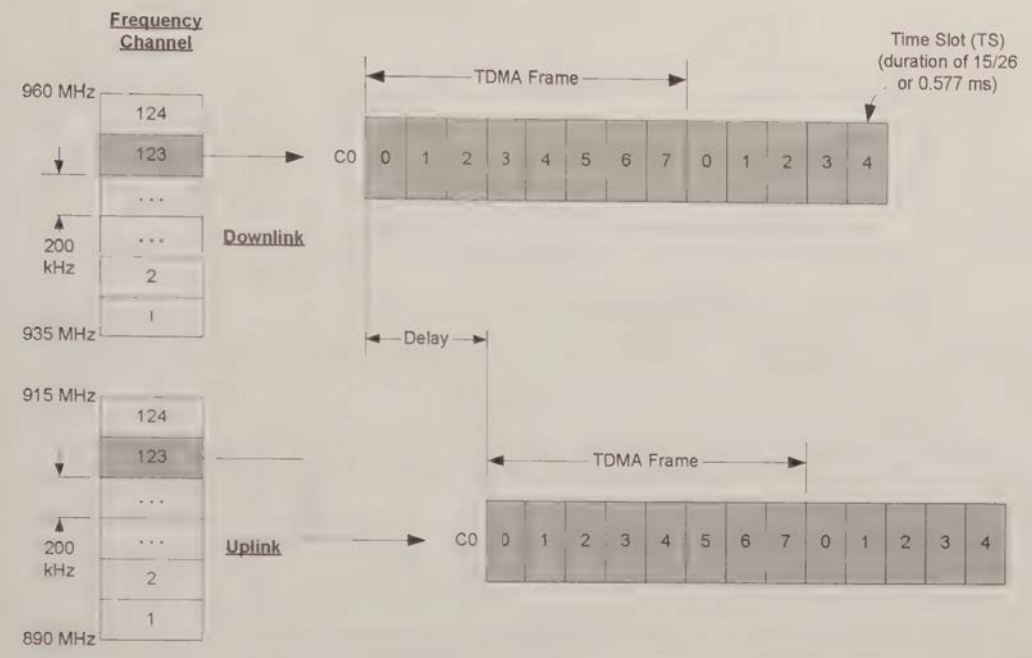


Figure 10.9 Physical Channel Structure of Standard GSM 900 Band

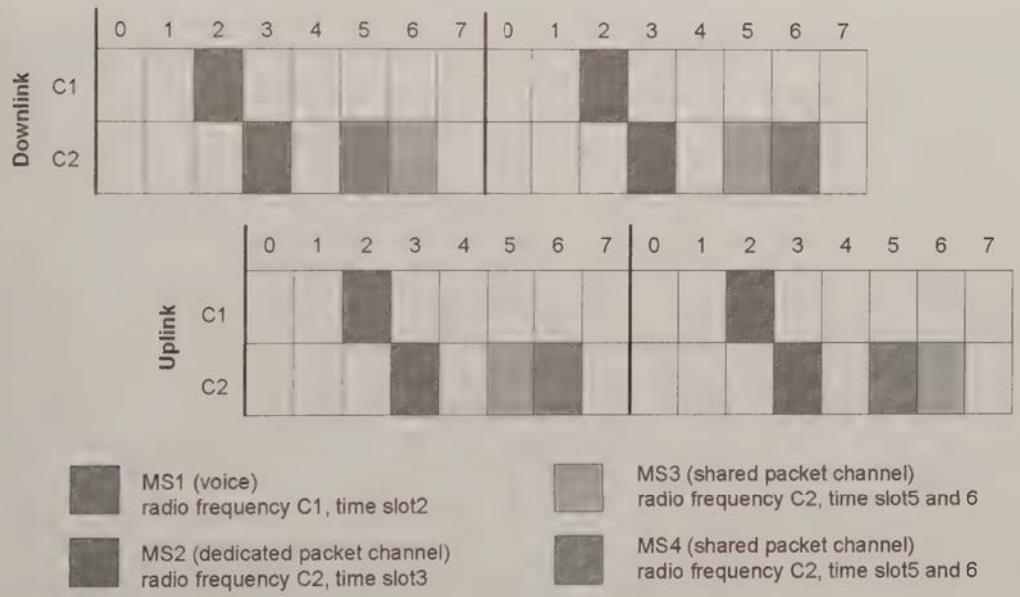


Figure 10.10 Example of Physical Channel Assignment

10.3.1 Hyperframes, Superframes, Multiframes, TDMA Frames and Time Slots

As shown in Figure 10.11, the standard defines different duration frames. The longest frame, called *hyperframe*, with a duration of 12533.76 seconds, is defined to support cryptographic mechanisms. A hyperframe is divided into 2048 *superframes*, each with duration of 6.12 seconds. A superframe is divided into *multiframes*. The number of multiframes in a superframe is based on the type of multiframes. There are four types of multiframes:

- 26-Multiframe: This is a 26-multiframe that contains 26 TDMA frames. Therefore, a superframe can accommodate 51 26-multiframes.
- 51-Multiframe: This is a 51-multiframe that contains 51 TDMA frames. Therefore, a superframe can accommodate 26 51-multiframes.
- 52-Multiframe: This 52-multiframe, which is constructed from two 26-multiframes, contains 52 TDMA frames. Therefore, a superframe can accommodate 26 52-multiframes.
- 52-Multiframe for CTS (Cordless Telephone System): This multiframe contains 52 TDMA frames.

Each type of multiframe supports a different type of logical channel. Figure 10.11 shows only the 26-multiframe type. However, we will focus more on the 52-multiframe type, which is used to accommodate data and control packets.

A TDMA frame contains eight time slots, each with a duration of 0.577 ms. A time slot can accommodate a burst size of 156.25 symbols. If GMSK modulation scheme is used, one symbol reflects one bit (i.e., a time slot contains 156.25 bits). If an 8-PSK modulation scheme is used, one symbol reflects three bits (i.e., a time slot contains 469.75 bits).

10.3.2 Packet Data Channel (PDCH)

The Packet Data Channel (PDCH) refers to the physical channel dedicated to packet data traffic—that is, control or user data traffic from the logical channel. PDCH uses 52-multiframe structure. As shown in Figure 10.12, a PDCH multiframe comprises 52 TDMA frames which are divided into: 12 blocks (four TDMA frames per block), two idle frames, and two frames used for PTCCH (Packet Timing Advance Control Channel).

A PDCH is defined by a combination of a radio frequency channel and a time slot. On a radio frequency channel, PDCHs can be represented logically as eight physical channel instances (see Figure 10.13). The PDCH number presented here corresponds to the time slot number of the TDMA frame (i.e., PDCH1 and time slot # 1)

10.3.3 Radio Block

The radio block is defined as a sequence of data bursts that contains one RLC/MAC protocol data unit (PDU). A packet is generated at the application layer and is sent to the lower layer. Each layer appends to the packet its own protocol header and trailer. Figure 10.14 illustrates the

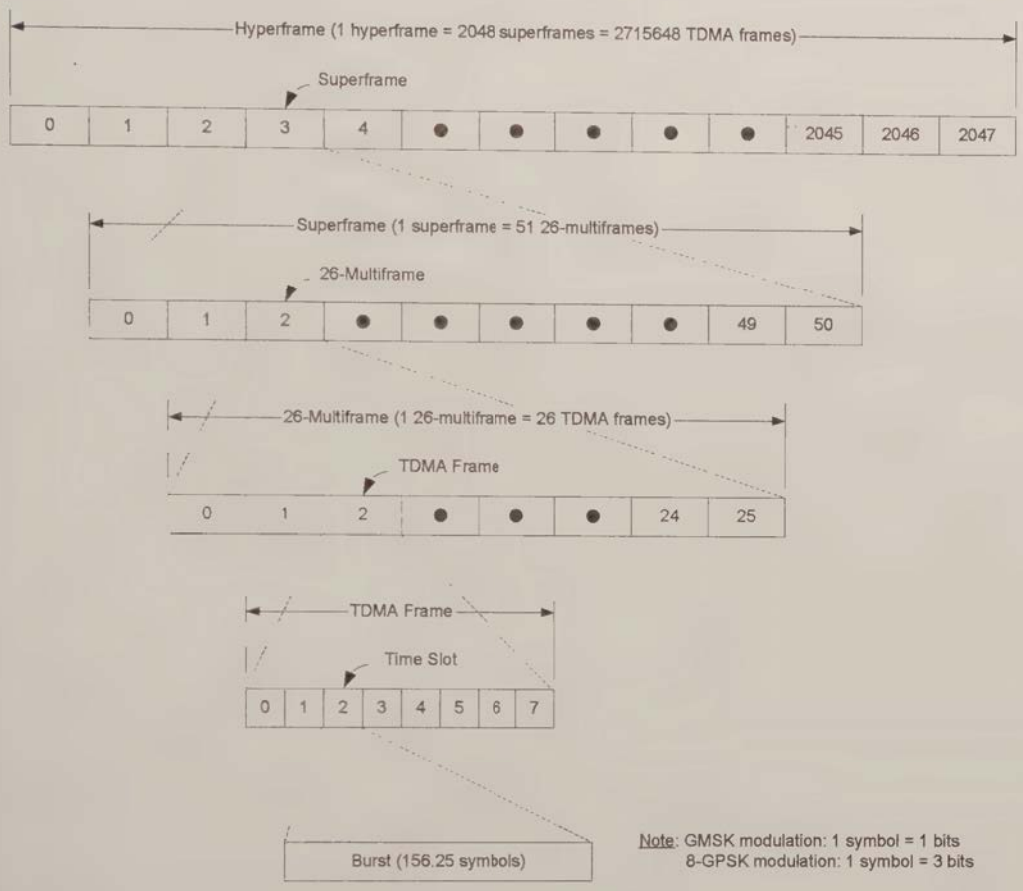


Figure 10.11 Time Frame

packet flow and its structure in each protocol layer. It is worth mentioning that the RLC/MAC PDU header contains the Uplink State Flag (USF) defined above, which plays an important role in the dynamic channel assignment. At the physical layer, the RLC/MAC PDU will be coded (using a coding scheme such as CS-1 to CS-4, or MCS-1 to MCS-9) and reformatted to fit into a PDCH block.

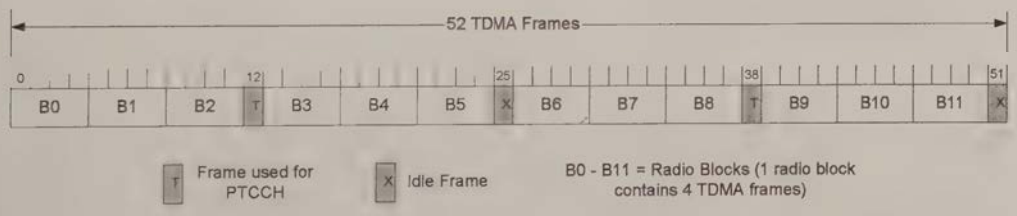


Figure 10.12 52-Multiframe for PDCHs

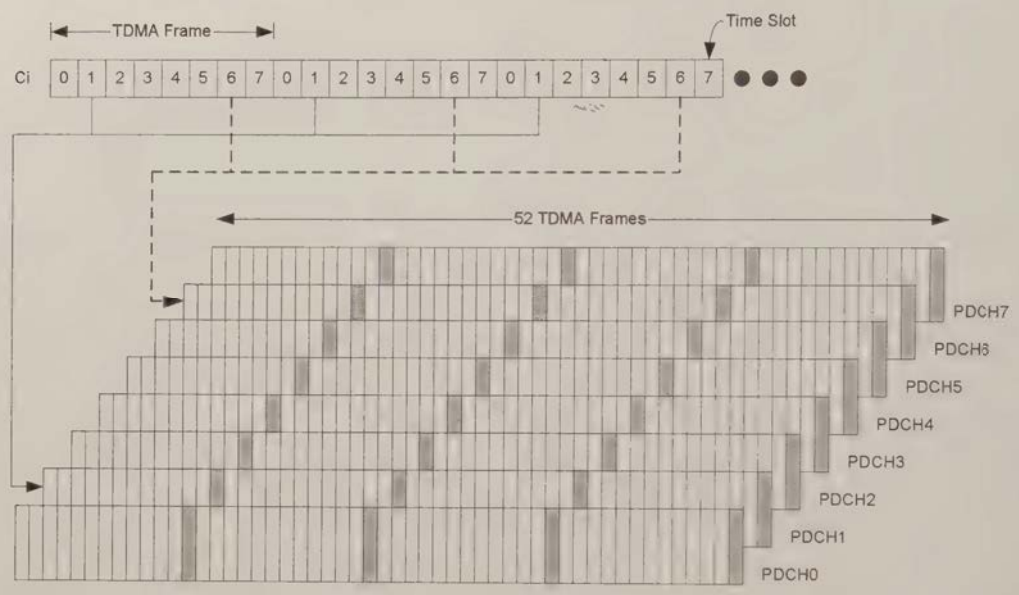


Figure 10.13 PDCHs' Logical View

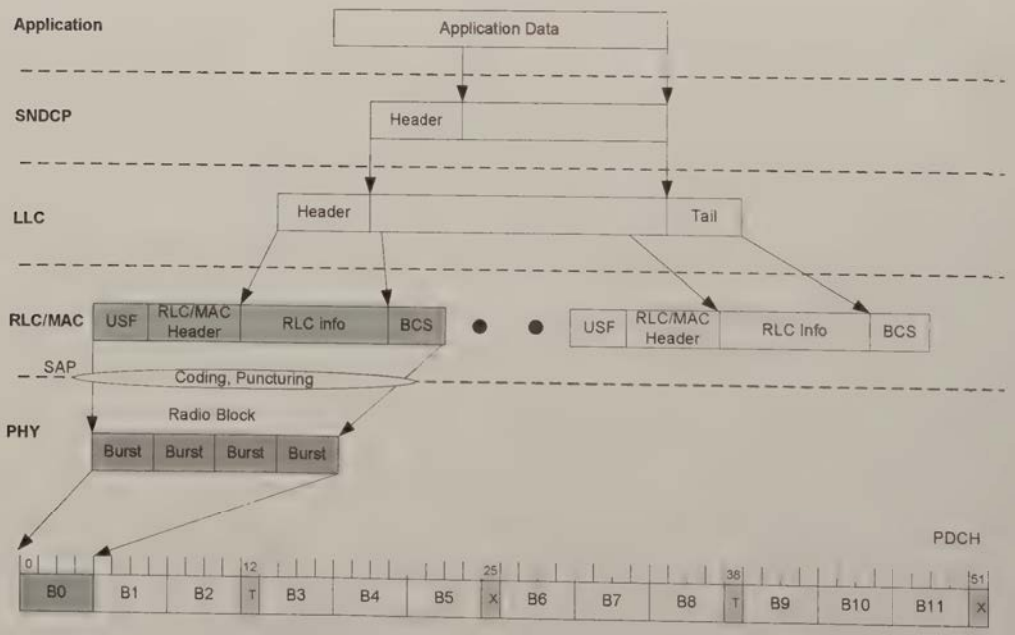


Figure 10.14 Packet Flow and Structure

10.4 Logical, Control, and Traffic Channels

10.4.1 Logical Channels

The standard defines logical channels that are mapped by the MAC to physical channels. These logical channels include both traffic channels for data and speech and control channels for control, synchronization, and signaling information. Several logical channels can be multiplexed on the downlink physical channel. Similarly, several logical channels can be multiplexed on the uplink physical channel. Since GPRS is built on the basis of GSM, some logical channels are inherited from GSM. In addition, GPRS introduced some new logical channels to support packet switching services. As shown in Figure 10.15, the naming of such logical channels begins with the word "packet," such as Packet Common Control Channel (PCCCH) and Packet Broadcast Control Channel (PBCCH).

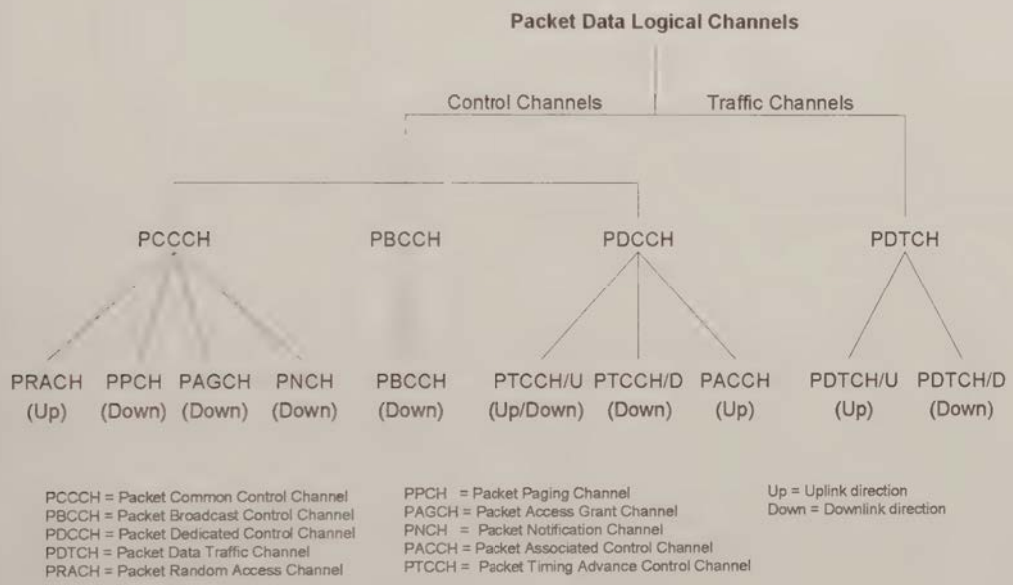


Figure 10.15 Packet Data Logical Channels

10.4.2 Control Channels

Control channels carry control, synchronization, and signaling information. There are three kinds of control channels: common, dedicated, and broadcast.

Common control channels include also Packet Common Control Channels (PCCCHs) that support packet transmission. They include packet paging channels, random access channels, packet grant channels, and packet notification channels. PCCCH is optional for the network. In case PCCCH is not allocated, the control information will be transmitted on the GSM control channels.

Dedicated control channels support operations on DBPSCH. They include Slow Associated Control Channel (SACCH) for radio measurements and data. SACCH is also used for SMS transfer during calls. They also include Fast Associated Control Channel (FACCH) for one TCH on DBPSCH and Stand-alone Dedicated Control Channel (SDCCH). Control channels supporting SBPSCH include controlling uplink and downlink activities using the Packet Associated Control Channel (PACCH), and Packet Timing Advance Control Channels (PTCCHs) for timing estimation.

Broadcast channels include 1) frequency correction channels that are used to correct the frequency of the mobile station (MS), 2) synchronization channels that synchronize the MS frequency with that of the base station, 3) broadcast control channels that broadcast general information on the base station, and 4) packet broadcast channels that broadcast parameters that the MS needs in order to access the network for packet transmission.

The control signaling messages include the following:

1. Packet Random Access Channel (PRACH) and Compact Packet Random Access Channel (CPRACH) are used by the mobile station in the uplink channel to initiate data or control information.
2. Packet Paging Channel (PPCH) and Compact Packet Paging Channel (CPPCH) are used to page a mobile station in the downlink channel before data transmission.
3. Packet Access Grant Channel (PAGCH) and Compact Packet Access Grant Channel (CPAGCH) are used in the downlink channel to transmit to the mobile station resource assignments as a preparation step toward data transmission.
4. Packet Notification Channel (PNCH) and Compact Packet Notification Channel (CPNCH) are used in the downlink to send a PTM-M (Point to Multipoint-Multicast) notification to several mobile stations about a data transfer.
5. Packet Broadcast Control Channel (PBCCH) and Compact Packet Broadcast Control Channel (CPBCCH) broadcast packet data specific system information in the downlink.
6. Packet Associated Control Channel (PACCH) is used to provide signaling information of a specified mobile station such as acknowledgments and power control information. It is also used to transmit resource assignment and reassignment messages.
7. Packet Timing Advance Control Channel/Uplink (PTCCH/U) is used to transmit random access burst for estimation of the timing advance for the mobile station in packet transfer mode.
8. Packet Timing Advance Control Channel/Downlink (PTCCH/D) is used to transmit timing advance information updates to several mobile stations. One PTCCH/D is paired with several PTCCH/Us.
9. Broadcast Control Channel (BCCH) in the downlink is used to broadcast cell specific information.

10.4.3 Packet Traffic Channels

Traffic channels (TCHs) carry either encoded speech or user data. These channels are multiplexed in either a predetermined manner or dynamically by the MAC. TCH can be either full rate (TCH/F) or half rate (TCH/H). Traffic channels are also distinguished by the modulation technique used such as GMSK and 8-PSK. Packet Data Traffic Channel (PDTCH) is for data transfer on both physical channels SBPSCH (Shared Basic Physical Sub Channel and DBPSCH (Dedicated Basic Physical Sub Channel). The PDTCH is a temporary channel provided to a single mobile station or to a group in case of multicast transmission. However, one mobile station may use several PDTCHs in parallel. PDTCH allows several MSs to be multiplexed on the same SBPSCH. PDTCH also allows several traffic classes to be multiplexed on the same shared or dedicated channel. In a multicast transmission a mobile station may use several PDTCHs for individual packet transfer. The PDTCH is either in the uplink direction (PDTCH/U) or downlink direction (PDTCH/D). A PDTCH may be either full rate (PDTCH/F) or half rate (PDTCH/H) depending on whether it is transmitted on a Packet Data Channel/Full (PDCH/F) or Packet Data Channel/Half (PDCH/H), respectively.

10.5 Media Access Control (MAC) and Radio Link Control (RLC)

The Media Access Control (MAC) and Radio Link Control (RLC) provide data traffic transfer from the upper layer to the physical channel. The MAC is connection oriented—that is, connections need to be established before any packets can be transmitted. In the standard such connections are called Temporary Block Flows (TBFs). A TBF is a logical unidirectional connection between two MAC entities, where one MAC entity belongs to the mobile station and the other to the BSS. The TBF is temporary entity since the connection ends once there are no more data to transfer and all acknowledgments have been successfully received. The TBF is allocated radio resources on one or more physical channels (i.e., PDCHs). All packets (i.e., RLC/MAC PDUs) that belong to the TBF are transmitted on the allocated PDCHs. A PDCH can accommodate multiple TBFs. To differentiate between TBFs, the standard introduces Temporary Flow Identity (TFI). The TFI value is unique among concurrent TBFs in the same direction (uplink or downlink). The TFI, together with its direction, provides a TBF unique identifier. In addition, a Global_TFI is assigned to each station for identification purposes.

In the following subsections we will focus on some key mechanisms incorporated in the GPRS MAC.

10.5.1 TBF Establishment

10.5.1.1 TBF Establishment Initiated by Mobile Station

The mobile station which is the source of the data traffic initiates TBF establishment with the BSS using one of the following access processes: One Phase Access or Two Phase Access. These processes are described below.

10.5.1.1.1 One Phase Access In the One Phase Access (Figure 10.16), the mobile station initiates the packet access procedure by sending PACKET CHANNEL REQUEST messages on the PRACH channel. The PACKET CHANNEL REQUEST messages contain an indication of the type of access, parameters, and requirements for radio resources. This includes the requested TBFs' type, Radio Priority, and number of radio blocks (or RLC/MAC blocks). The number of requested radio blocks cannot exceed the actual number of RLC/MAC blocks waiting in the mobile station. Due to the nature of the random access scheme used in PRACH, it is possible to have multiple stations sending PACKET CHANNEL REQUEST at the same time (i.e., collisions can occur). If a collision or packet loss occurs (i.e., the mobile station does not receive a response from the base station), the PACKET CHANNEL REQUEST will be retransmitted. The mobile station is allowed up to a predetermined number of attempts to send a PACKET CHANNEL REQUEST. The maximum number of attempts is combined with a persistence level that is in direct relationship to the mobile station priority. The higher the priority, the higher the persistence level. The number of allowed attempts is broadcasted by the base station on the PBCCH and PCCCH.

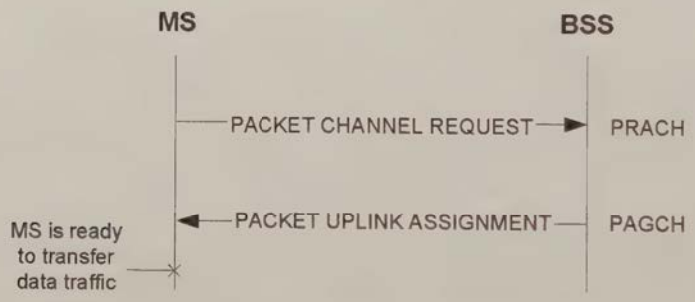


Figure 10.16 TBF Establishment Initiated by the MS: One Phase Access

After successful reception of the PACKET CHANNEL REQUEST, the BSS replies on the PAGCH channel with PACKET UPLINK ASSIGNMENT. The PACKET UPLINK ASSIGNMENT contains the following information:

- TFI: Unique value that identifies the requested TBF.
- One or more PDCHs assigned to the TBF: A radio frequency channel and one or more time slots.
- USFs: 3-Bit field associated with each assigned PDCH. For example, if a TBF connection is assigned frequency c_i and time slot numbers 2 and 5, there are two USFs assigned: one for time slot number 2 and the other for slot number 5.
- USF_GRANULARITY: 1-Bit field that indicates the number of RLC/MAC blocks transmitted at a time. Value "0" refers to one RLC/MAC block; value "1" refers to four consecutive RLC/MAC blocks.

10.5.1.1.2 Two Phase Access In the Two Phase Access (Figure 10.17), the mobile station initiates the packet access procedure by sending PACKET CHANNEL REQUEST. The BSS requests the mobile station to send a PACKET RESOURCE REQUEST message. This request is sent implicitly to the mobile station in the PACKET UPLINK ASSIGNMENT message. Upon receiving the PACKET UPLINK ASSIGNMENT, the mobile station transmits a PACKET RESOURCE REQUEST message to the BSS on PACCH. The PACKET RESOURCE REQUEST contains the following information:

- Mobile station radio access capability.
- Channel Request Description: the request uplink resource includes the radio peak throughput, priority class of the requested TBF, RLC mode of the requested TBF (i.e., RLC acknowledged mode, RLC unacknowledged mode), and the number of RLC/MAC blocks that the mobile station wishes to transmit.

After receiving the PACKET RESOURCE REQUEST, the BSS replies on the PACCH channel with PACKET UPLINK ASSIGNMENT.

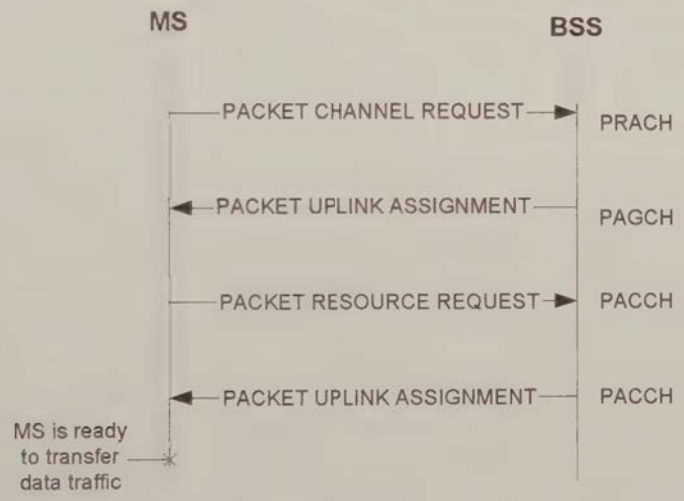


Figure 10.17 TBF Establishment Initiated by the MS: Two Phase Access

10.5.1.2 TBF Establishment Initiated by Network

The network may initiate a TBF to transfer packets from the network to the mobile station. The procedure may be entered when the mobile station is in MAC-Idle state (for Iu mode) or in Packet Idle State (for A/Gb mode) (Figure 10.18). Such TBF can also be initiated on PACCH if a TBF in this direction is already established. First the BSS performs a paging procedure to discover the location of the mobile station. After discovery, the BSS will perform resource assignment. The network may assign one or more PDCHs for the TBFs based on the network's discretion. The allocated radio resources are provided to the mobile station in the PACKET DOWNLINK ASSIGNMENT message transmitted on the PCCCH.

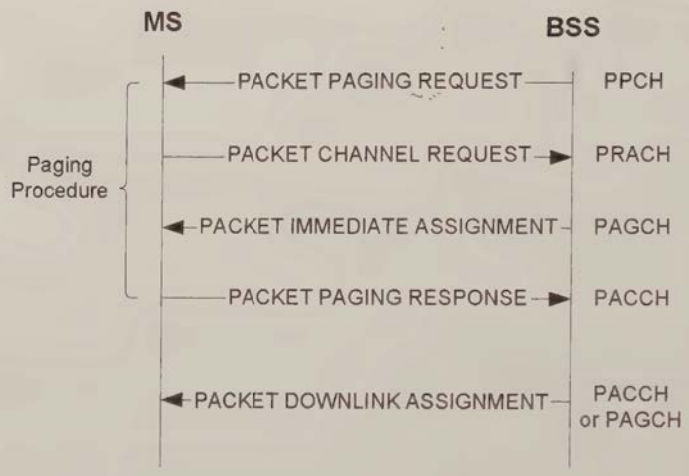


Figure 10.18 TBF Establishment Initiated by Network

10.5.2 Channel Access and Resource Allocation

The MAC is based on the time-slotted structure of the physical channel. There are two channel access methods:

- *Slotted Aloha method:* This random access method is applied only in PRACH where multiple mobile stations send request packets arbitrarily in the uplink direction at the beginning of a slot. In case the packet collides with a packet sent by another station, the station backs off for an arbitrary time and tries to transmit again.
- *Time Division Multiple Access (TDMA) method:* This contention-free channel access method is applied in all logical channels except PRACH. The packets are transmitted in predefined time slots allocated by the BSS. The standard defines three types of resource allocation mechanisms: Dynamic Allocation, Extended Dynamic Allocation, and Exclusive Allocation.

Using the USF mechanism described in the previous sections, the network can control the radio resource for each mobile station dynamically based on the demand of the mobile station (as indicated in the packet channel request) and the load of the network. USF is the 3-bit field included in the RLC/MAC header of the radio block (Figure 10.14) sent by the network in the downlink direction. This 3-bit field allows eight different USF values used for multiplexing in the uplink channel. On PCCCH, one USF value (USF = "111" or called USF = FREE) is used to indicate PRACH. The other USF values are used to reserve the uplink for different MSs.

10.5.2.1 Uplink Data Transmission

After TBF establishment, a TFI and assigned PDCHs are associated with the TBF. In addition, a USF is associated with an assigned PDCH. Up to eight TBFs can be multiplexed on the same PDCH. A mobile station listens and examines every RLC/MAC PDU on the assigned PDCHs (in the downlink). If the mobile station discovers its USF in the header of a RLC/MAC PDU, the following will occur. Depending on USF_GRANULARITY (assigned during the TBF establishment procedure) the MS will transmit starting at the next uplink block, either one or four consecutive radio blocks. Figure 10.19A shows an example of this procedure for the Dynamic Allocation medium access mode. The table in Figure 10.19B includes the TBFs at each MS. For TBF1 on MS1, USF GRANULARITY=0, resulting in one radio block transmission in the corresponding uplink block. In the case of TBF2 on MS2, USF GRANULARITY=1, resulting in four consecutive radio block transmissions.

Figure 10.19B shows an example of the USF procedure for the Extended Dynamic Allocation medium access mode where there are multiple PDCHs assigned to one connection. Notice that in this case if USF GRANULARITY=1, the four radio blocks will be transmitted on different PDCHs.

10.5.2.2 Downlink Data Transmission

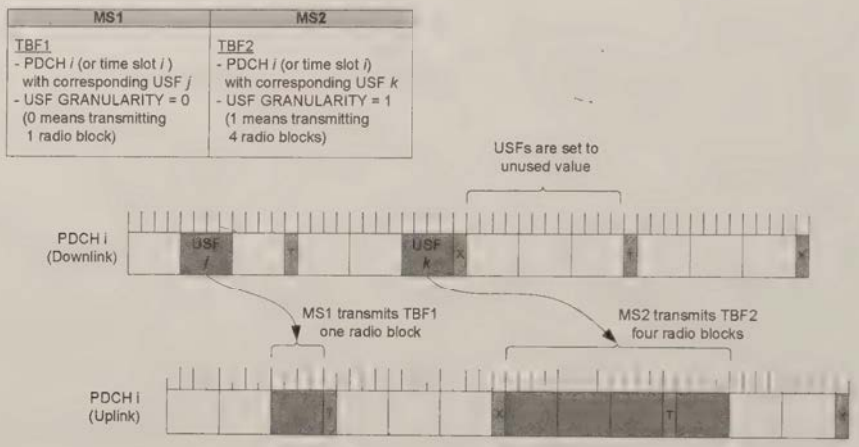
For downlink transmissions which are governed only by the BSS, there is no need for the USF mechanism. The BSS will choose the appropriate packets for transmission from the TBF queues which reside at the BSS. This transmission will occur on the downlink PDCHs associated with the TBF.

10.5.3 Radio Link Control (RLC)

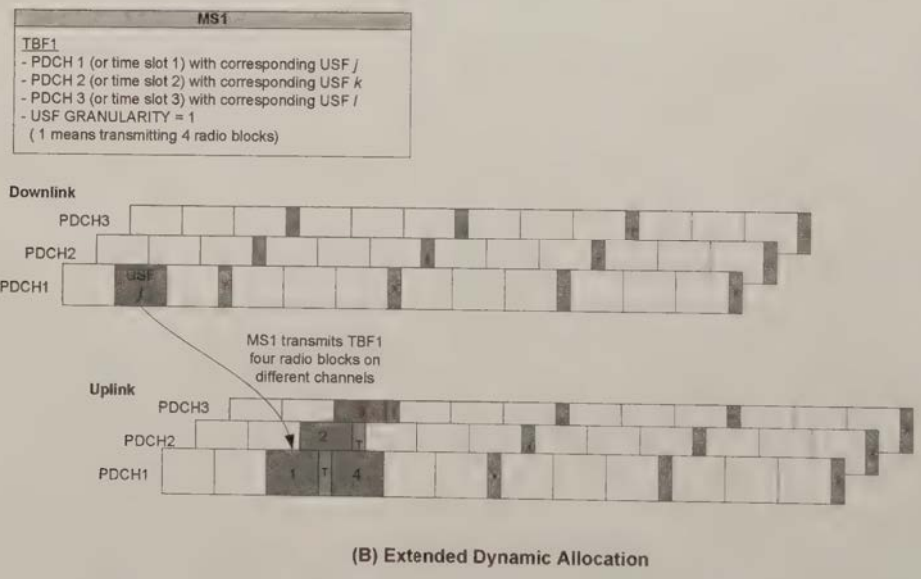
The RLC layer, which is located above the MAC layer, can provide reliability for MAC transmissions. The RLC can operate in one of the following three modes: transparent mode, acknowledged mode, and unacknowledged mode. The RLC in Iu mode includes all three modes while RLC in A/Gb mode includes only acknowledged mode and unacknowledged mode.

In transparent mode, the RLC has no functionality—that is, the packets pass through the RLC layer to the MAC layer without adding any protocol information.

In the acknowledged mode, the transfer of packets is controlled by a selective Automatic Repeat Request (ARQ) mechanism, in which the receiving station requests retransmission if an error occurs, coupled with the numbering of packets in one TBF. The sending station transmits packets within a window and the receiving station sends Packet Uplink Ack/Nack or Packet Downlink Ack/Nack messages. The ARQ mechanism implemented is Selective Repeat ARQ. In other words, every Ack message acknowledges all correctly received packets up to the indicated sequence number. The receiving station can selectively request erroneous packets for retransmission. The network may reallocate the network resources to accommodate the additional resources required for retransmissions. In EGPRS, acknowledged mode, the transmission of packets is also controlled by more advanced ARQ mechanisms that enable the retransmission of only part of the packet, reducing the retransmissions overhead.



(A) Dynamic Allocation



(B) Extended Dynamic Allocation

Figure 10.19 Examples of USF Mechanisms

In unacknowledged mode, the transmission of packets is controlled by the numbering of the packets within one TBF and does not include any retransmissions. The receiving station extracts user data from the received packets and attempts to preserve the user information length by replacing missing packets with dummy information bits.

10.5.4 MAC States

The MAC as applied to GERAN Iu mode can be in one of four states: MAC-Idle, MAC-Shared, MAC-DTM, and MAC-Dedicated.

In the MAC-Idle state there are no TBFs and the mobile station monitors relevant paging subchannels on the PCCCH. Once the upper layers have a packet for transmission and connect with the MAC, the MAC will establish a TBF on a shared channel, SBPSCH, and it transitions to MAC-Shared state. The RRC or RLC/MAC may also dictate to the MAC to establish a TBF on a dedicated channel, DBPSCH. In this case the MAC transits to a MAC-Dedicated state.

In the MAC-Shared state, the mobile station is allocated radio resources providing a TBF for a point-to-point, unidirectional transfer of upper layer packets on one or more shared channels (SBPSCHs). The MAC can transmit these packets in either RLC acknowledged mode or RLC unacknowledged mode. When all packets have been delivered and the acknowledgments have been received, then the MAC can release all TBFs on the downlink and uplink direction and return to the MAC-Idle state.

In the MAC-Dedicated state, the mobile station is allocated radio resources to transmit a TBF on one or more dedicated channels (DBPSCHs). The MAC can transmit these packets in RLC acknowledged mode, RLC unacknowledged mode, or transparent mode. After all packets have been delivered and acknowledgments have been received, the MAC can release all TBFs on the DBPSCHs and return to the MAC-Idle state.

In the MAC-Shared state, upper layers may require the transfer of an upper layer packet, which may trigger the establishment of a TBF on a dedicated channel, DBPSCH. In this case the MAC will transmit from its MAC-Shared state to the MAC-DTM state.

In the MAC-DTM state a mobile station has been allocated both shared and dedicated radio channels (one or more DBPSCHs and one or more SBPSCHs). Packets can be delivered in RLC acknowledged mode, RLC unacknowledged mode, or RLC transparent mode. When all packets that triggered the allocations of shared resources have been transmitted and consequent TBFs on the downlink and uplink SBPSCHs have been released, the MAC will transit to MAC-Dedicated state. Similarly, when all packets that triggered the allocation of dedicated channels have been transmitted and their consequent TBFs have been released to the MAC, the MAC will transit to MAC-Shared sate. Once all TBFs on both SBPSCHs and DBPSCHs have been released, the mobile station enters the MAC-Idle state.

When the MAC is in either MAC-Idle state or MAC-Shared state it continuously monitors the system information broadcasted in the PCCCH. The MAC on the mobile station may indicate to the RRC the availability of a new cell and a cell change. When a cell change is required either by the mobile station or by the network, the mobile station can operate in MAC-Idle state or MAC-Shared state in the current cell while getting system information on the new cell. However, the mobile station may suspend its TBF(s) and monitor the PCCCH in the current cell, in order to receive the necessary information on the new cell BCCH.

Once the switch to the new cell has been completed, the mobile station aborts any TBF in progress on both the downlink and uplink. The mobile station will reestablish its required TBF connections in the new cell.

10.6 Radio Resource Control (RRC) and Radio Resource (RR)

The Radio Resource Control (RRC) is responsible for radio resource management for Iu traffic, whereas the Radio Resource (RR) is responsible for managing the A/Gb traffic. The relationship between the two is presented in Figure 10.20.

The RRC and RR are responsible for allocating new dedicated basic physical subchannels as well as the intracell handovers of the dedicated basic physical subchannels.

The RRC broadcasts system information (such as location services in cells) to the mobile stations. The RRC also establishes, maintains, reconfigures, and releases connections between the mobile stations and the GERAN network. This includes cell reselection, admission control, and link establishment. This also includes selection of the connection parameters considering both control and applications needs. This allocation is then indicated to the mobile station. The RRC also handles mobility, which includes evaluation, decision, and execution of functions such as handover and moving from cell to cell. The RRC handover procedures control the mobility of the mobile station and include procedures to modify the channels allocated to the mobile station. Executing these functions, the RRC considers the requested QoS and ensures allocation of sufficient resources for the targeted QoS. In addition, the RRC performs monitoring, reporting, ciphering, and mediating between GERAN and the mobile stations.

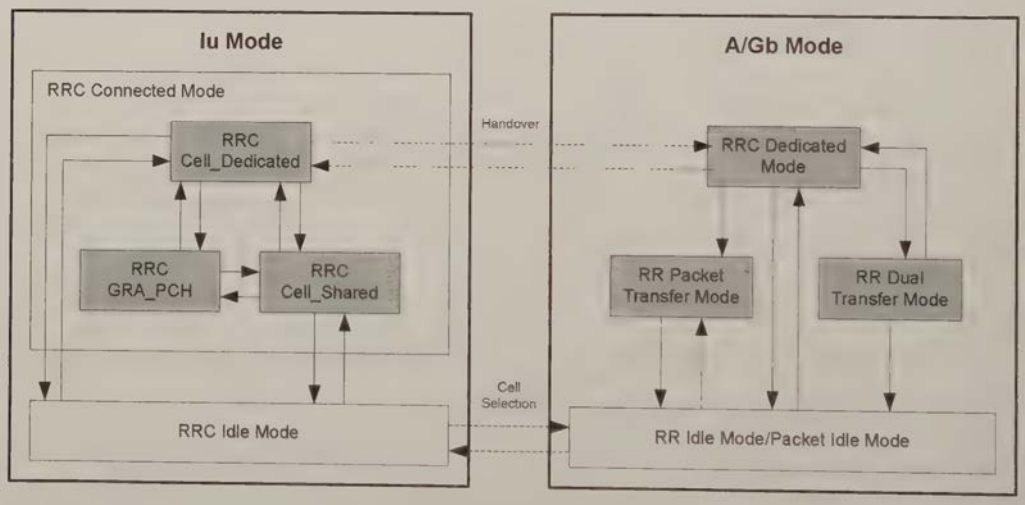


Figure 10.20 Relationship between RR and RRC

The RR maintains at least one PDCH that carries user data and all the necessary control signaling for initiating packet transfer whenever that signaling is not carried by the existing control channels. Other PDCHs, acting as slaves, are used for user data transfer and for dedicated signaling. The GPRS network is based on dynamically allocating capacity and hence does not require permanently allocated PDCHs. Capacity allocation is based on actual needs. A mobile station

can be allocated permanent or temporary physical resources (i.e., PDCHs). In cases where some PDCHs are congested, the network may allocate more resources. The existence of PDCHs does not imply the existence of PCCCH. In this case, the GPRS stations can use the GSM control channel CCCH. The network can then assign resources on PDCHs for uplink transfer. After the transfer, the MS returns to CCCH. However, when PCCCH is allocated in the cell, all GPRS stations will use it. The network can allocate a PCCCH either as a result of the increased demand for packet data transfers or if there are enough available physical channels. If the network finds that the PCCCH capacity is not adequate, it can allocate additional PCCCH resources on one or several PDCHs.

The RRC has several modes of operation. When the mobile stations powers on and the Iu mode is selected, the MS enters the RRC-Idle Mode. In this mode the MS monitors control broadcasts messages. Once a connection is established and the Iu mode is entered, the RR-Idle mode changes to RRC-Connected mode. Such a connection can be made only after the upper layers have requested a connection and the network has responded by assigning communication resources. The RRC-Connected mode is characterized by three states: RRC-Cell_Shared, RRC-Cell_Dedicated, and RRC-GRA_PCH.

The RR supports both GPRS packet traffic and GSM traffic circuit switched traffic. The circuit switch part includes an Idle mode and Dedicated mode. The GPRS part includes Packet Idle mode and Packet Transfer mode. Stations belonging to Class A, supporting both GPRS and GSM circuit switching traffic, are in Dual Transfer mode.

10.6.1 RRC Modes of Operation

The RRC has several modes of operation: The RRC-Cell_Shared, RRC-Cell_Dedicated, and RRC-GRA_PCH.

In RRC-Cell_Shared state the MS executes a cell update procedure on cell changes, monitors the PBCCH control channel for system information messages, and monitors neighboring cells for neighbour cell measurements. The RRC will transit to RRC-Idle mode when the RRC connection is released or when the operation mode is changed to A/Gb mode. In the RRC-Cell_Shared state the MAC is responsible for allocating the shared physical subchannels.

The RRC-Cell_Dedicated state is assigned when a Dedicated Basic Physical Sub Channel (DBPSCH) is allocated to the MS. In this mode the MS is assigned one or more dedicated basic physical subchannels in the uplink and downlink. A station in this state performs measurement and reporting activities, listens to neighboring cells for measurements, and executes handover procedures of the dedicated basic physical subchannels on a cell change. Transition from RRC-Cell_Dedicated state to RRC-Idle mode occurs when the RRC connection is released. In the RRC-Cell_Dedicated state the RRC is responsible for allocating the physical dedicated subchannels.

The RRC-Cell_Dedicated state changes to RRC-Cell_Shared state when 1) all the dedicated basic physical subchannels are released and shared basic physical subchannels exist or 2) no shared basic physical subchannels exist.

The RRC-GRA_PCH state is assigned when GERAN orders the MS to move to RRC-GRA_PCH state via explicit signaling. In this transition the MS aborts any TBF in progress. In RRC-GRA_PCH state, no basic physical subchannel is allocated to the MS and no radio resource allocation tasks are executed. Hence, no uplink activity is possible. However, the MS continues to monitor the control channel; PCCCH and its location is known to GERAN. RRC will change from RRC-GRA_PCH state to RRC-Cell_Shared state due to changes in GRA update, cell update, or response to paging. Also in the RRC-GRA_PCH state, the MS may request a radio resource to answer to a paging message or to perform a GRA/Cell update procedure.

The RRC in RRC-Connected mode is responsible for allocating dedicated basic physical subchannels, which causes the MS to enter the RRC-Cell_Dedicated state. The MAC is responsible for allocating shared basic physical subchannels (SBPSCH). The MAC allocates the PDTCHs according to the QoS class of the radio link and the multi-slot capability of the MS. The RRC provides the MAC with QoS class and indication of the MS multi-slot capability.

10.6.2 RR Modes of Operation

The RR supports both GPRS packet switched traffic and GSM circuit switched traffic. The circuit switched part includes an idle mode and a dedicated mode as well as other modes related to voice services that are not discussed in this book. The GPRS part includes packet idle mode and packet transfer mode.

10.6.2.1 Packet Idle Mode

In packet idle mode, the MS listens to the PBCCH and to the paging subchannel for the paging messages. If PCCCH is not present in the cell, the mobile station listens to the BCCH and to the relevant paging subchannels. A station in the packet idle mode that belongs to GPRS class A may simultaneously enter the different RR service modes defined for GSM circuit switch services (e.g., circuit switched connections management, mobility management, and radio resource management). In this mode upper layers can require the transfer of packets that results in the establishment of TBFs and transition to packet transfer mode. This mode is not applicable to an MS supporting DTM with an active RR connection.

10.6.2.2 Dedicated Mode

An MS that supports DTM, meaning supporting both GPRS and other GSM services simultaneously, and has an active RR connection and has no allocated packet resources is in dedicated mode.

10.6.2.3 Packet Transfer Mode

In packet transfer mode, the mobile station is allocated radio resources for its TBFs on one or more physical channels on both the uplink and downlink. Delivery of the packets can be done in RLC acknowledged or RLC unacknowledged modes. Packet transfer mode is not applicable to a mobile station supporting DTM that has an active RR connection.

When selecting a new cell, the mobile station leaves the packet transfer mode and enters the packet idle mode. After moving to the new cell, it reads the system information and may change back to Packet Transfer Mode and resumes packet transmission operations. A GPRS class A station may simultaneously enter different RR service modes for GSM circuit switched services.

10.6.2.4 Dual Transfer Mode (DTM)

In dual transfer mode the mobile station supports an active RR connection and is allocated radio resources for its TBFs on one or more physical channels in the uplink and downlink directions. This mode is only applicable for a mobile station supporting GPRS or EGPRS and is a subset of class A mode of operation (i.e., supporting both GPRS and other GSM services simultaneously).

Packets can be transferred in RLC acknowledged or RLC unacknowledged mode. A station in DTM is carrying out all of the tasks of a station in the dedicated mode. In addition, the upper layers can require the release of all the packet resources, which triggers the transition to the dedicated mode, and the release of the RR resources, which triggers the transition to idle mode and packet idle mode.

When the station is handed over to a new cell, the RR leaves the DTM, enters the dedicated mode, may read the system information messages sent on the control channels, and then enters the DTM.

10.6.3 Transition between Modes

Figure 10.21 shows the four RR states for a class A station that does not support DTM. The four states can be regarded as a combination of two state machines with two RR states each: circuit switched part comprises idle mode and dedicated mode and the GPRS part comprises packet idle mode and packet transfer mode.

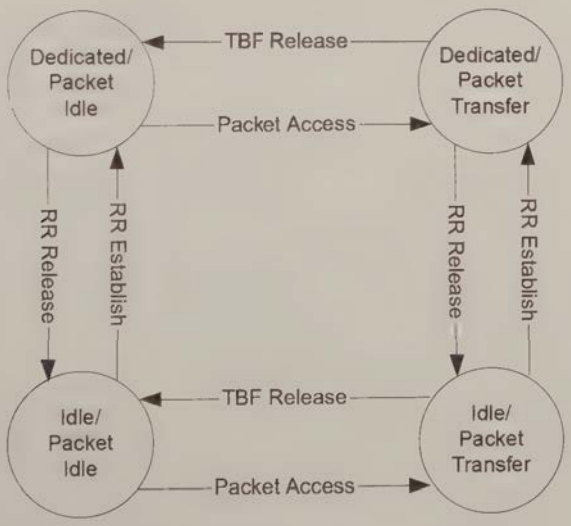


Figure 10.21 RR Modes for a Class A that Does Not Support DTM

Figure 10.22 shows the RR modes and transitions for a class A station that supports DTM and class B. Class B includes the following modes: packet idle mode, packet transfer mode, and dedicated mode.

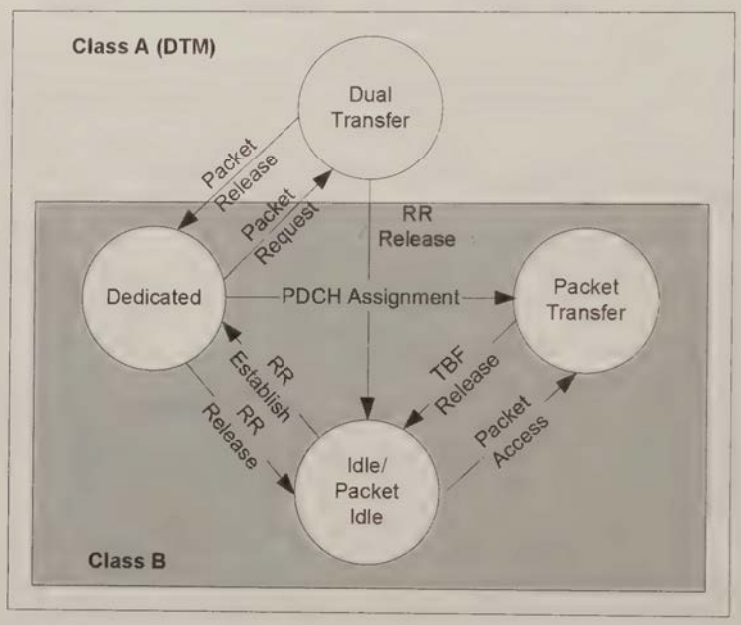


Figure 10.22 RR Modes and Transitions for Class B and Class A that Supports DTM

Figure 10.23 shows the RR modes and transitions for a Class C station. When it is attached to a GSM channel, there are two RR modes: idle mode and dedicated mode. When it is attached to a GPRS channel, there are two RR modes: packet idle mode and packet transfer mode.

10.7 QoS Support

The standard realizes that successful deployment of IP multimedia services requires support and management capability to provide different degrees of end-to-end QoS under various conditions. End-to-end QoS may be specified by Service Level Agreements. Hence, it requires consideration of available bandwidth, QoS classes, measurement, monitoring, and other tools. It requires that QoS support for IP multimedia sessions includes the following functions:

- Negotiate QoS for IP multimedia sessions as a whole as well as their individual components, when the session is established and during its execution. The assumption is that the IP multimedia applications are able to define their requirements, negotiate their capabilities, and identify and select the available media components, such as QoS.

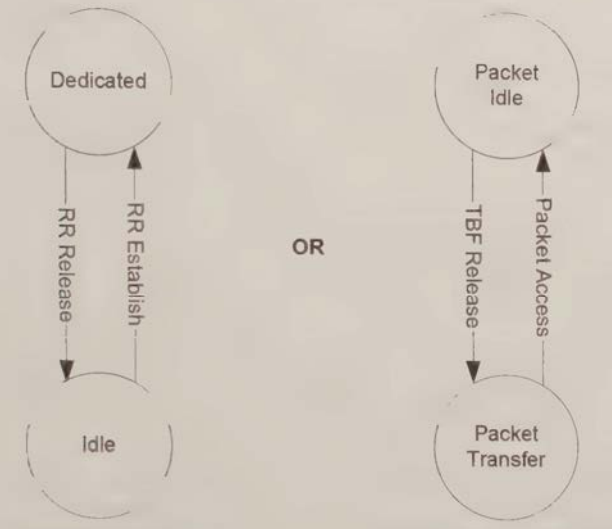


Figure 10.23 RR Modes and Transitions for Class C

- Allow either the user or the network to identify alternative destinations for IP multimedia sessions and their individual components. Based on this identification, these sessions can be redirected to these alternate destinations at various stages of the multimedia sessions.
- Support end-to-end QoS for voice that has quality at least as good as that provided by circuit-switched networks.
- Support roaming and negotiation between carriers for QoS.
- Deploy IP Policy Control for IP multimedia applications.
- Support more than one IP multimedia application in a session.
- Provide security services similar to those of circuit switched networks.
- Support for networking between the packet and circuit switched services.

GPRS specifies signaling that can enable support for various traffic streams with different characteristics such as constant bit rate or variable bit rate, connection or connectionless, point-to-point or point-to-multipoint, and bi-directional or unidirectional streams. These traffic streams can be established on a demand, reserved, or permanent basis.

The standards define several subscriber profiles that include information and parameters based on the contractual service agreement between the user and the carrier. The profile includes subscriber services and subscriber QoS profiles (e.g., service priority, reliability, delay, and throughput).

To provide end-to-end QoS, we need support from several components of the mobile system. The GPRS protocol architecture (control plane) is shown in Figure 10.24. We will focus on two QoS aspects: the GPRS bearer service QoS profile (Section 10.7.1) and radio bearer service QoS mechanisms (Section 10.7.2).

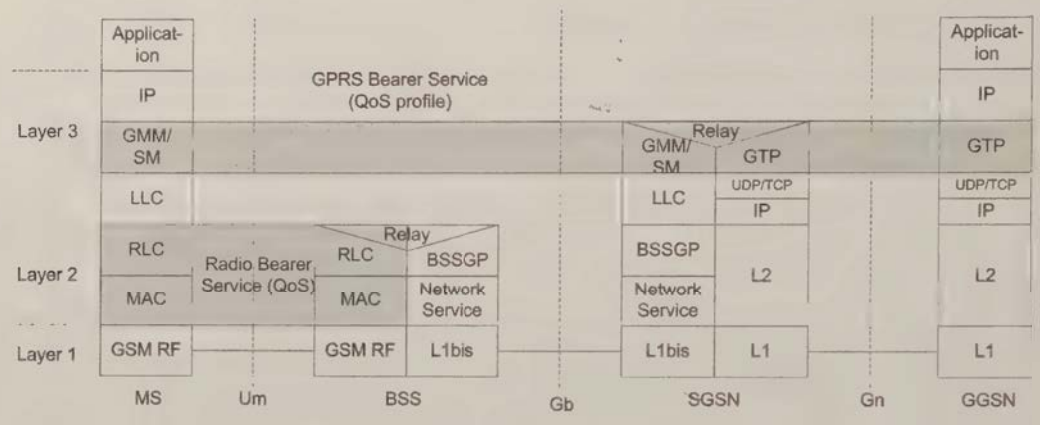


Figure 10.24 GPRS Protocol Architecture (Control Plane)

10.7.1 QoS Profile in GPRS Bearer Service

In order to provide QoS to an application, the network resources on each component of the mobile system (i.e., mobile station, Serving GPRS Support Node [SGSN], Gateway GPRS Support Node [GGSN]) need to be reserved. Resource reservation is carried out by the signaling mechanism that uses QoS profiles. A QoS profile is the set of QoS parameters that describes the application's characteristics and QoS requirements. A QoS profile consists of four parameters: service precedence (priority) parameter, reliability parameter, delay parameters, and throughput parameter. These parameters are described below.

10.7.1.1 Service Precedence or Priority Parameter

This includes the priority of supporting a specific traffic stream compared to other traffic streams. Higher priority streams will be served before lower priority streams. In case the network is congested, lower priority packets will be discarded before the higher priority packets. Three levels (classes) of priorities are applied (see Table 10.1).

Table 10.1 Service Precedence Classes

Precedence	Precedence Name
1	High Priority
2	Normal Priority
3	Low Priority

10.7.1.2 Reliability Parameter

This indicates the transmission characteristics required by the application in terms of loss probability, duplication of packets, mis-sequencing of packets, or corruption of packets. GPRS defines three reliability classes that are described in Table 10.2.

Table 10.2 Reliability Classes

Reliability Class	Lost Packet Probability	Duplicate Packet Probability	Out of Sequence Packet Probability	Corrupt Packet Probability
1	10^{-9}	10^{-9}	10^{-9}	10^{-9}
2	10^{-4}	10^{-5}	10^{-5}	10^{-6}
3	10^{-2}	10^{-5}	10^{-5}	10^{-2}

10.7.1.3 Delay Parameter

This parameter defines the maximum values for the mean packet delay and the 95 percentile delay that the GPRS network can provide. This delay can consist of the transmission delay from the user to the network (uplink), or from the network to the user (downlink), and the delay in the GPRS backbone. This delay does not include external networks or user higher layers. GPRS defines five classes of delay values described in Table 10.3.

Table 10.3 Delay Classes

Delay Class	Delay (maximum values)			
	Packet Size: 128 octets		Packet Size: 1024 octets	
	Mean Transfer Delay (sec)	95 Percentile Delay (sec)	Mean Transfer Delay (sec)	95 Percentile Delay (sec)
1. (Predictive)	< 0.5	< 1.5	< 2	< 7
2. (Predictive)	< 5	< 25	< 15	< 75
3. (Predictive)	< 50	< 250	< 75	< 375
4. (Best Effort)	Unspecified			

10.7.1.4 Throughput Parameter

The throughput parameters include the maximum and mean bit rates. These terms can be negotiated between the user and the network before and during the communication session.

10.7.1.5 PDP Context Procedures

Each application's QoS requirements are mapped to a QoS profile. The mapping process is not defined in the standard. The QoS profile is included in the Packet Data Protocol (PDP) context. QoS profiles negotiation is managed by PDP context procedures (i.e., activation, modification, and deactivation). PDP context procedures are carried out by the Session Management (SM) protocol layer between MS and SGSN and by the GPRS Tunneling Protocol (GTP) layer between SGSN and GGSN as shown in Figure 10.25. Generally, PDP context procedures are used in PDP address (i.e., IP address) assignment and host configuration to a mobile station in addition to QoS profile signaling. Each application on a mobile station performs the PDP context procedures separately.

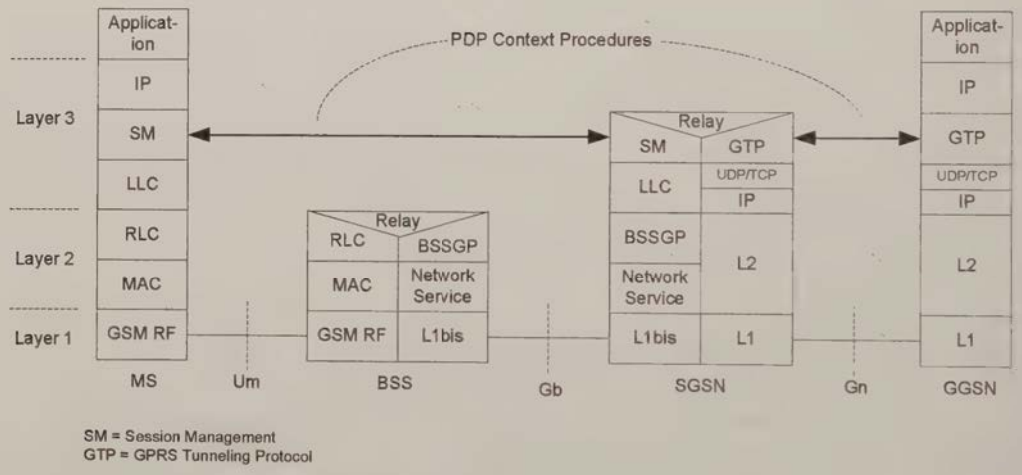


Figure 10.25 PDP Context Procedures

Figure 10.26 shows the PDP context activation procedure initiated by the MS. First, the MS sends SGSN an "Activate PDP Context Request" message that contains several information elements as well as the desired QoS profile of an application. The SGSN decides to accept or reject the request based on the available resources at the SGSN and subscribed QoS profile. If the SGSN accepts the request, it will send GGSN a "Create PDP Context Request" message containing the QoS profile. After receiving the "Create PDP Context Request" message, the GGSN decides to accept or reject the request based on the available resources at the GGSN and the mobile station's subscription information. If the GGSN accepts the request, GGSN sends the SGSN a "Create PDP Context Response" message including the negotiated QoS profile. Finally, SGSN includes the negotiated QoS profile in an "Activate PDP Context Accept" message and sends it to the MS.

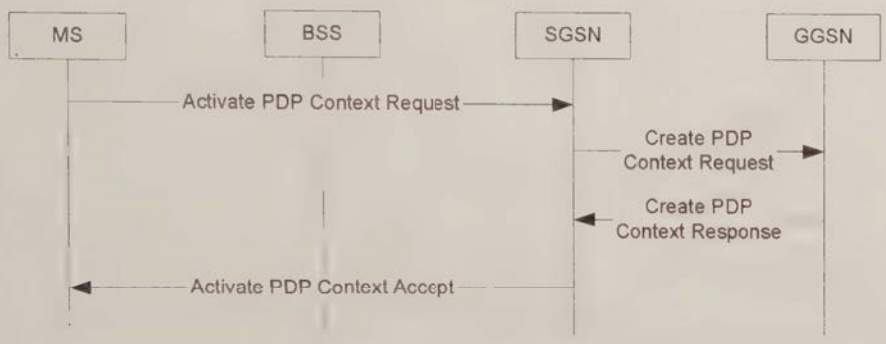


Figure 10.26 PDP Context Activation Procedure Initiated by MS

There are cases where packets originated from the external network are received by the GGSN and are destined to a mobile station. In these cases, the GGSN will initiate the PDP context activation procedure shown in Figure 10.27. In Step 2 the GGSN acquires the routing information to the MS from the Home Location Register (HLR). After receiving this routing information from the HLR, in Step 3 the GGSN sends a "PDU Notification Request" message to the SGSN and then the SGSN replies back with a "PDU Notification Response" to confirm that the SGSN will initiate a "Request PDP Context Activation" message. The SGSN sends the MS the "Request PDP Context Activation" message. In Step 5, the MS continues with a similar process as in PDP context activation initiated by the MS case (shown in Figure 10.26).

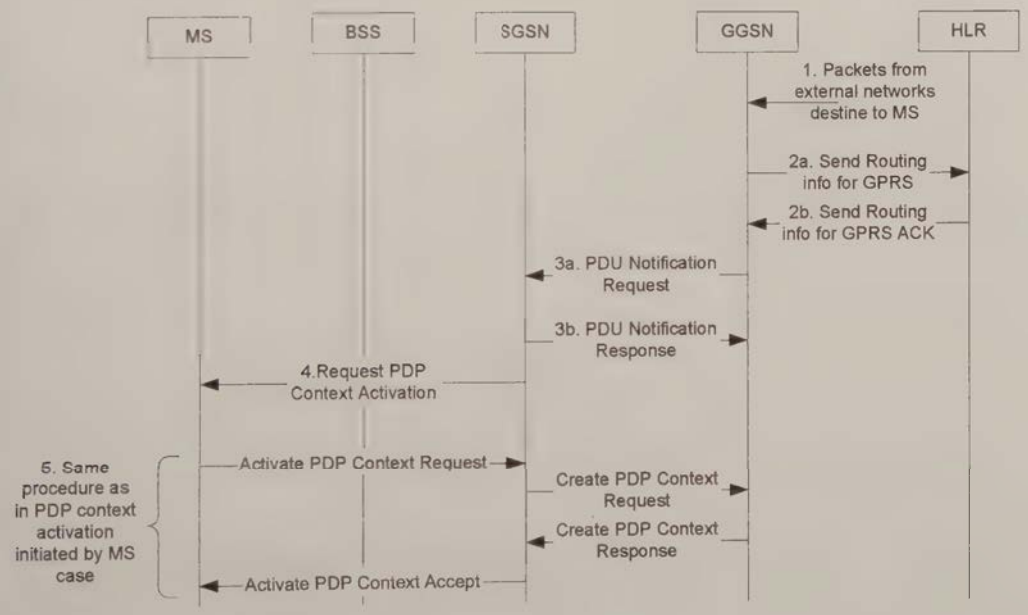


Figure 10.27 PDP Context Activation Procedure Initiated by GGSN

10.7.2 QoS Mechanisms in the Radio Bearer Service

In this subsection we will focus on the radio interface QoS mechanisms that enable quantitative QoS services: classification and packet scheduling. Figure 10.28 shows a simplified diagram of these QoS mechanisms.

First, an application performs the QoS negotiation with the SGSN as described in the previous subsection. When data packets arrive from the upper layer to the RLC/MAC, the TBF establishment process will be activated. During the TBF establishment process, the QoS profile will be mapped to RLC/MAC parameters (i.e., radio priority) included in the PACKET CHANNEL REQUEST. The mapping process is not defined in the standard. After the TBF is established, the TBF QoS parameters are used at the MS to classify the packets and at the BSS to make packet scheduling decisions. In the remaining part of this section we provide more details on the classification and packet scheduling mechanisms.

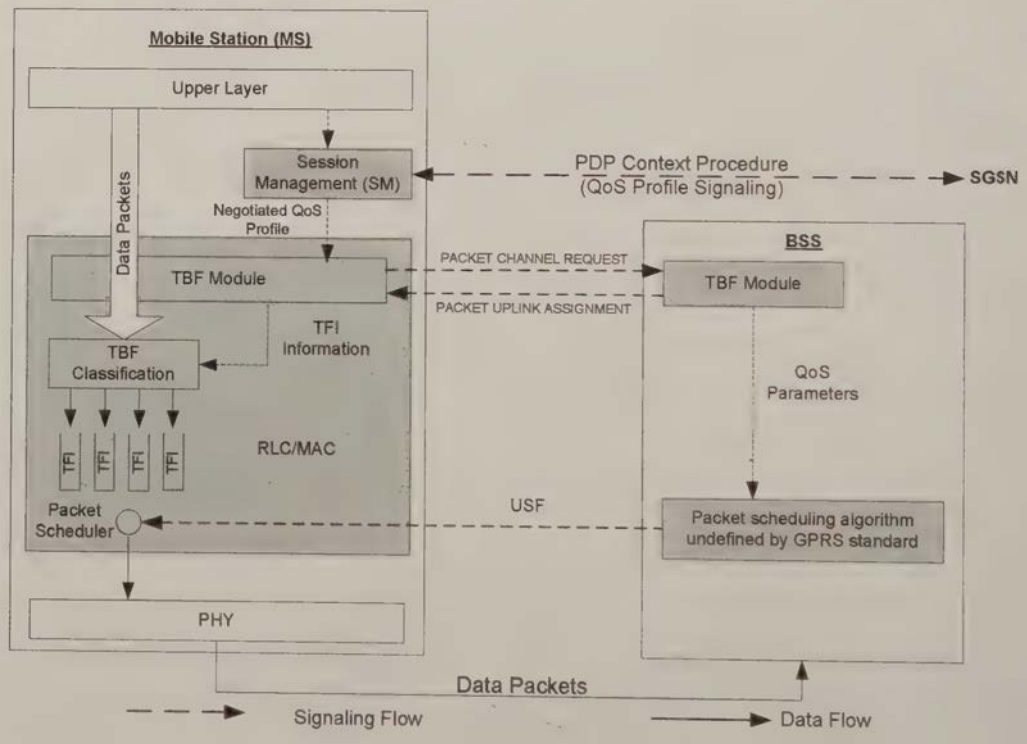


Figure 10.28 Simplified GPRS QoS Architecture on the Radio Interface

10.7.2.1 Classification

All packets that belong to a specific TBF are tagged with the corresponding TFI. These tags along with the direction (i.e., uplink, downlink) enable packet classification. Therefore, GPRS uses per-flow classification which supports per-flow QoS services. Notice that due to the tempo-

rary nature of the TBF, an application may have the TBF established and terminated several times during the course of the service. Therefore, TFI will be different for each TBF connection.

10.7.2.2 Packet Scheduling

As described in the Section 10.5.2, the channel access is based on TDMA. The time slot assignment is based on the request-grant process. The current bandwidth demand in terms of the number of RLC/MAC blocks waiting in queue is included in the PACKET CHANNEL REQUEST message sent during the TBF establishment process. Packet scheduling uses bandwidth demand information as well as TBF QoS parameters to decide when packets that belong to a specific TBF are allowed to transmit. Therefore, the packet scheduling algorithm can dynamically allocate the bandwidth based on an application's bandwidth demand and QoS requirements. The dynamic bandwidth allocation decisions performed at the BSS are communicated to the mobile stations using the USF process (see Section 10.5.2). It is important to mention that the packet scheduling algorithms are not defined by the standard. These algorithms should be defined and implemented by the GPRS network designers and carriers.

In summary, the GPRS system combined with proper packet classification and packet scheduling algorithms can enable per-flow quantitative QoS services.



CHAPTER 11

UMTS

11.1 Introduction

Universal Mobile Telecommunications System (UMTS) is a 3G technology that provides high-speed connection of up to 2 Mbps to support a wide variety of services, including multimedia services with different QoS requirements. As shown in Figure 11.1, UMTS evolved from 2G GSM technology and 2.5G GPRS. The effective bandwidth provided is up to 144 kbps for vehicular users, 384 kbps for mobile users, and up to 2 Mbps for static users. The recent UMTS Rel-5 added to previous releases (Rel-99 and Rel-4) the High-Speed Download Packet Access (HSDPA) technology. HSDPA adds an option of higher speeds of up to 10 Mbps required for multimedia applications.

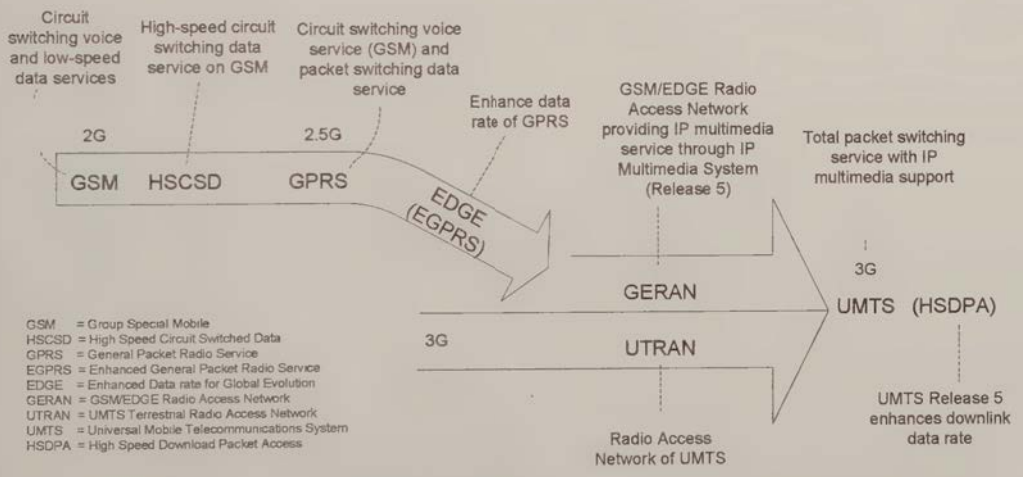


Figure 11.1 UMTS Evolution

UMTS, which is also referred to as WCDMA (Wideband CDMA or Wideband Code Division Multiple Access), is part of IMT-2000 (International Mobile Telecommunication–2000) effort, which is designed to provide high-speed communication with high-quality multimedia services and global roaming support. The IMT-2000 effort is led by the ITU (International Telecommunications Union), formerly the CCITT (Consultative Committee for International Telephony and Telegraphy), is an international organization that sets communication standards and consists of more than 150 member countries.

The IMT-2000 effort strives to create a family of compatible standards that can be used worldwide for all mobile applications. This family is expected to support both circuit and packet switched applications and provides QoS support for multimedia traffic. This effort considered several proposals for both terrestrial and satellite communication, from which WCDMA and CDMA 2000 were selected for terrestrial communication.

UMTS has been introduced and evolved in several releases. Starting with Release 99 UMTS integrated GSM and GPRS such that previous investments in those networks can be preserved. UMTS Terrestrial Radio Access Network (UTRAN) is UMTS's radio access network that provides the communication path between the mobile station and the 3G core network through the Iu interface. UMTS shares the same core network as GPRS except the UTRAN radio interface, which is newly designed (see Figure 11.2). Therefore, GPRS and UMTS are fully harmonized.

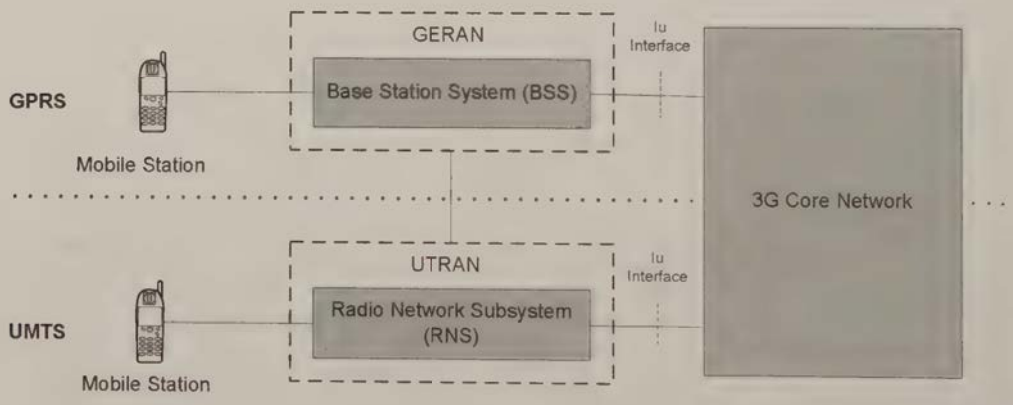
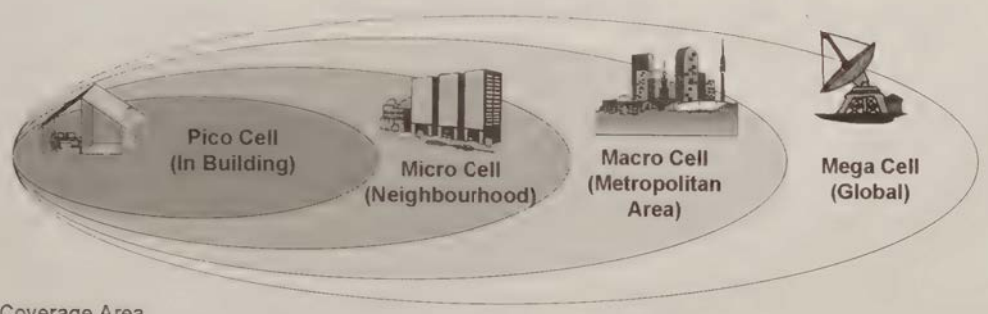


Figure 11.2 GPRS and UMTS

UTRAN supports two modes of operation: 1) Frequency Division Duplex (FDD), where uplink transmissions (from the mobile stations to UTRAN) and downlink transmissions (from UTRAN to the mobile stations) operate simultaneously using two separate frequency bands; and 2) Time Division Duplex (TDD), where uplink and downlink transmissions operate interchangeably in different time periods on the same frequency band.

In UTRAN FDD mode, UTRAN deploys Wideband Code Division Multiple Access (WCDMA), whereas in UTRAN TDD mode, UTRAN deploys Time Division–Code Division

Multiple Access (TD-CDMA). Figure 11.3 shows UMTS coverage scenarios. FDD mode, which is geared toward wide area coverage (i.e., public macro and micro cell), supports high user mobility and data rates of up to 384 kbps. TDD, which is geared toward smaller geographical areas (i.e., public micro and pico cells), supports data rates of up to 2 Mbps and slow user mobility (i.e., cordless phones). In order to operate in both wide and local areas, a mobile station or user equipment (UE) should support both TDD and FDD modes.



Coverage Area
Pico Cell 100 m. Macro Cell 5-10 km.
Micro Cell 0.5 km. Global Cell > 10 km.

Figure 11.3 UMTS Geographical Coverage

In this book we focus on UMTS Rel-5, which is presented in the following documents:

- TS 23.002 3rd Generation Partnership Project; Technical Specification Group Services and Systems Aspects; Network Architecture (Release 5)
- TS 25.301 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Radio Interface Protocol Architecture (Release 5)
- TS 25.401 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; UTRAN Overall Description (Release 5)
- TS 25.302 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Services provided by the physical layer (Release 5)
- TS 25.211 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Physical channels and mapping of transport channels onto physical channels (FDD) (Release 5)
- TS 25.321 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; MAC Protocol Specification (Release 5)
- TS 25.322 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Radio Link Control (RLC) Protocol Specification (Release 5)
- TS 25.323 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Packet Data Convergence Protocol (PDCP) Specification (Release 5)
- TS 25.331 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Radio Resource Control (RRC); Protocol Specification (Release 5)

- TS 25.308 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; High-Speed Downlink Packet Access (HSDPA); Overall Description; Stage 2 (Release 5)

11.2 UMTS Architecture

UMTS Rel-5 provides the ultimate evolution of voice and data convergence. As shown in Figure 11.4, similar to GPRS architecture, UMTS consists of three main entities: Mobile Station (MS), UTRAN, and Core Network (CN). A mobile station or user equipment (UE) communicates with Node B which controls the radio channel within its coverage area or cell. Multiple Node Bs are controlled by the Radio Network Controller (RNC). UMTS's Node B is equivalent to GPRS's Base Transceiver Station (BTS), while RNC is equivalent to GPRS's Base Station Controller (BSC). RNC and associated Node B form the radio network subsystem (RNS). The RNCs are interconnected to each other through the Iur interface. RNC connects to the core network through Iu interface which supports both voice and data services.

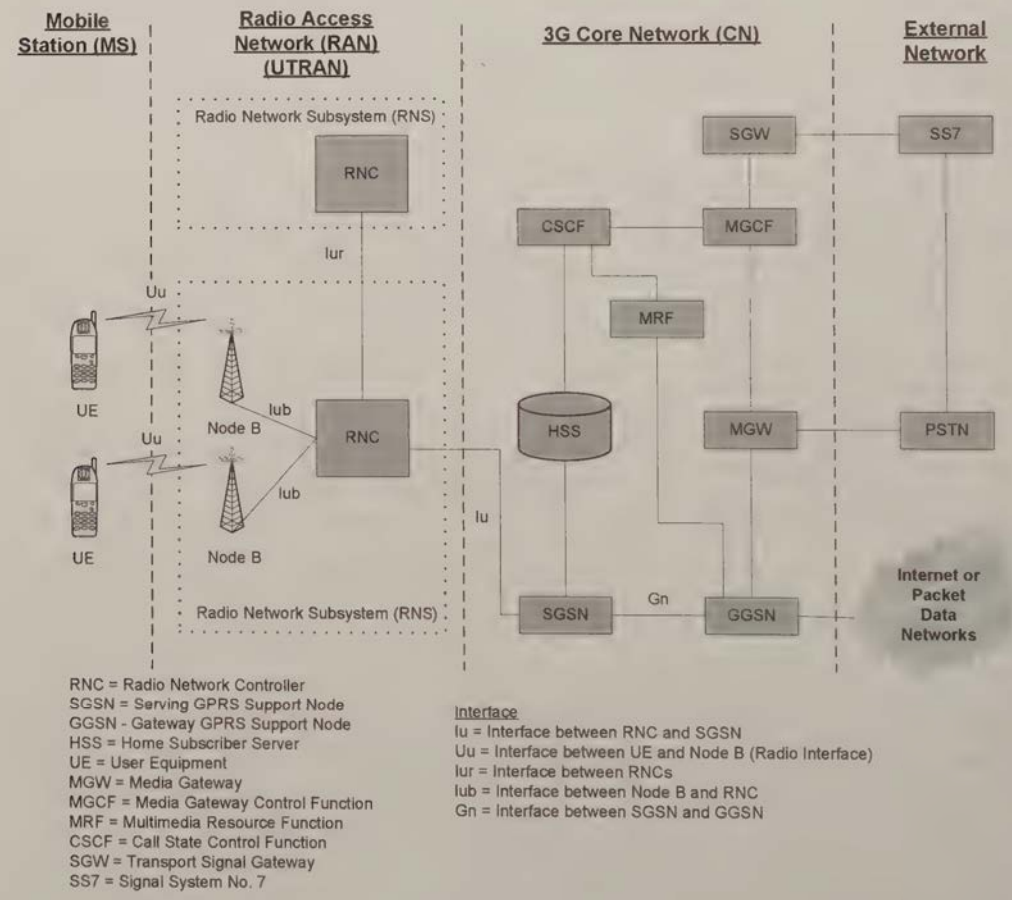


Figure 11.4 UMTS Architecture

UTRAN's protocol stack presented in Figure 11.5 consists of the Physical Layer (Layer 1), Data Link layer (Layer 2), and Network layer (Layer 3). The Physical Layer (PHY) includes the radio. The Data Link includes the Media Access Control (MAC), the Radio Link Control (RLC), the Packet Data Convergence Protocol (PDCP), and the Broadcast/Multicast Control (BMC). The Network Layer includes the Radio Resource Control (RRC). The RRC and RLC are divided into Control and User planes. PDCP and BMC exist in the User plane only. The PDCP and RLC in Rel-5 are unchanged from the Rel-99 and Rel-4 architecture, whereas the MAC is changed to include a new module that supports HSDPA. Layers 1, 2, and 3 are part of UMTS's Access Stratum (AS). The higher layer that is part of UMTS's Non-Access Stratum (NAS) includes Mobility Management (MM), Call Control (CC), and Session Management (SM).

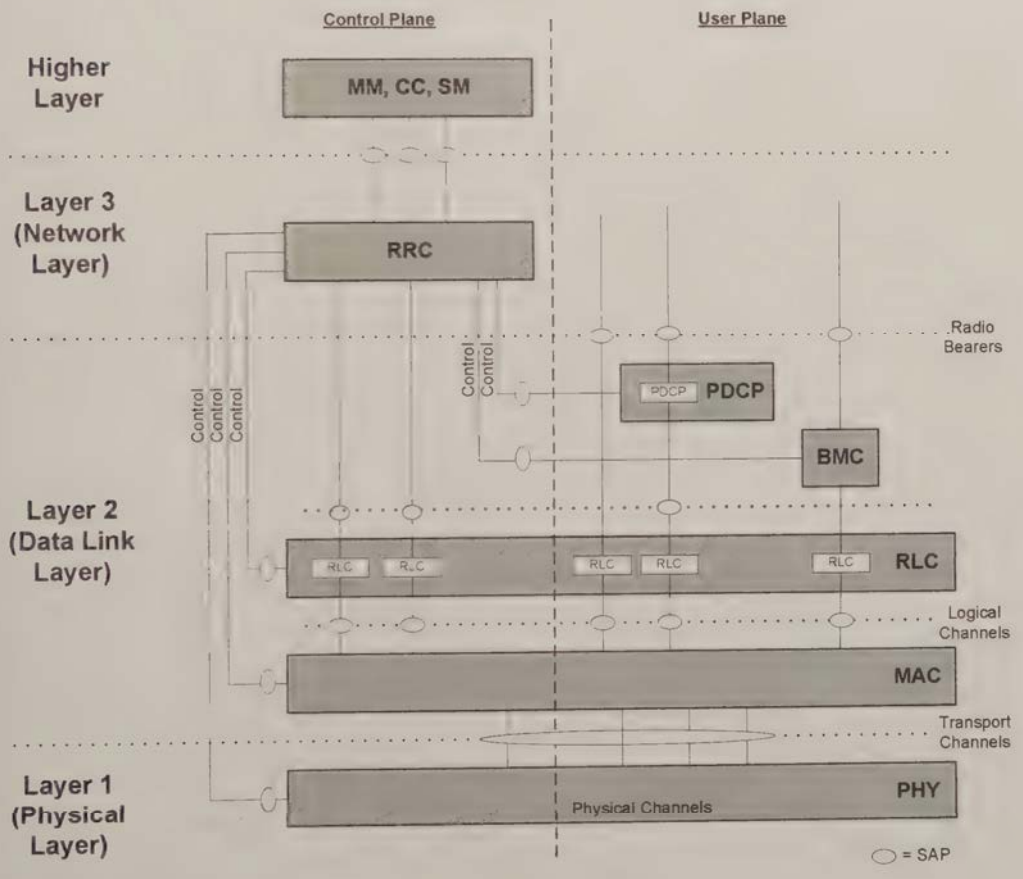


Figure 11.5 UTRAN's Protocol Stack

The transport channels which indicate how the data are transferred over the radio interface are defined by the service access point (SAP) between the MAC and PHY layers. The logical channels which indicate the contents or types of data transferred are defined by the SAP between the RLC and MAC layers. Therefore, one of the MAC's functions is to map the logical channels to the transport channels. The services provided by layer 2 are considered to be the radio bearer.

The Physical Layer, which is described in detail in the next section, provides transport services to the MAC through the transport channels. The physical layer transport channels are mapped to the physical channels by defining a number of radio mechanisms (i.e., modulation, channel coding, radio matching, multiplexing, interleaving). The MAC layer contains several MAC entities (i.e., MAC-d, MAC-c/sh) which will be described in Section 11.4. The Radio Link Control (RLC), the Packet Data Convergence Protocol (PDCP), the Broadcast/Multicast Control (BMC), and the Radio Resource Control (RRC) are introduced in Section 11.5.

11.3 Physical Layer

The PHY provides data transfer services to the MAC and higher layers. The PHY is responsible for 1) various handover functions, 2) error detection and report to higher layers, 3) multiplexing of transport channels, 4) mapping of transport channels to physical channels, 5) power control, 6) synchronization in TDD mode, and 7) other radio responsibilities associated with transmitting and receiving signals over the wireless media.

The PHY's UMTS Terrestrial Radio Access Network (UTRAN) supports the following two modes: FDD (Frequency Division Duplex) mode and TDD (Time Division Duplex) mode. In the FDD mode, the PHY radio works in two frequency bands (each band has 5 MHz channel bandwidth), one band for uplink transmission and the other for downlink transmission. In TDD mode, the same frequency band (with a 5 MHz channel bandwidth) is used for both uplink and downlink transmissions. The uplink and downlink operate reciprocally in different time periods. Figures 11.6 and 11.7 illustrate the 3GPP (3G Partnership Project) frequency spectrum for the FDD and TDD modes, respectively. However, some countries may define their own frequency bands for 3G.

The FDD mode allows symmetric data transmissions on the uplink and downlink. On the other hand, the TDD mode has more flexibility in assigning asymmetric uplink and downlink transmissions. Therefore, TDD is suitable to support asymmetric services, for example where most of the traffic is on the downlink (from the backbone to the mobile users). However, since TDD requires time synchronization, it cannot be deployed in wide coverage areas (i.e., mega cell) where the large variations in propagation delays do not allow tight synchronization between the nodes.

For channel access, the PHY deploys Wideband Direct Sequence Code Division Multiple Access (WCDMA), in which the information bits spread over 5 MHz channel bandwidth using a number of chip signals. The 3.84 Mcps chip rate is used in both FDD and TDD modes. In addition, TDD has an option of 1.28 Mcps chip rate, which spreads the information bits over 1.6 MHz channel bandwidth. The channel access of the latter case is denoted as narrowband

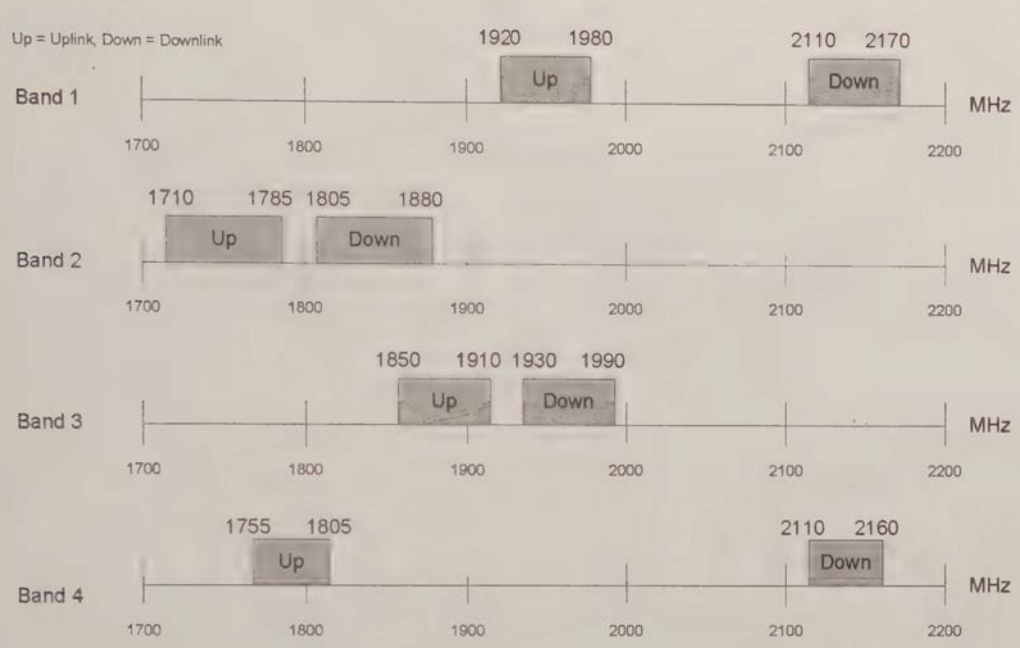


Figure 11.6 UMTS FDD Frequency Bands

CDMA. The key concept of code division multiple access is that multiple users can transmit data simultaneously on the same frequency band using different codes. Figure 11.8 illustrates the channel access of the FDD and TDD modes.

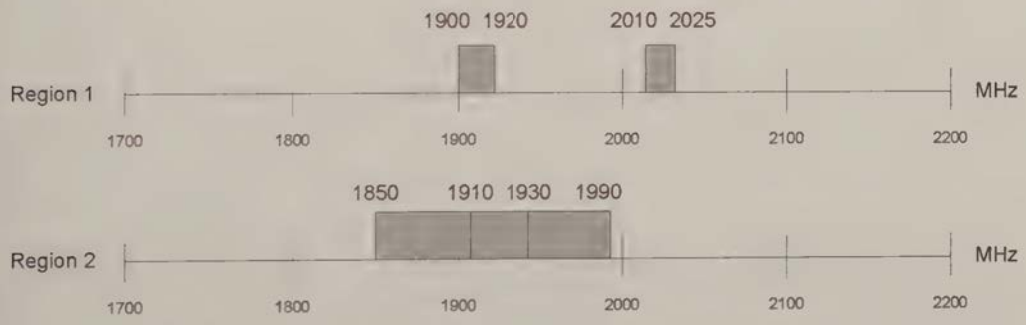


Figure 11.7 UMTS TDD Frequency Bands

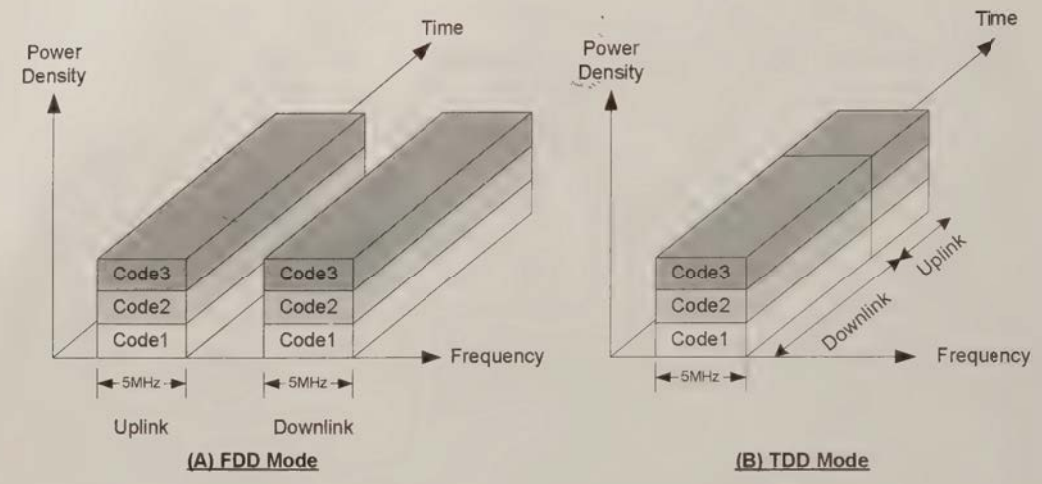


Figure 11.8 Channel Access

The code division multiple access involves two types of codes: scrambling code and channelization code. Figure 11.9 illustrates the simplified diagram of the coding process. The data from a physical channel are coded with channelization code and scrambling code and then transmitted. At the receiver end, the same codes (both channelization and scrambling) are used to decode the signal.

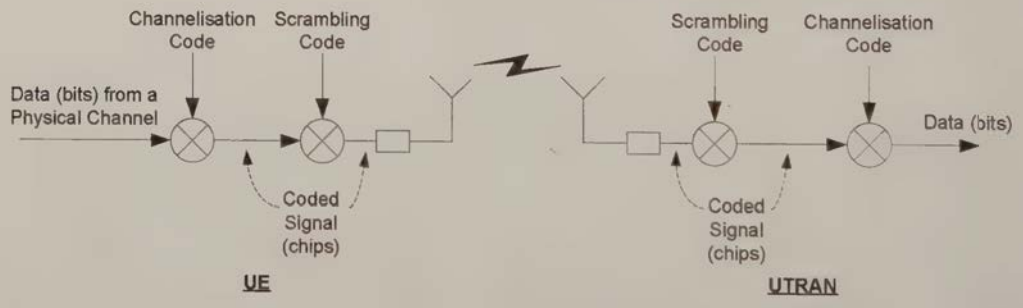


Figure 11.9 Channelization and Scrambling Process

The scrambling code is based on the complex-valued Gold Code sometimes called Pseudo Noise (PN) code. The scrambling code is used to separate between transmissions from different nodes. For example, when multiple transmissions arrive simultaneously on the uplink, Node B can retrieve the data signal from a specific mobile station by applying the same scrambling code of the mobile station to the incoming signal. On the downlink, where only Node Bs transmit, the scrambling code can also be applied to separate the data signals from different cells. For the

uplink, there is a large number of scrambling codes (i.e., in the order of several millions) to be assigned to the mobile stations. For the downlink, the standard limits the number of codes to only 512. One of the reasons for this limited number of codes is to reduce the time it takes a new station to join a cell. When a new station joins a cell, the station has no knowledge of what scrambling code is used by Node B. The station has to scan the channel to find out this code. Obviously, searching only 512 codes, as opposed to millions of codes, expedites this search process.

The channelization code is based on Orthogonal Variable Spreading Factor (OVSF) codes, sometimes called Walsh codes. The channelization code is used to separate the sources of different physical channels on a mobile station. The physical channels will be described in a later section. Different physical channels on a mobile station deploy different OVSF codes. It is possible to have the same OVSF code assigned to physical channels on different mobile stations. An OVSF code that contains a sequence of chips spreads the data signal (in bits) to a higher bandwidth data signal (in chips). OVSF codes are organized in a tree structure as shown in Figure 11.10.

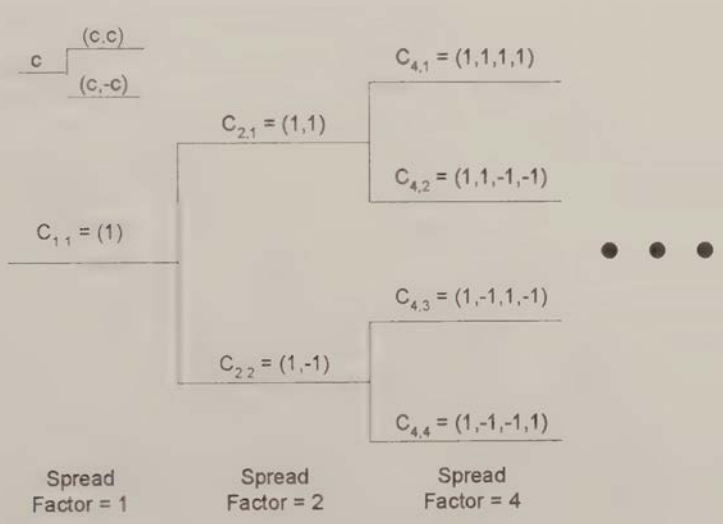


Figure 11.10 OVSF Code Tree

The OVSF code tree contains the hierarchical structure of codes where each level is referred to the spread factor (SF). For example, SF = 4 contains four OVSF codes with the length of four chips each. Codes within the same spread factor are orthogonal to each other. The code assignment for the uplink is managed by each mobile station, and by the RNC on the downlink. There are some restrictions for the code assignment. A code can be assigned to a physical channel if there is no other physical channel that is allocated this code or codes in the underlying branch. For example (see Figure 11.10), code $C_{2,1}$ can be assigned if code $C_{2,1}$ and codes in the underlying branch (i.e., $C_{4,1}$, $C_{4,2}$, $C_{8,1}$, $C_{8,2}$, $C_{8,3}$, $C_{8,4}$ and so on) are not assigned to any physical channel. Furthermore, smaller spread factor codes on the path to the root cannot be used (i.e., $C_{1,1}$).

The level of signal spreading is determined by the spread factor. For example, a spread factor equal to 256 allows 256 OVSF codes (256 chip length each code). The higher the spread factor is, the lower the symbol data rate (or bit rate) but the higher the number of physical channels that can transmit simultaneously. The possible spread factor numbers are 1, 2, 4, 8, 16, 32, and so on.

In FDD mode, the spread factors are from 256 to 4 on the uplink and from 512 to 4 on the downlink. With 3.84 Mcps chip rate, in FDD, the information rate varies from 15 ksymbols/s (3.84 M/256) to 960 ksymbols/s (3.84 M/4) on the uplink, and from 7.5 ksymbols/s (3.84 M/512) to 960 ksymbols/s on the downlink.

In TDD mode, the spread factors range from 16 to 1 on both the uplink and downlink. In TDD, the information rate varies from 240 ksymbols/s (3.84M/16) to 3.84 Msymbols/s.

The assigned data rate or bandwidth to a connection is controlled by the spread factor. The spread factor assignment can be fixed or dynamically adjusted based on the bandwidth demand of the connection. The lower the spread factor is, the higher the achievable data rate of the connection. Another approach to provide higher data rates is to assign multiple physical channels to a connection.

An important issue we need to consider in WCDMA is the power control (especially on the uplink). After the incoming signal is appropriately decoded (i.e., scrambling and channelization decoding), the desired signal is eminent from other signals (which are considered as noise interference). If the power density of the undesired signals (other channels) is too high, the decoded signal will contain a high level of noise interference and eventually compromise the desired signal detection. Therefore, without power control, an overpowered station could interfere or block the signals from other stations. Figure 11.11 illustrates power control in WCDMA.

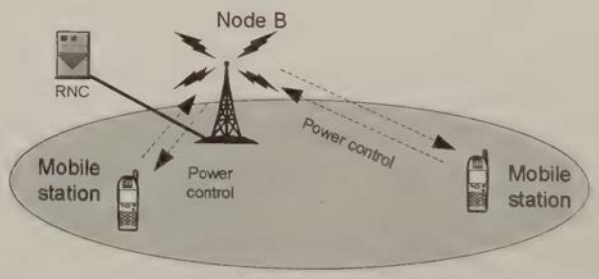


Figure 11.11 Power Control in UMTS

The standard defines two types of power control: open-loop power control and fast closed-loop power control. In the open-loop power control mechanism, a mobile station estimates the signal strength from the downlink beacon signal and sets its uplink strength power. This power control is inaccurate and often used in initial power setting. In the fast closed-loop power control mechanism, Node B measures the signal-to-interference ratio (SIR) from the mobile station. Then, Node B reports this SIR measurement to the RNC, which in turn determines the appropriate value of the mobile station's signal power. The RNC sends the Transmit Power Control (TPC)

command (included in the physical control channel) to the mobile station. The mobile station readjusts the transmission power according to the received TPC command.

UTRAN deploys the QPSK modulation scheme. 8-PSK is used for 1.28 Mcps TDD option, whereas 16-QAM is used in HS-DSCH.

11.3.1 Transport and Physical Channels

One of the functions of the physical layer is to perform the mapping process between the transport and physical channels. As shown in Figure 11.12, the MAC packets on a transport channel are called transport blocks. A number of transport blocks transmitted on the same transport channel are called a Transport Block Set. A Transport Block Set size is defined as the number of bits in a Transport Block Set. As shown in Figure 11.13, the interarrival time between consecutive Transport Block Sets is defined as the Transmission Time Interval (TTI).

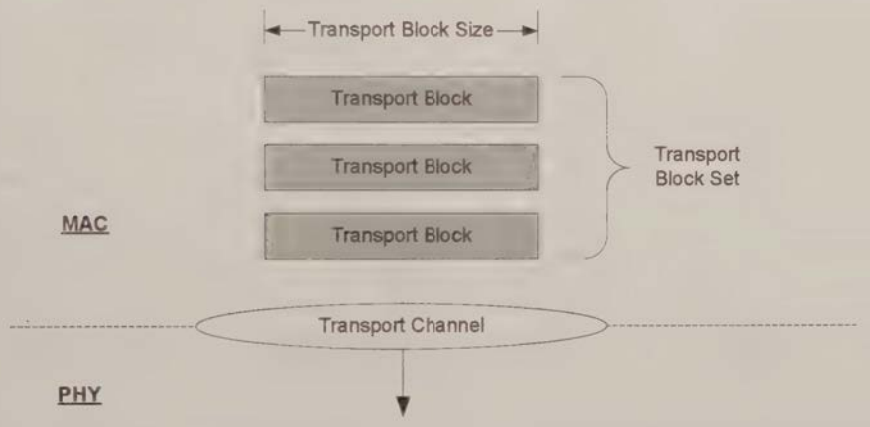


Figure 11.12 Transport Block

The Transport Block Size, the Transport Block Set Size, and the Transmission Time Interval are included in the Transport Format. The Transport Format contains two parts: the dynamic and semi-static parts. The dynamic part contains the Transport Block Size and the Transport Block Set Size. The semi-static part contains the Transmission Time Interval, the error protection scheme (channel code, coding rate, rate matching), and the CRC size. There are a number of Transport Format combinations called Transport Format Combination Set (TFCS). For example, a TFCS is shown in Tables 11.1 and 11.2 for dynamic and semi-static parts, respectively. The TFCS is assigned by the Radio Resource Control (RRC). The MAC selects an appropriate Transport Format Combination (TFC) from the TFCS to support the connection's traffic characteristics and data rate. The MAC uses dynamic attributes for the TFC and TTI, while the PHY uses semi-static attributes for the TFC.

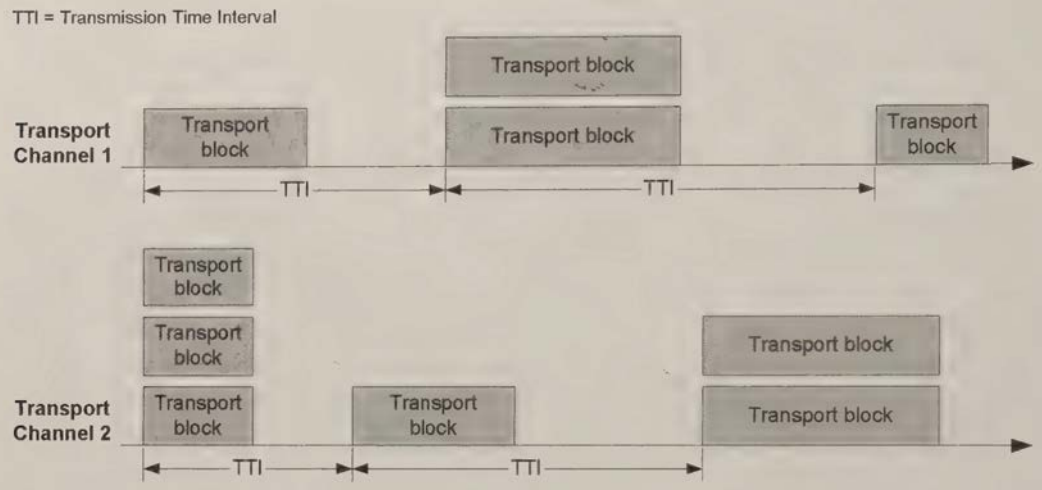


Figure 11.13 Transport Time Interval

Table 11.1 Transport Format Combination Set Dynamic Part

	Transport Channel 1		Transport Channel 2		Transport Channel 3	
	Transport block size (bits)	Transport block set size (bits)	Transport block size (bits)	Transport block set size (bits)	Transport block size (bits)	Transport block set size (bits)
Combination 1	20	20	100	200	120	240
Combination 2	40	40	160	160	320	320
Combination 3	320	1280	40	40	320	1280

Table 11.2 Transport Format Combination Set Semi-Static Part

	Transport Time Interval (ms)	Type of Error Protection Code	Static Rate Matching Parameter
Transport Channel 1	10	Convolution code	1
Transport Channel 2	20	Turbo code	1
Transport Channel 3	30	Turbo code	2

Figure 11.14 shows the physical layer mapping process. In a certain period of time, transport blocks arrive from the MAC along with Transport Format Indicator (TFI) which indicates the transport format of the transport blocks. The transport blocks from different transport channels are multiplexed, channel coded (i.e., convolution code, turbo code), split, and passed to the physical data channels. The TFIs are also multiplexed onto the Transport Format Combination Indicator (TFCI) and then passed to a physical control channel. There can be one or multiple physical data channels but there is only one physical control channel. At the receiver end, after descrambling and channelization decoding, the receiver passes the incoming packets to the decoding, demultiplexing, and channel joining module which uses the information within the TFCI. The transport blocks are routed to the appropriated transport channels to the higher layer.

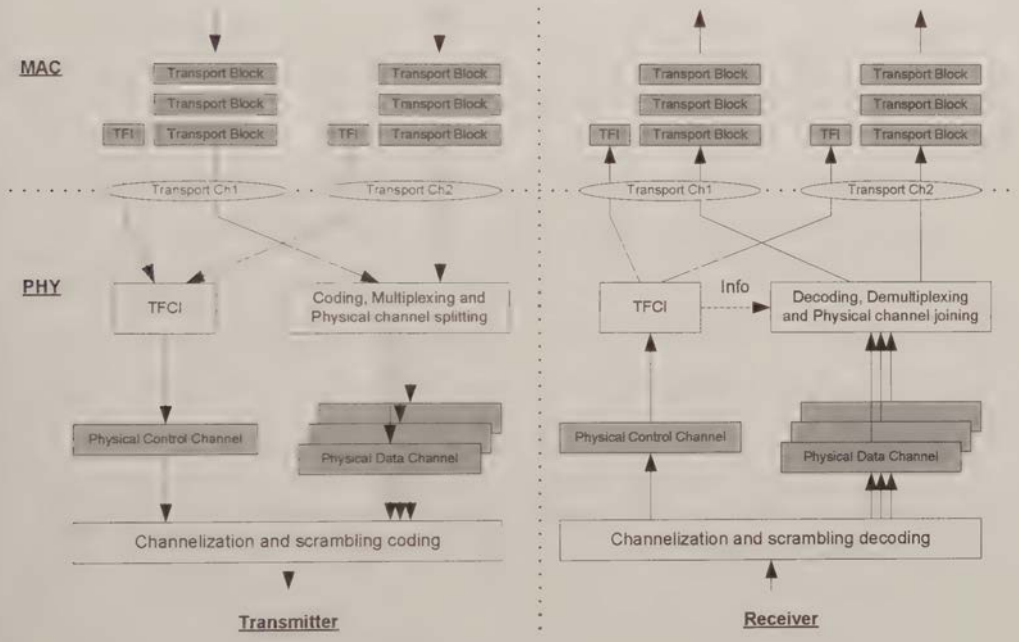


Figure 11.14 Mapping Process at the Physical Layer

11.3.1.1 Transport channels

The transport channels (see Figure 11.15) that transmit the data through the radio interface can be categorized as either dedicated transport channels or common transport channels. Dedicated transport channels are identified by the physical channel—that is, 1) code and frequency in FDD mode, or 2) code and time slot in TDD mode. Common transport channels are identified (if required) by an in-band identification.

Since network resources are reserved for the dedicated transport channels, these channels are suitable for real-time applications. Dedicated Channel (DCH) is a channel dedicated to one mobile station and is used in either uplink or downlink direction. DCH may contain user or control data from the upper layer.

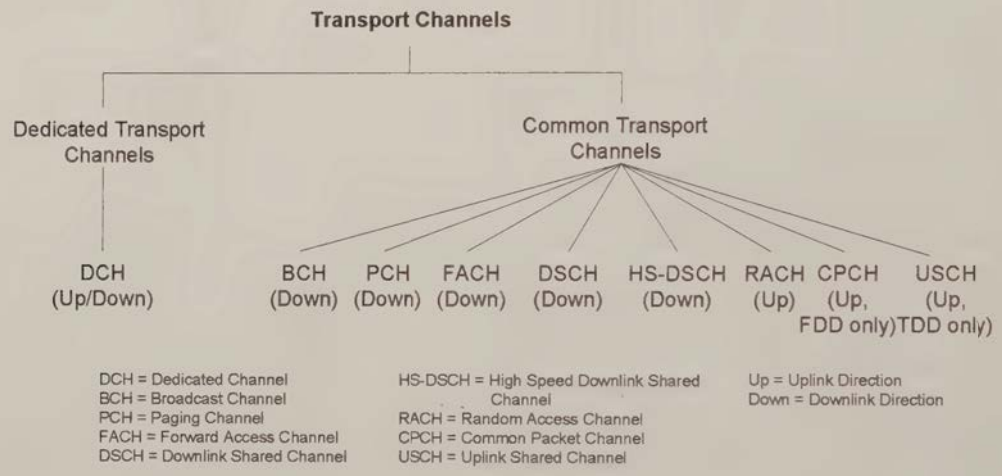


Figure 11.15 Transport Channels

Common transport channels include:

- Broadcast Channel (BCH) is a downlink channel used to broadcast system information to the entire cell such as the available access code and access time slots used for the random access mechanism. BCH's transmission power should be sufficient to reach all mobile stations within a cell.
- Paging Channel (PCH) is a downlink channel used to broadcast control information to the entire cell in order for the mobile station to execute its sleep mode procedures.
- Forward Access Channel (FACH) is a common downlink channel used to transmit relatively small amounts of data (i.e., SMS message) or control messages. FACH may contain messages destined to several mobile stations. Therefore, in-band identification is required. FACH provides low bit rate and does not perform fast closed-loop power control.
- Downlink Shared Channel (DSCH) is a downlink channel shared by several mobile stations. It is used for transmission of dedicated user or control data. DSCH provides variable bit rate and is required to perform fast closed-loop power control.
- High-Speed Downlink Shared Channel (HS-DSCH) is a downlink channel shared between mobile stations by allocation of individual codes, from a common pool of codes assigned for the channel. It is similar to DSCH but provides higher data rates.

- Random Access Channel (RACH) is a contention based uplink channel used for transmission of relatively small amounts of data (e.g., for initial access or non-real-time control or user data). RACH does not perform fast closed-loop power control. Due to unpredictable access delays of the contention based scheme, RACH is not suitable for real-time control and user data.
- Common Packet Channel (CPCH) is a contention based uplink channel shared by the mobile stations used for transmission of bursty data traffic. CPCH provides variable bit rate and is required to perform fast closed-loop power control. (*Note: This channel is used in FDD mode only.*)
- Uplink Shared Channel (USCH) is an uplink channel shared by several mobile stations. It is used for dedicated control or user data. (*Note: This channel is used in TDD mode only.*)

In summary, traffic can be transmitted through:

- Uplink
  - RACH: contention based, small amounts of data, no power control
  - CPCH (FDD mode only): contention based, more data than RACH, power control required
  - USCH (TDD mode only)
  - DCH: contention free, dedicated bandwidth, large amounts of data, power control required and QoS support
- Downlink
  - FACH: small amounts of data, shared with multiple users
  - DSCH: more data than FACH, shared with multiple users
  - DCH: dedicated bandwidth to a user and QoS support

11.3.1.2 Physical Channels

The physical channels are defined in the physical layer by a specific channel frequency, channelization code, and time duration. The standard defines the structure of the physical channel in radio frames and time slots. A radio frame has the duration of 38400 chips, which is equivalent to 10 ms at 3.84 Mcps chip rate. A radio frame consists of 15 time slots and the duration of each time slot corresponds to 2560 chips. Each time slot is numbered from 0 to 14 (see Figure 11.16). This frame structure is applied to both TDD and FDD modes. A physical channel can be transmitted on one or multiple time slots (consecutively or nonconsecutively). Multiple physical channels with different channelization codes can coexist in the same time slot. Some physical channels may have different structures.

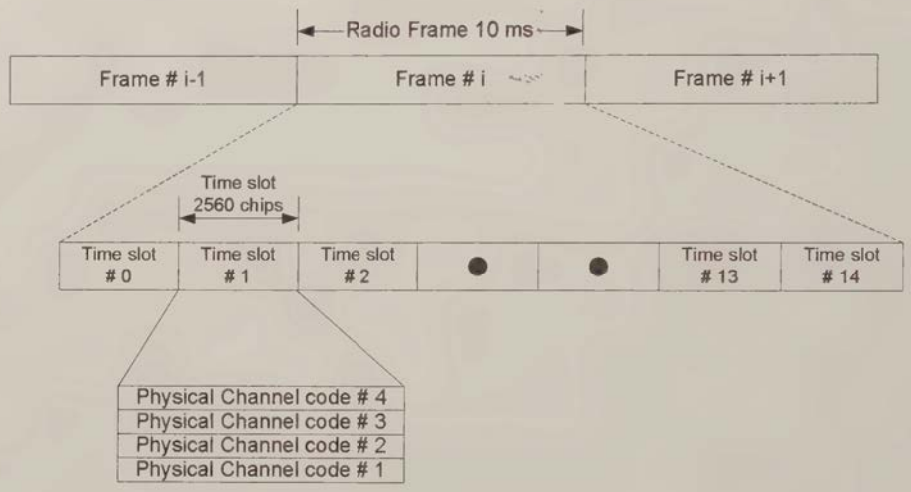


Figure 11.16 Physical Channel Frame Structure

Figure 11.17 shows a frame structure of the UTRAN TDD mode with several switching point configurations.

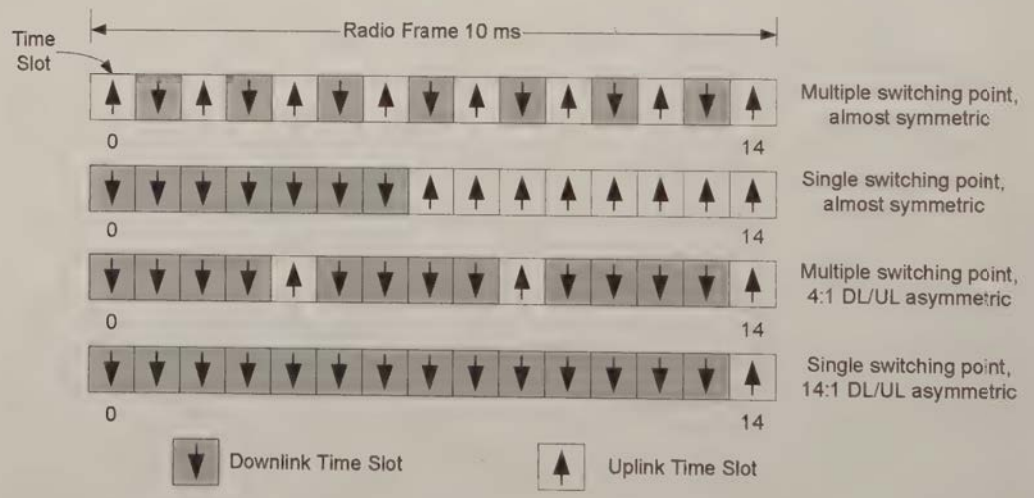


Figure 11.17 UTRAN TDD Frame Structure

The standard defines several physical channels to support the transport channels. Some physical channels are used for Layer 1 control exchange between UE and UTRAN and are not visible to the upper layer.

The FDD physical channels include:

- Dedicated Physical Data Channel (DPDCH)
- Dedicated Physical Control Channel (DPCCH)
- Physical Random Access Channel (PRACH)
- Physical Common Packet Channel (PCPCH)
- Common Pilot Channel (CPICH)
- Primary Common Control Physical Channel (P-CCPCH)
- Secondary Common Control Physical Channel (S-CCPCH)
- Synchronization Channel (SCH)
- Physical Downlink Shared Channel (PDSCH)
- Acquisition Indicator Channel (AICH)
- Access Preamble Acquisition Indicator Channel (AP-AICH)
- Paging Indicator Channel (PICH)
- CPCH Status Indicator Channel (CSICH)
- Collision-Detection/Channel-Assignment Indicator Channel (CD/CA-ICH)
- High-Speed Physical Downlink Shared Channel (HS-PDSCH)
- HS-DSCH-related Shared Control Channel (HS-SCCH)

The TDD physical channels include:

- Dedicated Physical Channel (DPCH)
- Primary Common Control Channel Physical Channel (P-CCPCH)
- Secondary Common Control Physical Channel (S-CCPCH)
- Physical Random Access Channel (PRACH)
- Physical Uplink Shared Channel (PUSCH)
- Physical Downlink Shared Channel (PDSCH)
- Paging Indicator Channel (PICH)
- Synchronization Channel (SCH)

Figure 11.18 shows the mapping of the transport channels to the physical channels.

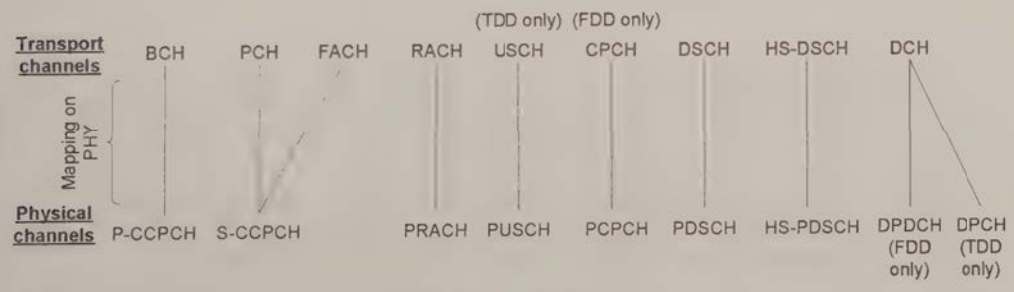


Figure 11.18 Transport Channels Mapped onto Physical Channels

In this chapter we cover the following mechanisms: dedicated data transmissions and random access uplink data transmissions.

11.3.2 Dedicated Data Transmission

DCH which supports dedicated data transmissions (uplink and downlink) is mapped to DPDCH and DPCCH as shown in Figure 11.19.

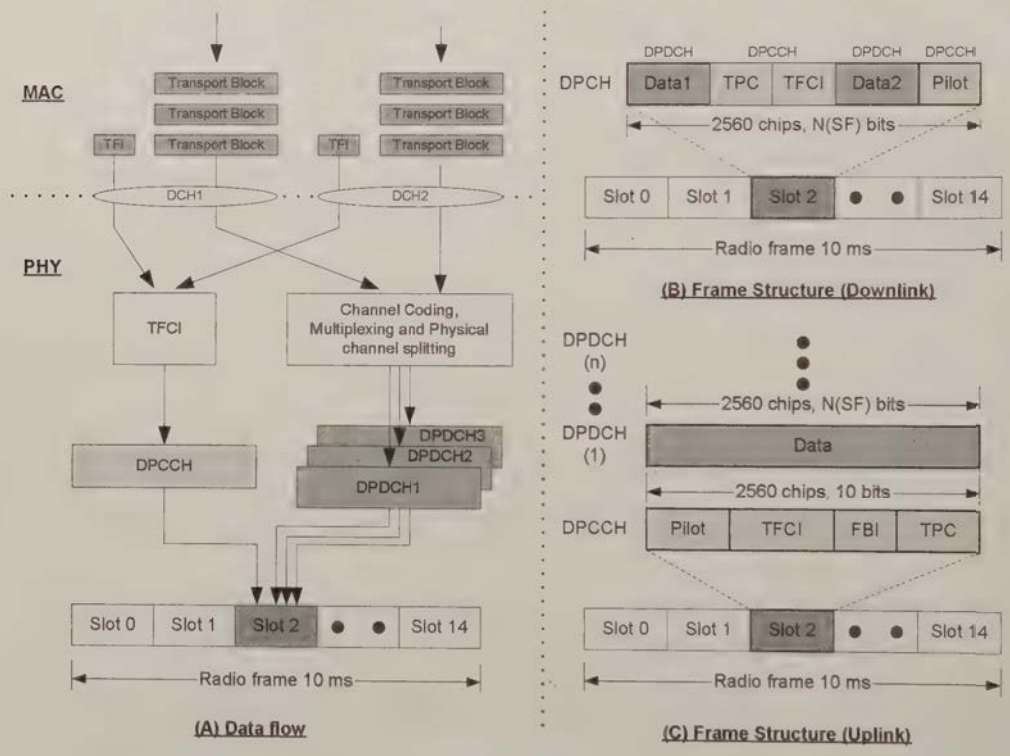


Figure 11.19 DCH Mapping Process and Physical Channel Frame Structure

11.3.2.1 Uplink

DPCCH carries control information generated at the physical layer. A pilot bit is used for channel estimation in coherent detection. Transport Format Combination Indicator (TFCI) notifies the receiver about the format combination of transport channels mapped to DPDCHs. Transmit Power Control (TPC) is used for fast close-loop power control.

DPDCH contains user data (transport block) from the upper layer. FBI contains feedback information. DPCCH uses a fixed channelization code with SF = 256. Therefore, a DPCCH frame contains 10 bits (2560/256).

DPDCH carries the user data (transport blocks) from DCHs. There are up to six DPDCHs in a time slot. If only one DPDCH exists, the DPDCH uses a channelization code with SF rang-

ing from 256 to 4. If multiple DPDCHs exist, DPDCHs use a channelization code with SF = 4. It is flexible to vary the data rate of dedicated data transmissions using varying channelization code (from frame to frame) and a number of concurrent DPDCHs. On the uplink, each time slot contains one or more DPDCHs (up to six) as well as a DPCCH.

11.3.2.2 Downlink

DPCH, the downlink dedicated physical channel, contains the multiplexing of DPDCHs and DPCCHs. DPCH uses a channelization code with SF ranging from 512 to 4.

11.3.3 Random Access Uplink Data Transmission

RACH and CPCH support random access data transmission (uplink only). CPCH is used only in FDD mode. RACH is mapped to PRACH whereas CPCH is mapped to PCPCH. Figures 11.20 and 11.21 show the mapping process of RACH and CPCH, respectively. Each mobile station has only one RACH and one CPCH. In RACH, the control part contains TFCI that provides the decoding information used for the data part of the PRACH. In CPCH, the control part also contains TPC (for power control), pilot, and FBI in addition to TFCI. Both control and data part use different channelization codes.

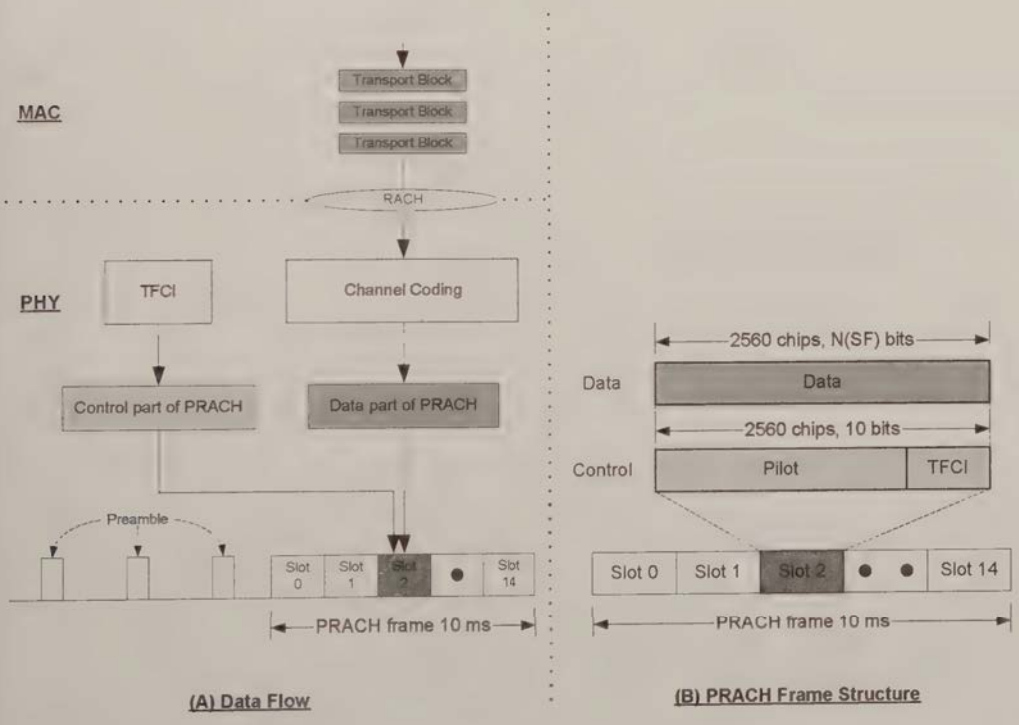


Figure 11.20 RACH Mapping Process and PRACH Frame Structure

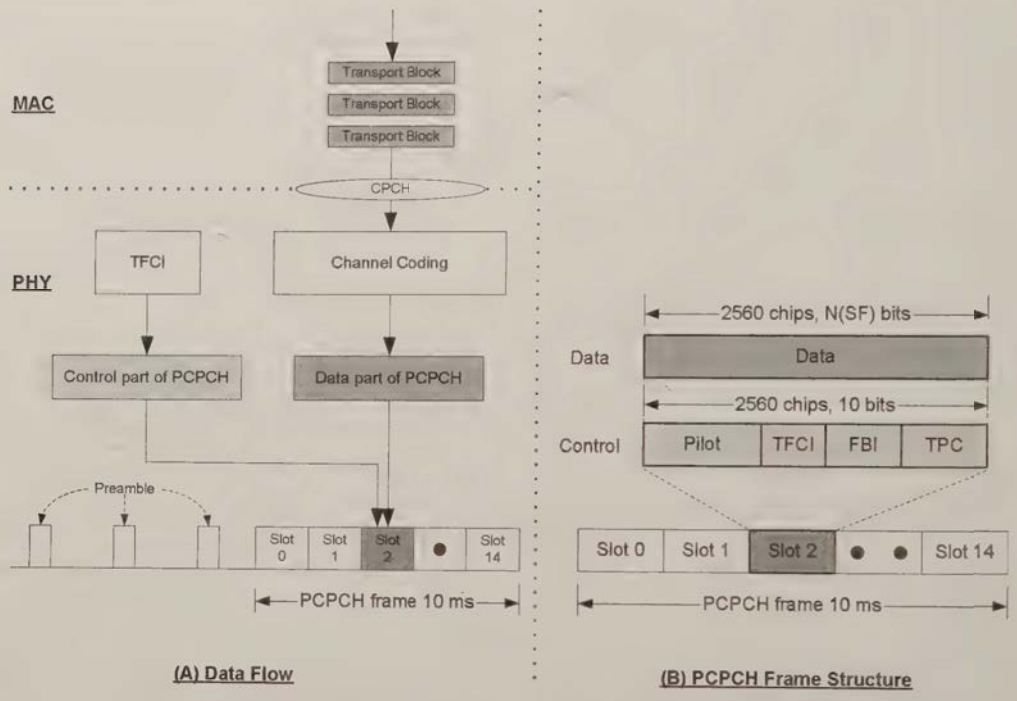


Figure 11.21 CPCH Mapping Process and PCPCH Frame Structure

The size of the preamble part of RACH and CPCH is 4096 chips and consists of 256 repetitions of a 16-chip signature. There are a maximum of 16 16-chip signatures available. The preamble part is coded with a scrambling code (Gold Code).

PRACH's control part deploys a channelization code with SF = 256 while PRACH's data part deploys a channelization code with SF ranging from 256 to 32.

PCPCH's control part deploys a fixed channelization code with SF = 256 while PCPCH's data part deploys a channelization code with SF ranging from 256 to 4.

11.3.3.1 Random Access Uplink Data Transmission Procedure (for RACH)

The Random Access Uplink Data Transmission is based on slotted-Aloha with fast acquisition indication. The data are transmitted at the beginning of an access slot. The access slots are spaced 5120 chips apart. There are 15 access slots spanning on two radio frames (2 x 10 ms = 20 ms) as shown in Figure 11.22. The Acquisition Indicator Channel (AICH) is a physical channel used for acquisition indication. AICH is defined at the base station whereas PRACH is defined at the mobile station. AICH and PRACH access slots are not aligned.

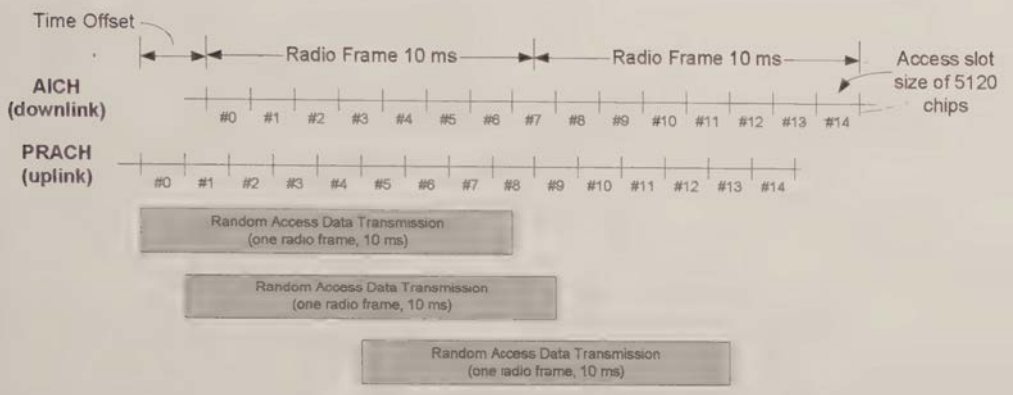


Figure 11.22 RACH Access Slots

As shown in Figure 11.23, RACH procedure includes the following steps:

- A mobile station retrieves the available RACH subchannel, scrambling codes, and signatures from BCH.
- The mobile station selects a RACH subchannel randomly and also further selects a signature from the pool of available signatures.
- RACH preamble that contains the selected signature is transmitted on a randomly selected access slot.
- If the mobile station does not receive the AICH preamble from the base station after the RACH preamble time out, the mobile station will retransmit the RACH preamble with higher transmission power on the next available access slot. If the number of retransmissions reaches the maximum number of retransmissions, the RACH procedure stops and notifies the upper layer.

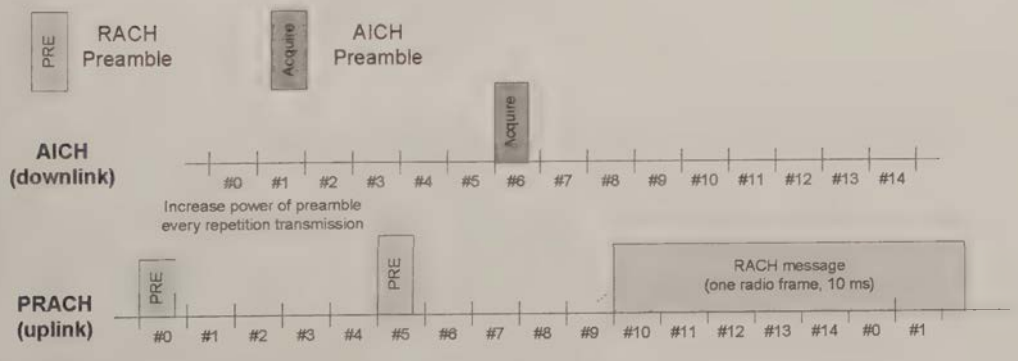


Figure 11.23 RACH Procedure

- If the mobile station receives the AICH preamble with NACK (negative acknowledgment), meaning that the selected signature is already used by another station, the RACH procedure stops and notifies the upper layer.
- If the mobile station receives the AICH preamble with ACK (positive acknowledgment), the mobile station transmits RACH messages with a duration of 10 or 20 ms.
- The backoff mechanism is controlled by the upper layer.

11.3.3.2 Random Access Uplink Data Transmission Procedure (for CPCH)

Random Access Uplink Data Transmission for CPCH is similar to that for RACH. The difference is that CPCH uses AP-AICH and CD/CA-ICH instead of AICH. In addition, CPCH includes a collision detection mechanism (CD) to reduce the probability of collision. The access slots are similar to those for RACH (see Figure 11.24). AP-AICH and CD/CA-ICH are defined at the base station whereas PCPCH is defined at the mobile station. AP-AICH and CD/CA-ICH access slots align but do not align with PCPCH access slots.

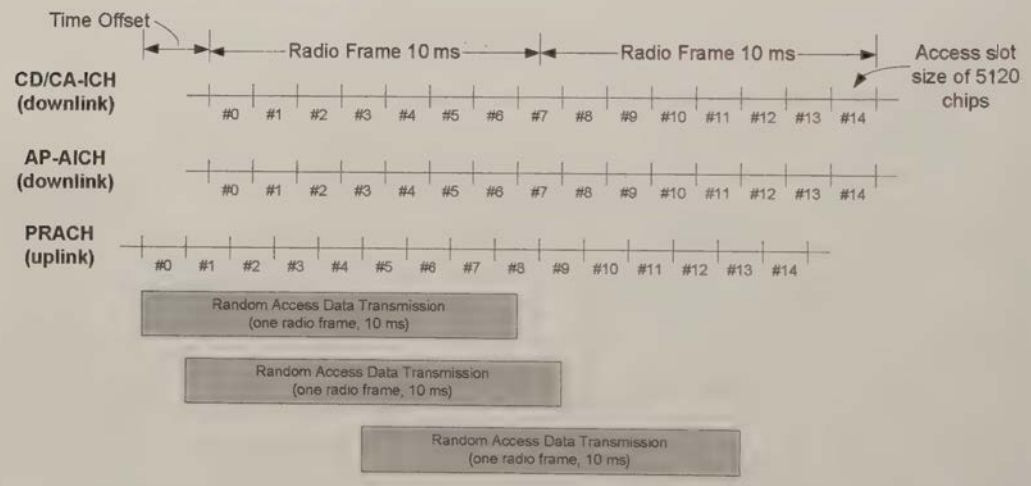


Figure 11.24 CPCH Access Slots

As shown in Figure 11.25 the CPCH procedure includes the following steps:

- The procedure is similar to RACH procedure up until the mobile station receives AP-AICH preamble with ACK.
- The mobile station transmits Collision Detection (CD) preamble to the base station.
- The base station echoes back with CD indication. This handshaking process reduces the probability of collision.
- The mobile station transmits a CPCH message.

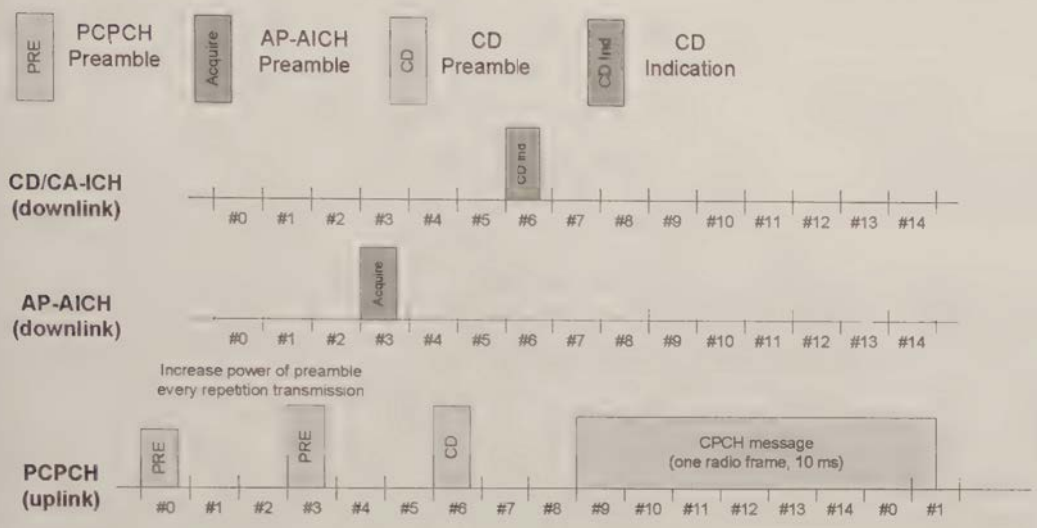


Figure 11.25 CPCH Procedure

11.4 Media Access Control (MAC)

The MAC provides the mapping process between logical and transport channels. Before we describe the MAC architecture, we introduce the logical channels.

11.4.1 Logical Channels

Logical channels (see Figure 11.26) are channels that relate to the content and what kind of data are transmitted through the radio interface. The Logical Channels are categorized into two types based on their content: Control Channels, which contain control information, and Traffic Channels, which contain user data.

The Control Channels (CCHs) include the following:

- Broadcast Control Channel (BCCH) is a downlink channel for broadcasting system control information.
- Paging Control Channel (PCCH) is a downlink channel for paging information. This channel is used when the network does not know the location cell of the mobile station, or when the mobile station is in the cell connected state using sleep mode procedures.
- Common Control Channel (CCCH) is a bidirectional channel for transmitting control information between the network and the mobile station. This channel is commonly used by a mobile station with no RRC connection with the network and by mobile stations using common transport channels when accessing a new cell after cell reselection.

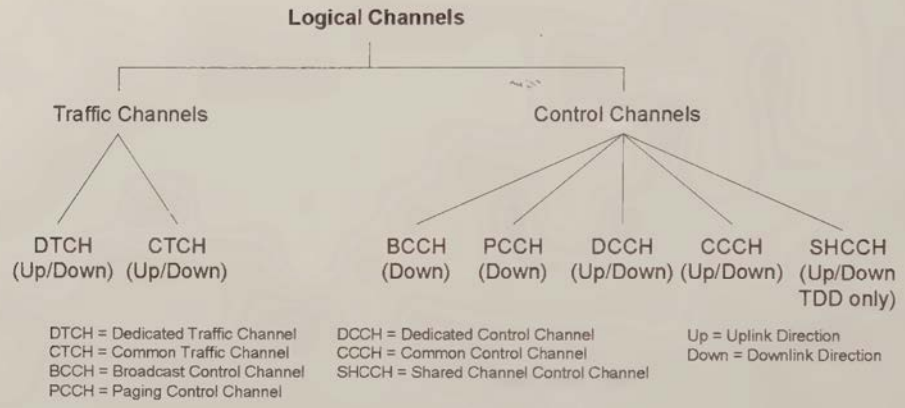


Figure 11.26 Logical Channels

- Dedicated Control Channel (DCCH) is a point-to-point bidirectional channel that transmits dedicated control information between the mobile station and the network. This channel is established through the RRC connection setup procedure.
- Shared Channel Control Channel (SHCCH) is a bidirectional channel that transmits control information for uplink and downlink shared channels between the network and the mobile stations. (*Note: This channel is used in TDD mode only.*)

The Traffic Channels (TCHs) include the following:

- Dedicated Traffic Channel (DTCH) is a point-to-point channel dedicated to a single mobile station for the transfer of user information. A DTCH can exist in both uplink and downlink.
- Common Traffic Channel (CTCH) is a point-to-multipoint unidirectional channel for transfer of dedicated user information for all or a group of specified mobile stations.

The logical channels can be mapped onto the transport channels in the MAC layer as shown in Figure 11.27.

11.4.2 MAC Architecture

Figure 11.28 presents the mobile station MAC architecture (Rel-5) and Figure 11.29 presents UTRAN MAC architecture. The MAC consists of the following modules: MAC-d, MAC-c/ch and MAC-b. In addition, UMTS Release 5 introduced a new MAC-hs module that supports HSDPA's high-speed mode.

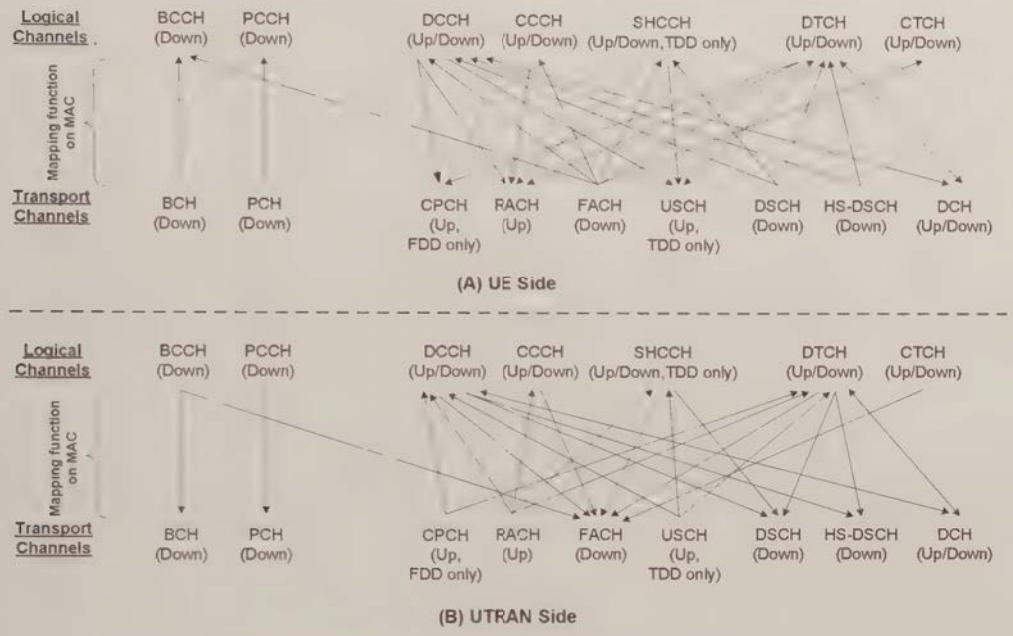


Figure 11.27 Logical Channels Mapped onto Transport Channels

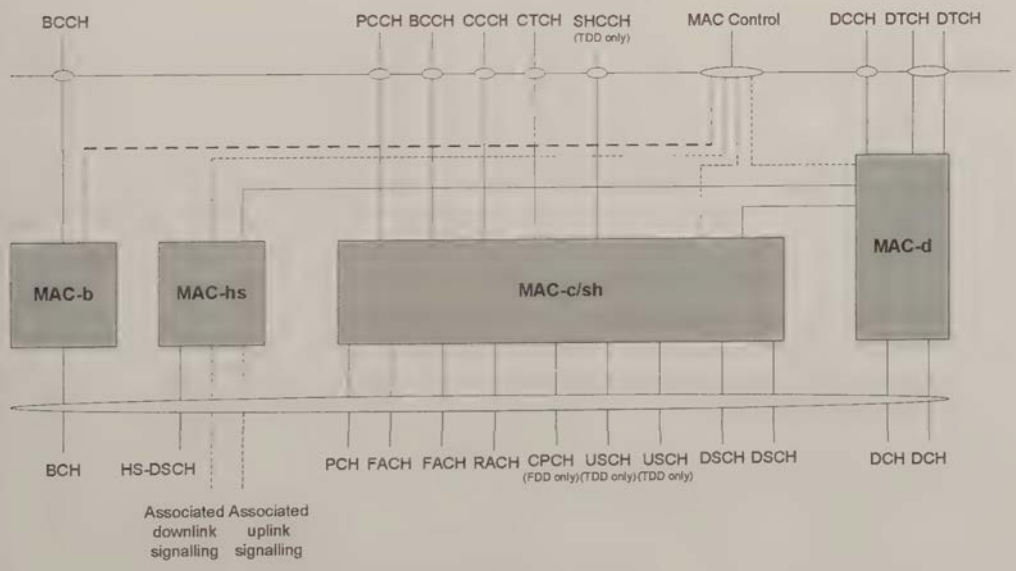


Figure 11.28 Mobile Station MAC Architecture

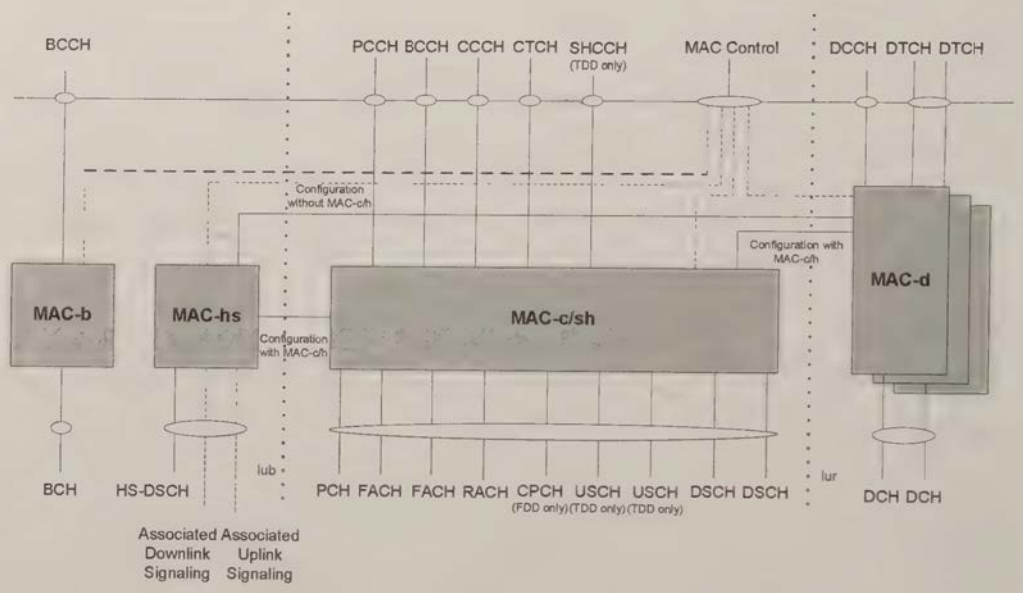


Figure 11.29 UTRAN Side MAC Architecture

The MAC executes the following functions:

- Maps between the logical and transport channels.
- Selects the appropriate Transport Format, defined in Section 11.3, from the Transport Format Combination Set assigned by the RRC for each Transport Channel depending on the instantaneous source rate. The Transport Format (which includes the Transport Block Size, the Transport Block Set Size, and the Transport Time Interval) accommodates the source bandwidth demand.
- Prioritizes between the data flows of a mobile station. Priority considerations can be achieved by selecting a Transport Format Combination for which the high-priority data are mapped into a "high bit rate" Transport Format, while lower priority data are mapped into a "low bit rate" Transport Format.
- Prioritizes between mobile stations via dynamic scheduling. The MAC handles priorities on the common and shared transport channels. For dedicated transport channels, the equivalent of the dynamic scheduling function is included as part of the RRC.
- Identifies mobile stations on common transport channels via in-band identification (i.e., UE ID).
- Multiplexes and demultiplexes upper layer packets into/from transport blocks delivered to/from the physical layer on common transport channels and dedicated transport channels.
- Measures traffic volume on the logical channels and reports it to the RRC. The RRC may switch transport channels based on these measurements.

- Switches between common and dedicated transport channels based on the switching decision made by the RRC.
- Encrypts data for security purposes.
- Accesses RACH and CPCH based on Service Classes. The RACH resources (access slots and preamble signatures for FDD, timeslot and channelization code for TDD) and CPCH resources (access slots and preamble signatures for FDD only) may be divided between different Access Service Classes (ASCs) in order to provide different priorities of RACH and CPCH. This MAC function indicates the appropriate backoff to the physical layer for the RACH and CPCH associated with the MAC packet transfer.
- Executes HARQ (Hybrid Automatic Repeat Request) functionality for HS-DSCH transmission to ensure reception of all packets. This function is carried by part of the MAC referred to as the MAC-hs.
- Delivers and assembles higher layer packets on HS-DSCH.

The execution of the aforementioned functions is undertaken by the following MAC entities: MAC-b for broadcast channels, MAC-c/sh for common channels, MAC-d for dedicated channels, and MAC-hs for the high-speed downlink shared channel. These MAC entities have different functionality at the mobile station and at the UTRAN.

11.4.2.1 MAC-b

MAC-b maps the BCCH logical channel to the BCH transport channel.

11.4.2.2 MAC-c/sh

MAC-c/sh handles the following transport channels: paging channel (PCH), forward access channel (FACH), random access channel (RACH), uplink common packet channel (CPCH) that exists only in FDD mode, downlink shared channel (DSCH), and uplink shared channel (USCH) that exists only in TDD mode. The mapping of logical channels on transport channels depends on the multiplexing that is configured by the RRC.

In the downlink, if the logical channels of the dedicated type are mapped to the common transport channels, MAC-d receives the data from MAC-c/sh or MAC-hs via the illustrated connection between the functional entities.

In the uplink, if the logical channels of the dedicated type are mapped to the common transport channels, MAC-d submits the data to MAC-c/sh via the illustrated connection between the functional entities.

The MAC controls the timing of RACH and CPCH transmissions. The physical RACH resources may be divided between eight different ASCs in order to provide different priorities of RACH usage. When the MAC determines that the packet has not been received based on the ACK, the MAC initiates retransmissions and backoff timing procedures before trying to retransmit. The number of retransmissions and the backoff timings are based on ASC considerations.

11.4.2.3 MAC-d

MAC-d handles the dedicated transport channel (DCH) to MAC-c/sh and MAC-hs.

11.4.2.4 MAC-hs

MAC-hs handles the high-speed downlink shared channel (HS-DSCH). It is a new entity introduced in Rel-5 that supports HSDPA (High-Speed Downlink Packet Access).

11.4.3 Examples of MAC Data Transmission

In this section we describe a number of examples of the MAC data transmission (Figure 11.30). The logical channel for user data is DTCH, which can be mapped to a dedicated transport channel (i.e., DCH), or common transport channel (i.e., RACH and CPCH for uplink, FACH for downlink), or shared transport channel (i.e., USCH for uplink, DSCH for downlink). If DTCH is mapped to a dedicated transport channel, the data travel through the MAC-d module, whereas if DTCH is mapped to a common transport channel or shared transport channel, the data travel through the MAC-d and MAC-c/sh modules. For HS-DSCH, the data travel through the MAC-d and MAC-hs modules. Figure 11.30A shows the uplink data flow when DTCH is mapped to RACH. The diagram presents only the channels involved in this flow. The data flow is presented in bold lines. Figure 11.30B illustrates the packet format at each layer.

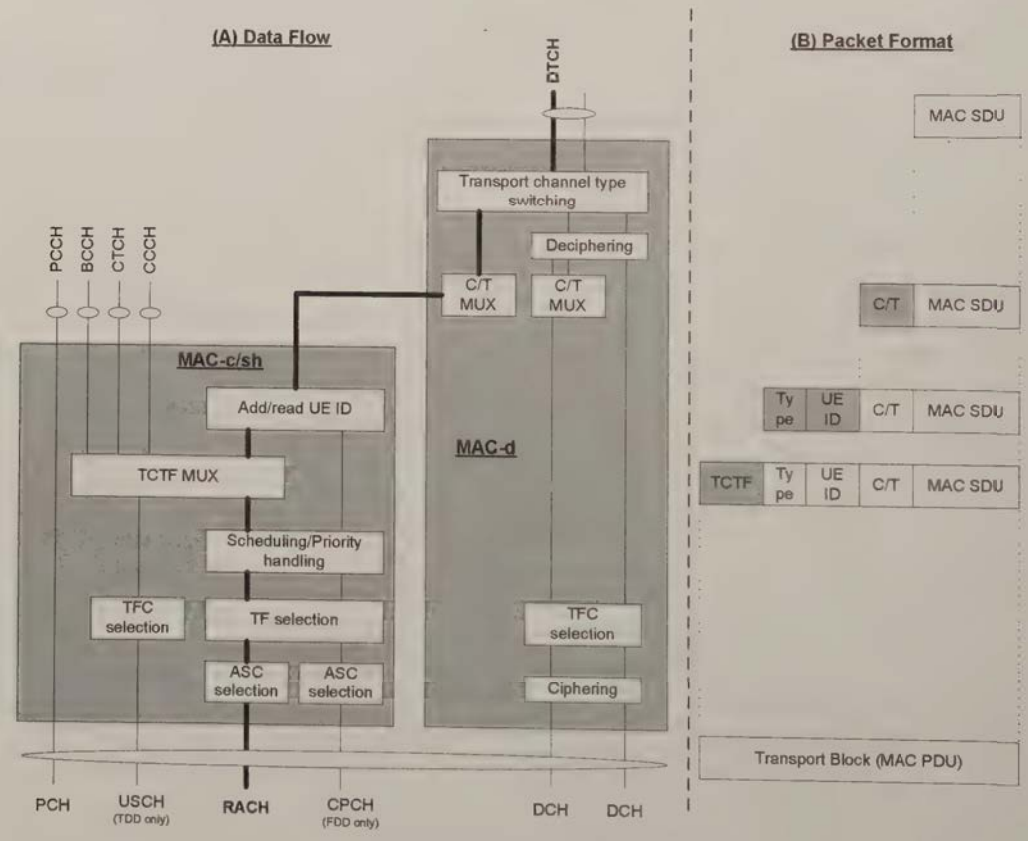


Figure 11.30 Example of MAC Data Transmission

The MAC SDU from DTCH visits the following modules sequentially:

1. Transport Channel Type Switching module, which decides to which transport channels to map it. The mapping is based on the traffic characteristics and QoS requirements (RACH for this example).
2. C/T MUX module, which is used when multiple dedicated logical channels are mapped to a transport channel. C/T header is added to the SDU to provide an identification of which logical channel the packet belongs to.
3. MAC-c/sh Add/Read UE ID module, which appends to the packet the UE ID header that includes the mobile station identification. The UE Type header (2 bits) provides information of what kind of UE ID is used (i.e., C-RNTI 16 bits or U-RNTI 32 bits).
4. TCTF MUX module, where the packet is multiplexed with packets from other common logical channels. TCTF header is also added to the packet, which includes the identification of the logical channel the packet belongs to.
5. Scheduling/Priority module, which provides priority services.
6. Transport Format (TF) Selection module, which selects a transport format from the transport format combination set.
7. ASC Selection module, which performs the priority random access procedure.

11.5 Data Link Layer Protocols (RLC, PDCP, and BMC)

11.5.1 Radio Link Control (RLC)

The RLC transfers data from the upper layers in transparent or non-transparent mode. In transparent mode upper layer packets are transferred without adding any protocol information. In non-transparent mode the RLC will segment and reassemble packets and may concatenate and pad packets to adjust the packets to the transport format. In addition, the RLC can transfer data in either unacknowledged or acknowledged mode. In unacknowledged data transfer, the RLC transmits upper layer packets without guaranteeing delivery to addressee. In acknowledged data transfer, the RLC guarantees delivery to the addressee. When the packet cannot be transmitted, the sender is being notified. The RLC uses sequence numbers to identify in-sequence and out-of-sequence delivery to allow resequencing of packets. In case errors are identified, the RLC requests retransmissions from the sender. The RLC maintains QoS as defined by the upper layers by providing different levels of service by means such as 1) notifying the upper layer of errors that cannot be resolved by the RLC and 2) adjusting the maximum number of retransmissions according to QoS delay requirements.

11.5.2 Packet Data Convergence Protocol (PDCP)

PDCP executes header compression and decompression of IP data streams (e.g., TCP/IP and Real Time Protocol (RTP)/UDP/IP headers) at the transmitting and receiving entity. It transfers user data from the upper layers and forwards the data to the RLC layer and vice versa and maintains PDCP sequence numbers in some cases.

11.5.3 Broadcast/Multicast Control (BMC)

BMC supports broadcast/multicast transmission services in the user plane for common user data in unacknowledged mode. The BMC stores broadcast messages for scheduled transmission and transmits these messages at the scheduled time. In the mobile station side the BMC also evaluates the scheduled messages to indicate the scheduling parameters to the RRC. The BMS also monitors traffic volume, calculates required resources and requests from the RRC these resources on CTCH and FACH. The BMS in the mobile station receives these broadcast messages and delivers error-free messages to the upper layers.

11.6 Radio Resource Control (RRC)

RRC executes the control plane signaling of the network layer between the mobile stations and the UTRAN network.

The RRC performs the following functions:

- Establishes, re-establishes, maintains, and releases RRC connections between the mobile station and UTRAN. The establishment of an RRC connection is initiated by a request from the mobile station higher layers. Multiple links can be established to a mobile station simultaneously. In this process, the RRC performs admission control and selects parameters describing the radio link based on information from higher layers. The RRC allocates the radio resource on the uplink and downlink so that the mobile station and UTRAN can communicate with the required QoS. The release of an RRC connection can be initiated by a request from higher layers or by the RRC layer itself in case of RRC connection failure. In case of connection loss, the RRC may re-establish the RRC connection. In case of RRC connection failure, the RRC releases resources associated with the RRC connection.
- Signals the allocation of radio resources to the mobile station.
- Evaluates, decides, and executes RRC connection mobility functions such as handover, preparation of handover to GSM or other systems, cell reselection, and cell/paging area update procedures.
- Ensures and controls that requested QoS parameters are met. In this capacity, the RRC allocates a sufficient number of radio resources.
- Controls measurements done by the mobile station—that is, it decides what to measure, when to measure, and how to report. It also reports these measurements to the network.
- Selects and reselects a cell based on idle mode measurements and cell selection criteria.
- Broadcasts information provided by the network to all mobile stations. For example, RRC may broadcast location service area information related to some specific cells. The RRC configures the BMC for cell broadcast services and allocates resources for this broadcasting.
- Performs other functions related to power control, encryption, and integrity protection.

The interaction between the mobile station's RRC and the UTRAN's RRC in the control plane can be viewed in Figure 11.31. The RRC also controls the radio resource through the RLC, MAC, and PHY layers.

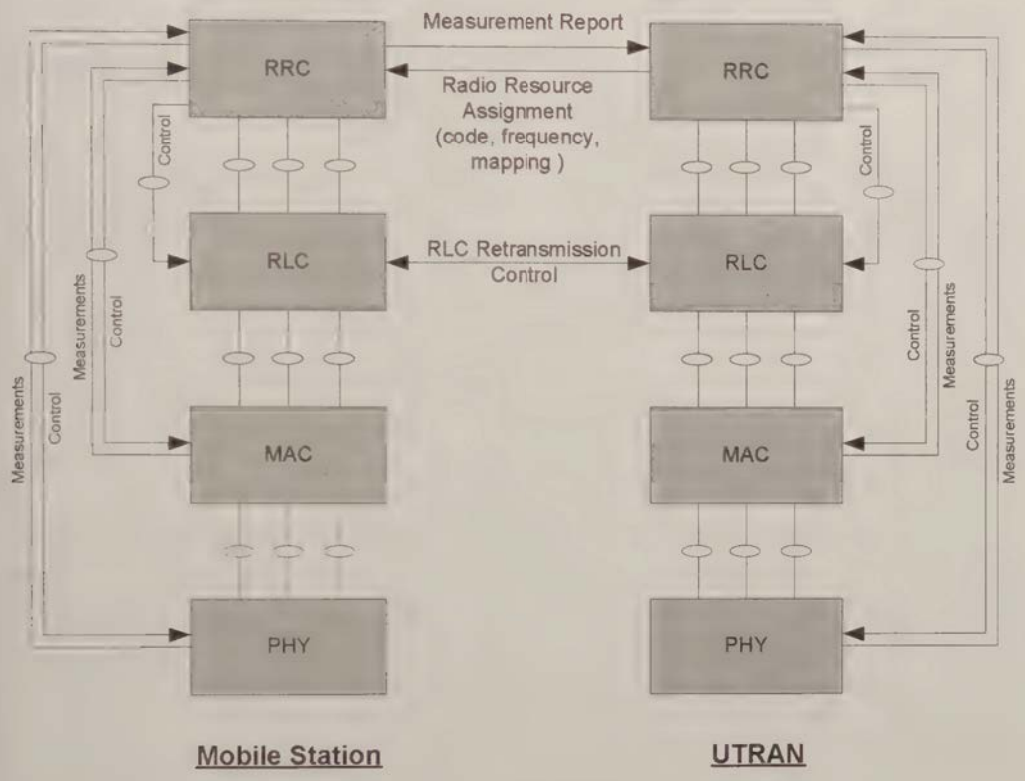


Figure 11.31 RRC Interaction between UTRAN and the Mobile Station

11.6.1 RRC States

The mobile station can operate in either idle mode or connected mode. During startup, a mobile station performs the cell search procedure by scanning for the broadcast channel (BCH). After a cell is discovered and the mobile station decides to join the cell (sometimes called "camp on a cell"), the mobile station will be in idle mode and will keep listening to the BCH. In order to communicate with the UTRAN, the mobile station is required to establish an RRC connection with the UTRAN and changes to connected mode. One mobile station can have at most one RRC connection. As shown in Figure 11.32, in connected mode, the RRC is in one of the following four states: CELL_DCH, CELL_FACH, URA_PCH, and CELL_PCH. Each RRC state reflects the physical channels allocated to the mobile station.

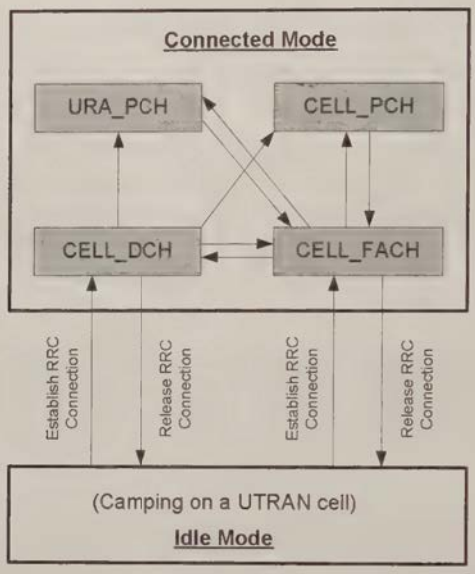


Figure 11.32 Mobile Station Modes and RRC States

In CELL_DCH RRC state, the dedicated channel is allocated. The RRC 1) reads system information broadcasted on FACH, 2) performs measurements, 3) selects and configures the radio links and multiplexing options applicable for the transport channels, and 4) acts upon RRC messages received on the control channels.

In CELL_FACH RRC state, the RACH and FACH are allocated. The mobile station 1) maintains up-to-date system information as broadcasted by the serving cell, 2) performs cell reselection processes, 3) performs measurements, 4) selects and configures radio links and multiplexing options applicable for the transport channels, and 5) acts upon RRC messages received on the control channels. When in this state and the station is out of service, the RRC performs a cell selection process.

In the URA_PCH or CELL_PCH state, there is no physical channel allocated. The mobile station maintains up-to-date system information as broadcasted by the serving cell, performs cell reselection process, and performs a periodic search for a higher priority network. It also monitors the paging channels and performs measurements. When the station is out of service, the station conducts a cell selection process.

Figure 11.33 illustrates RRC states for a mobile station that can operate in dual mode (UMTS and GPRS).

11.6.2 RRC Procedures

The standard defines several RRC functions and procedures. In this subsection, we introduce only the connection establishment and the radio bearer establishment procedures.

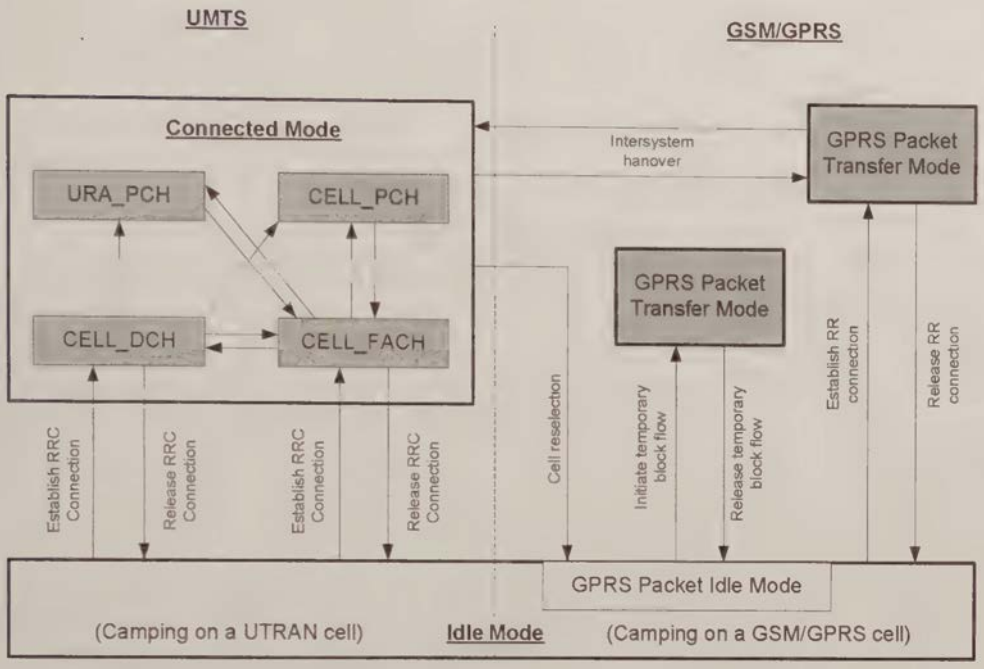


Figure 11.33 RRC States for a Dual Mode UMTS/GPRS Mobile Station

11.6.2.1 RRC Connection Establishment Procedure

The RRC connection establishment procedure (see Figure 11.34) is initiated when the upper layers in the mobile station need to establish a signaling connection and the mobile station is in idle mode. First, the mobile station's RRC sends an "RRC Connection Request" message to UTRAN's RRC through CCCH/RACH. Then, UTRAN's RRC replies with "RRC Connection Setup" message through CCCH/FACH. If the RRC Connection Setup message includes a dedicated channel assignment, the mobile station will be in connected mode in CELL_DCH state. On the other hand, if the RRC Connection Setup message includes a common channel assignment, the mobile station will be in connected mode in CELL_FACH state. Finally, the mobile station confirms with a "RRC Connection Setup Complete" message through DCCH.

11.6.2.2 Radio Bearer Establishment Procedure

Figure 11.35 illustrates the radio bearer establishment procedure. The radio bearer establishment procedure is initiated when the upper layers in the mobile station need to set up the transport and physical channels to accommodate the traffic flow from the upper layers. This procedure starts after the UTRAN performs the admission control and selects the parameters for the transport (i.e., transport format set) and physical (i.e., channelization coding) channels.

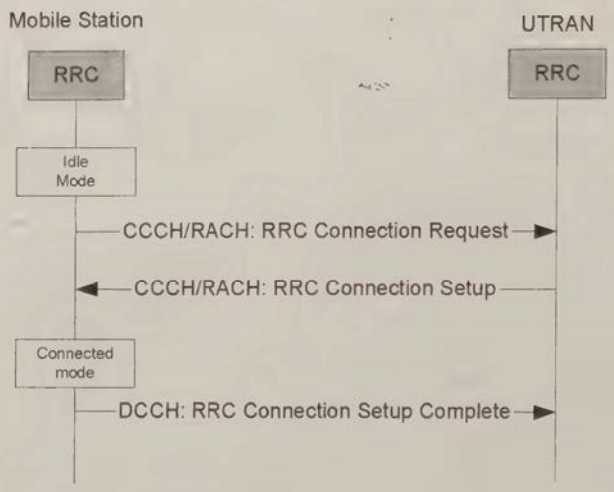


Figure 11.34 RRC Connection Establishment Procedure

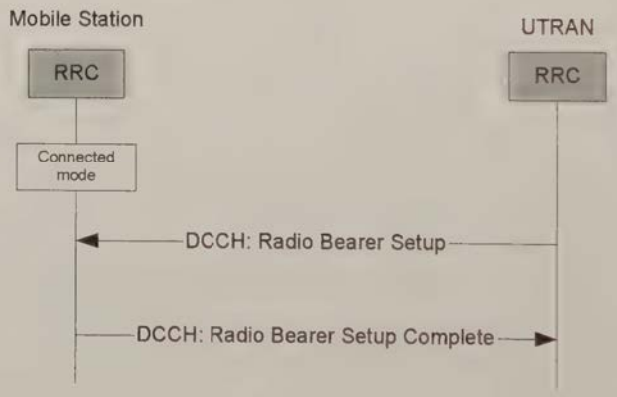


Figure 11.35 Radio Bearer Establishment Procedure

11.7 QoS Support

UMTS services adhere to the following QoS principles:

- Provide a finite set of QoS definitions and attributes that can be controlled. Their complexity should be reasonably low and the information involved should be kept low as well.
- Map between application requirements and UMTS services. The mapping should consider asymmetric uplink and downlink.
- Work with current QoS schemes and provide different QoS levels.

- Support session based QoS and allow multiple QoS streams per address.
- Manage QoS to yield efficient resource utilization.
- Modify QoS attributes when the session is ongoing and active.

The end-to-end QoS delivered to the user may be specified by Service Level Agreements (SLAs) between domains, parts of the network, and operators. The standard QoS end-to-end architecture is described in Figure 11.36. The bearer service defines the mechanisms (i.e., signaling, user plane transport, QoS management) that provide QoS support. Each service bearer relies on the service provided by the bearer service of the layer below. To enable QoS management based on SLAs across domains, consideration must be given to 1) the available bandwidth and QoS classes and how they map across domains, 2) policing and shaping requirements, 3) security mechanisms, and 4) reports of service usage, billing information, commercial information, and financial obligations in case of breech of contract, etc.

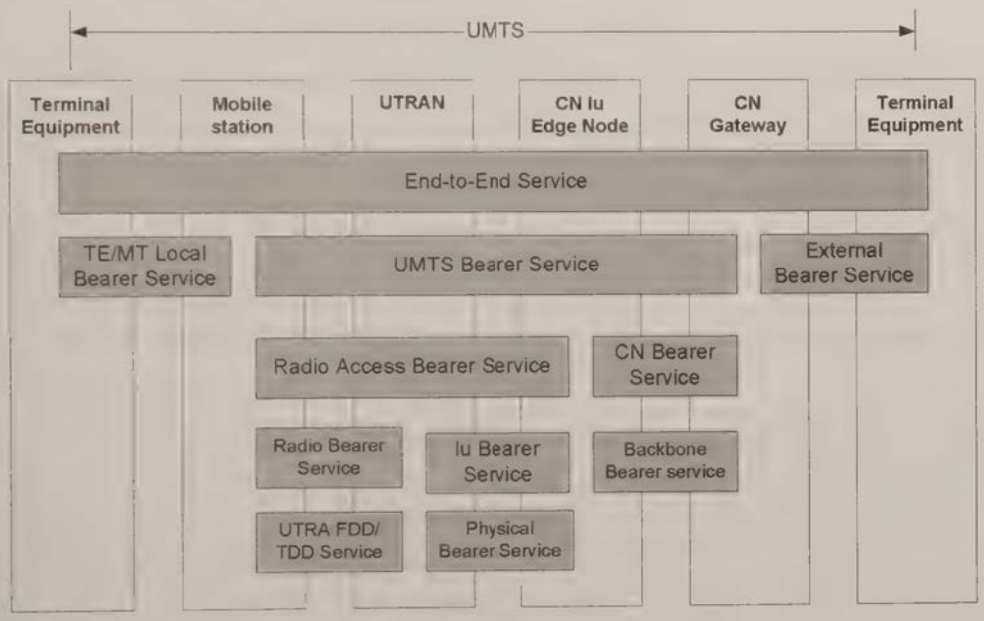


Figure 11.36 UMTS QoS Architecture

The standard provides an overview of the functionality needed to establish, modify, and maintain a UMTS link with a specific QoS. This functionality is divided into control and user planes. The standard provides examples of how such modules interact to request and commit QoS resources in conjunction with protocols such as Resource Reservation Protocol (RSVP). However, the standard does not provide the algorithms necessary to implement such functionality.

11.7.1 Control Plane QoS Management Functions

As shown in Figure 11.37, the control plane QoS management functions include several functions that are responsible for managing, translating, admitting, and controlling user requests and network resources.

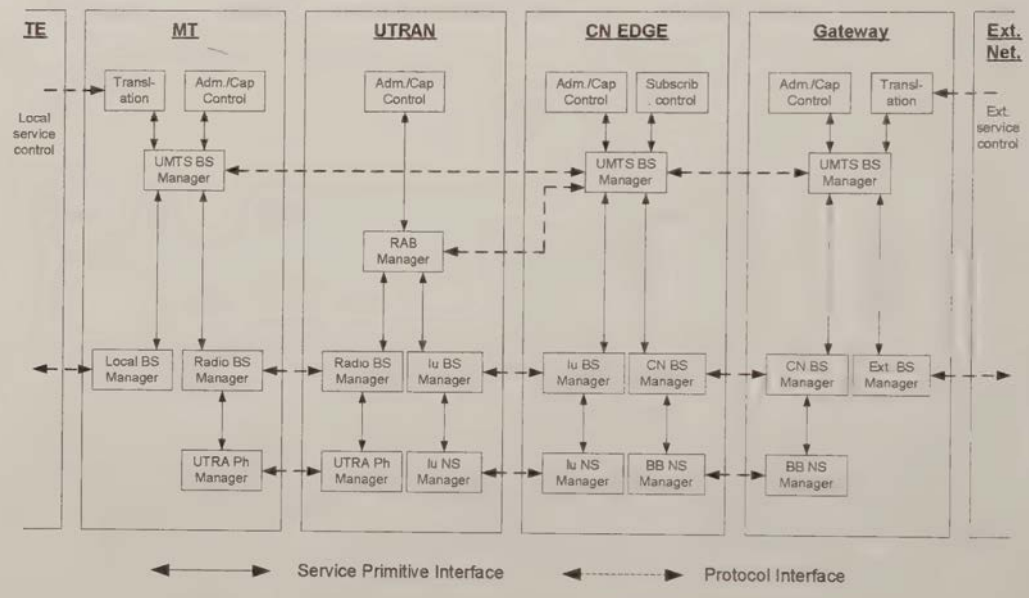


Figure 11.37 QoS Management Functions in the Control Plane. NS = network series, Ph = Physical, RAB (Radio Access Bearer).

The following functions in the control plane provide QoS management:

- *Service manager* coordinates the establishment, modification, and maintenance of services. It provides the user plane with QoS management functions. It also signals with peer service managers and uses services provided by other instances. The service manager may perform an attribute translation to request lower layer services and other control functions for service provisioning.
- *Translation function* maps between the internal service primitives for UMTS and other external protocols for service control. The translation includes the conversion between UMTS services and QoS attributes of the external network's service control protocol.
- *Admission/capability control* maintains information about all the network's available resources and all resources allocated to UMTS services. It determines for each UMTS service request or modification whether the required resources can be provided. When these resources are available they will be reserved for this service.
- *Subscription control* checks the administrative rights of the user to request the service with specified QoS attributes.

11.7.2 User Plane QoS Management Functions

The user plane QoS management functions are responsible for QoS signaling and monitoring of user data traffic. Such functions will ensure that the traffic is delivered within certain limits imposed by specific QoS attributes as negotiated with the UMTS network.

- *Mapping function* provides packets with the specific information required to receive the intended QoS attributes.
- *Classification function* assigns packets to the established services of the mobile station according to the related QoS attributes.
- *Resource manager* distributes the available resources between all services sharing the same resource according to the required QoS. For example, the resource manager can employ techniques such as scheduling, bandwidth management, and radio link power control.
- *Traffic conditioner* is a module that provides the traffic conformance with the negotiated QoS attributes. To achieve this goal, the traffic conditioner deploys traffic policing and/or traffic shaping mechanisms to all traffic. The traffic policing mechanism monitors the traffic's actual QoS attributes and compares them to the negotiated QoS attributes. If these attributes do not match, the traffic policing mechanism marks the packets as non-conformant or drops them. The traffic shaping mechanism shapes traffic according to the negotiated QoS attributes. For a more detailed description of traffic policing and traffic shaping mechanisms see Chapter 3.

An example of data flow within these various user plane QoS functions is shown in Figure 11.38.

11.7.3 QoS Classes

UMTS defines four different QoS classes: Conversational, Streaming, Interactive, and Background.

The main difference between these QoS classes is their sensitivity to time delay. The conversational class, for example telephony, is the most time delay sensitive while the background class is the least time delay sensitive.

The conversational and streaming classes carry real-time traffic flows. The conversational class is used for applications such as telephony (e.g., GSM), voice over IP and video conferencing applications. Real-time conversation is always performed between peers (or groups) of live (human) end users. Since the maximum transfer delay is dictated by the human perception of video and audio conversation, the limit for acceptable transfer delay is very strict. Failure to provide low enough transfer delay will result in unacceptable low quality.

The streaming class includes applications such as real-time video and audio streams. The highest acceptable delay variation over the transmission media is given by the capability of the time alignment function of the application.

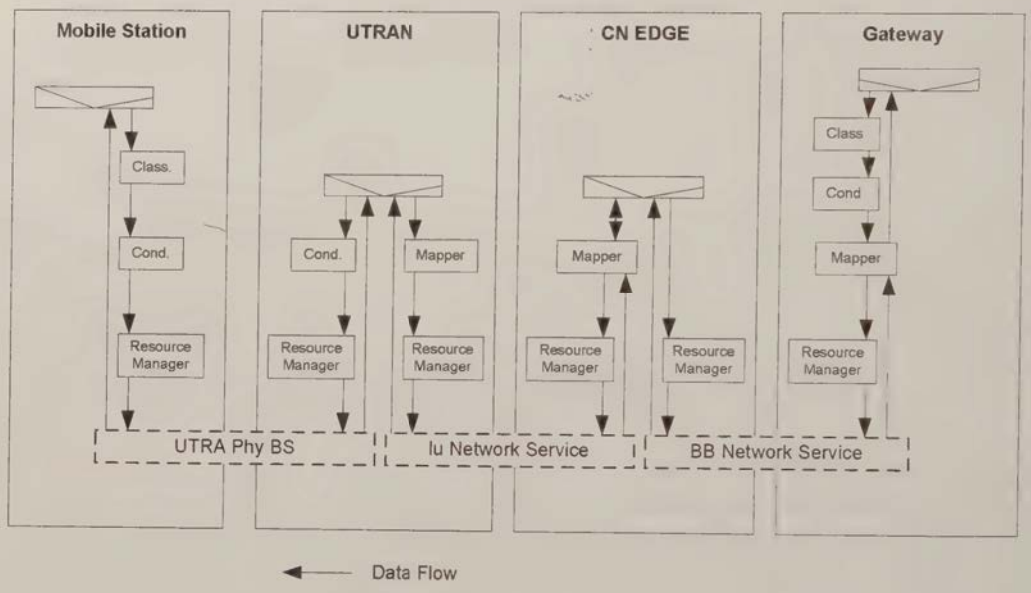


Figure 11.38 UMTS User Plane QoS Management Functions

The interactive class is mainly used by applications that request data from remote servers such as web browsing, data retrieval, and server access. Interactive traffic is characterized by the request-response time delay pattern of the end user.

The background class is used by applications performed in the background, such as downloads of emails and files. Since these applications are delay insensitive, the overall expectation of time delay is minimal or nonexistent.

As shown in Table 11.3, each traffic class is described by a set of QoS parameters.

Table 11.3 UMTS Bearer Service Attributes

UMTS Bearer Service Attribute	Conversational Class	Streaming Class	Interactive Class	Background Class
Maximum bit rate (kbps)—upper limit of the bit rate with which the UMTS delivers packets	2048	2048	< 2048—Overhead	< 2048—Overhead
Guaranteed bit rate (kbps)—guaranteed number of bits delivered by UMTS within a period of time	< 2048	< 2048		

Table 11.3 UMTS Bearer Service Attributes (Continued)

UMTS Bearer Service Attribute	Conversational Class	Streaming Class	Interactive Class	Background Class
Delivery order—indicates whether the UMTS link should provide in-sequence packet delivery or not	Yes/No	Yes/No	Yes/No	Yes/No
Maximum packet size (octets)	1500 or 1502	1500 or 1502	1500 or 1502	1500 or 1502
Delivery of erroneous packets —indicates whether packets detected as erroneous are delivered or discarded	Yes/No	Yes/No	Yes/No	Yes/No
Residual BER—indicates the undetected bit error ratio in the delivered packets	$5*10^{-2}$, 10^{-2}, $5*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}	$5*10^{-2}$, 10^{-2}, $5*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$
Packet error ratio—indicates the fraction of packets lost or detected as erroneous	10^{-2}, $7*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}	10^{-1}, 10^{-2}, $7*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}	10^{-3}, 10^{-4}, 10^{-6}	10^{-3}, 10^{-4}, 10^{-6}
Transfer delay (ms)—indicates the maximum delay for 95th percentile of delay distribution for all delivered packets during the lifetime of the communication link	100—Maximum value	250—Maximum value		
Traffic handling priority—differentiates and prioritizes between traffic with different QoS requirements within a traffic class			Under work by 3GPP	
Allocation/Retention priority—differentiates and prioritizes between traffic classes	Under work by 3GPP	Under work by 3GPP	Under work by 3GPP	Under work by 3GPP

Table 11.3 UMTS Bearer Service Attributes (Continued)

UMTS Bearer Service Attribute	Conversational Class	Streaming Class	Interactive Class	Background Class
Source statistic descriptor—specifies source characteristics	Speech/ unknown	Speech/ unknown		
SDU format information—indicates the fraction of packets lost or detected as erroneous	Under work by 3GPP	Under work by 3GPP		

11.7.4 QoS Mechanisms in the Radio Bearer Service

Figure 11.39 depicts a simplified diagram of the radio bearer key QoS mechanisms that reside in the RRC, MAC, and PHY layers. The RRC, which plays the center role for QoS management, manages the signaling between the mobile station and the UTRAN. Furthermore, the RRC can control the MAC and PHY layers.

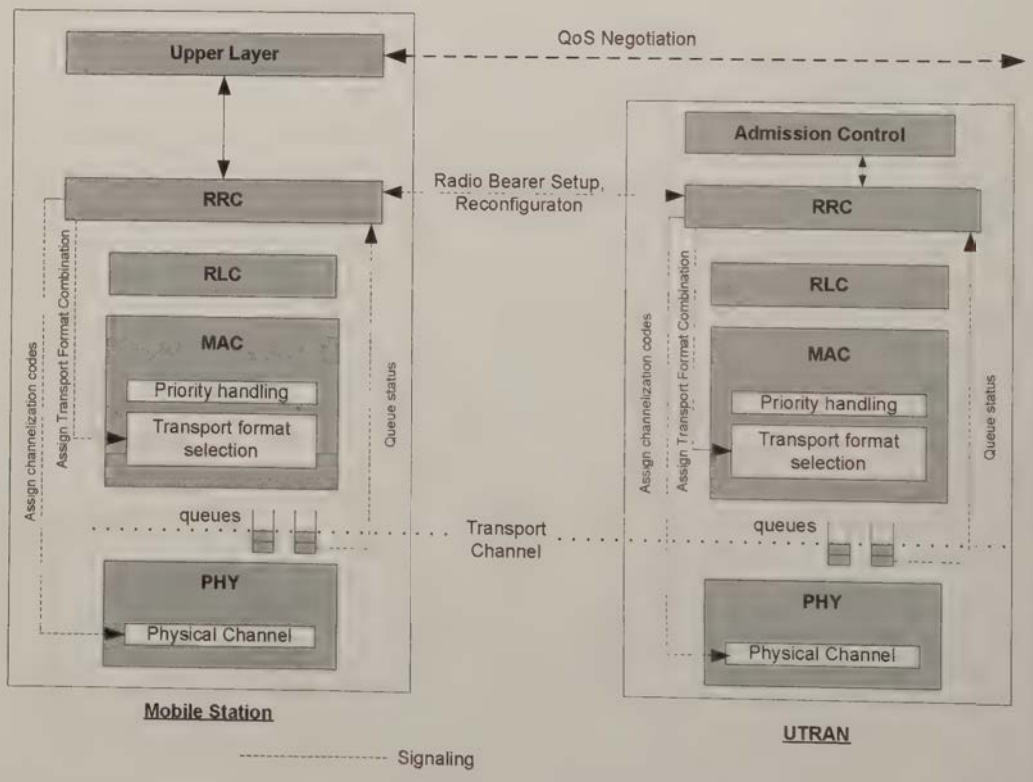


Figure 11.39 QoS Mechanisms in Radio Bearer

First, an application performs QoS negotiation with the UMTS core network in the upper layer. The upper layer service attributes are mapped into the radio access bearer (RAB) service attributes. The RRCs of the mobile station and UTRAN perform the radio bearer setup and reconfiguration procedures. During these procedures the UTRAN's RRC consults with UTRAN's admission control module in order to check if there are enough resources and make sure that the new connection does not interfere and does not degrade the existing services. In case the application is admitted, the RRC allocates bandwidth through channelization code assignment in the physical layer and transport format combination in the MAC layer. Furthermore, the MAC also contains a priority handling mechanism.

Next, we describe the following aspects of the radio bearer QoS mechanisms: bandwidth allocation and priority handling.

11.7.4.1 Bandwidth Allocation

After a new application performs the QoS negotiation, the RRC establishes the radio bearer services which define the transport and physical channels. The transport channel is controlled by the MAC while the physical channel is controlled by the PHY.

As discussed in Section 11.3.1, the parameters that describe the transport channel are included in the Transport Format: transport block size, transport block set size, and transport time interval. Therefore, these parameters will define the bandwidth allocation.

The physical channel parameter is the channelization code. As described in Section 11.3, the bandwidth allocation can be changed by changing the spread factor (SF). The smaller the spread factor code, the larger the bandwidth (or data rate).

The queue size of the transport layer (at the uplink and at the downlink) is used to determine the application's dynamic bandwidth demand. When this queue grows beyond a certain threshold, the RRC will perform radio bearer reconfiguration by adjusting the physical channel configuration (i.e., adjust channelization code) and the transport channel configuration (i.e., adjust transport format and channelization code). Figures 11.40 to 11.42 show such reconfiguration examples for different scenarios.

11.7.4.2 Priority Handling

Priority handing is located in the MAC-c/sh as shown in Figure 11.30. The traffic with the highest priority receives service first. The priority value is related to the Transport Format selection. A high priority value is associated with a Transport Format that provides high data rate while a low priority value is associated with a Transport Format that provides low data rate.

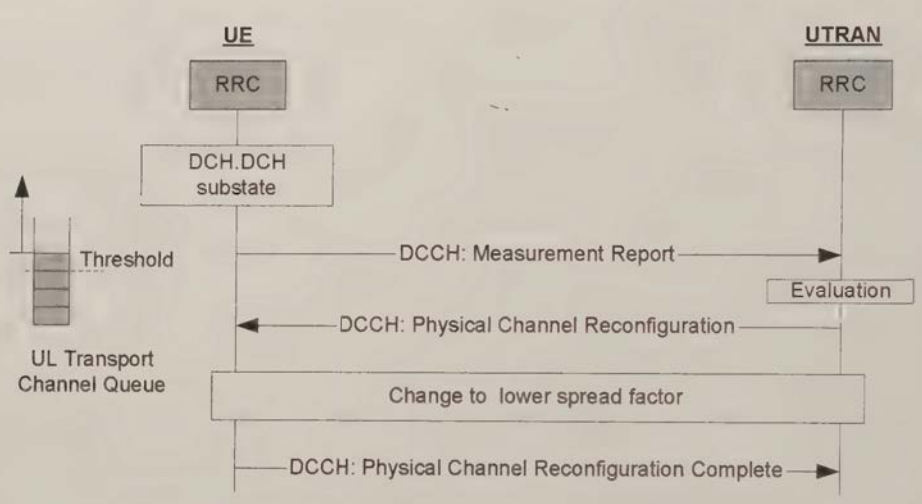


Figure 11.40 Increase of Uplink Bandwidth Using Physical Channel Reconfiguration

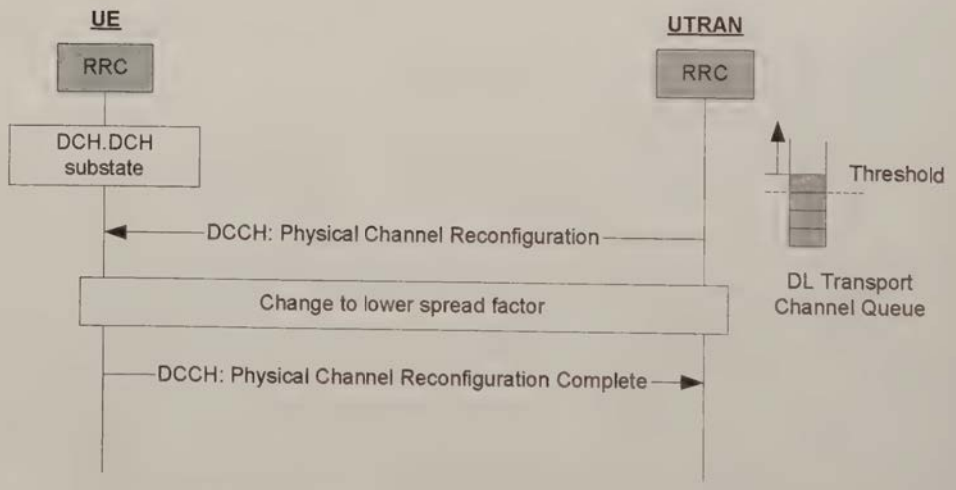


Figure 11.41 Increase of Downlink Bandwidth Using Physical Channel Reconfiguration

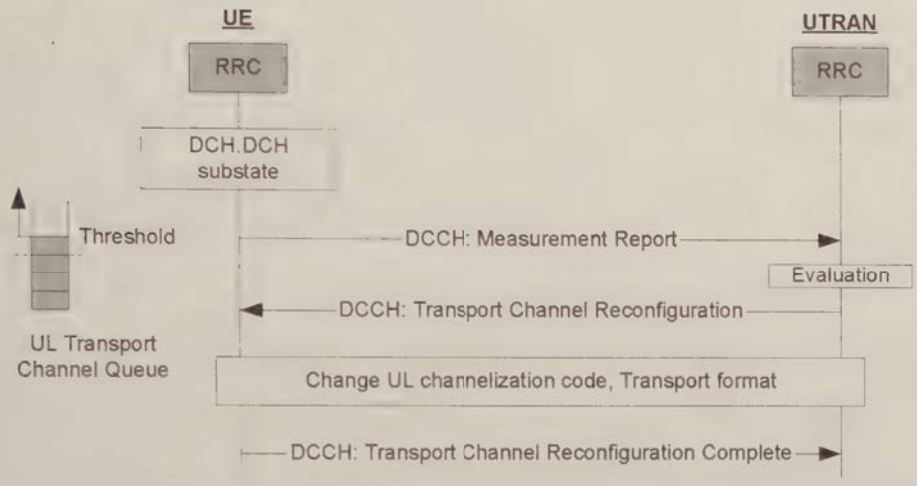


Figure 11.42 Increase of Uplink Bandwidth Using Transport Channel Reconfiguration



CHAPTER 12

cdma2000

12.1 Introduction

cdma2000 is a 3G technology whose standards are specified by the Third Generation Partnership Project 2 (3GPP2). 3GPP2 is a collaborative organization that includes members from all over the world, with a majority of members from North America and Asia. 3GPP2 is part of IMT-2000 (International Mobile Telecommunication–2000) effort that is designed to provide high-speed communication with high-quality multimedia services and global roaming support.

Figure 12.1 shows the evolution of the cdma2000 standard. cdmaOne, or IS-95, was influenced by various standards such as Advanced Mobile Phone Service (AMPS), IS-136 TDMA, and GSM. IS-95 has two revisions: IS-95A and IS-95B. IS-95A is a 2G technology with a data rate of 14.4 kbps, while IS-95B is 2.5G technology with a data rate of 115 kbps. The 3G cdma2000 continued to evolve and support IS-95.

cdma2000, which is also referred to as IMT2000-Mc (IMT-CDMA Multicarrier), has been divided into the following two phases: Phase 1 cdma2000 1x (sometimes called cdma2000 1xRTT) and Phase 2 cdma2000 3x (sometimes called cdma2000 3xRTT). cdma2000 1x deploys a single radio frequency carrier (1.25 MHz bandwidth) and delivers 307 kbps in a mobile environment, whereas cdma2000 3x deploys multicarrier technology (i.e., a multiple of 1.25 MHz bandwidth carriers) and delivers speeds of up to 2 Mbps. cdma2000 1x continued to evolve to cdma2000 1x Evolution (1xEV). cdma2000 1xEV is backwards compatible with cdma2000 1x and cdmaOne.

cdma2000 1xEV utilizes Frequency Division Duplex (FDD), where the uplink (from the mobile station to the base station, also called reverse link) and downlink (from the base station to the mobile station, also called forward link) operate on two separate frequency bands.

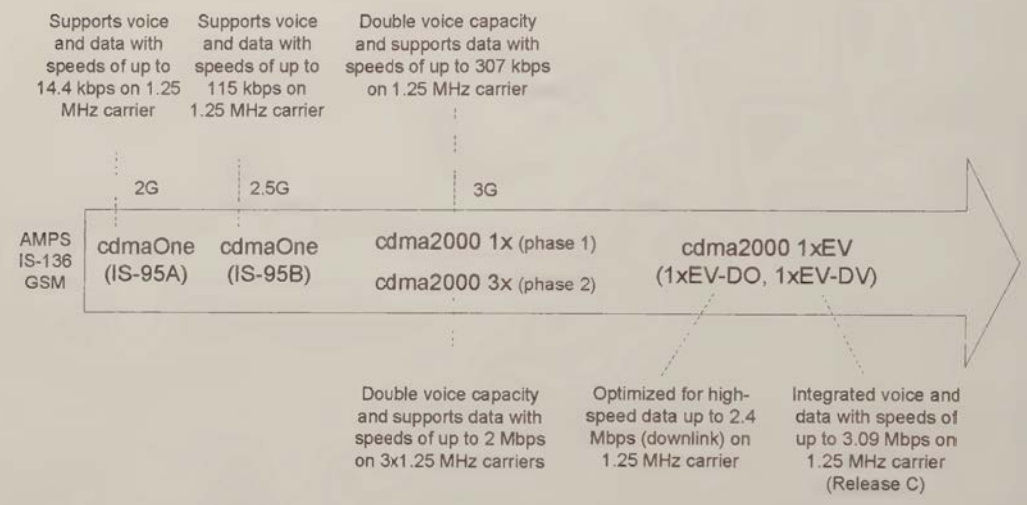


Figure 12.1 cdma2000 Evolution

cdma2000 1xEV has two variations: cdma2000 1xEV-DO (Data Only) optimized for high-speed data transmission (up to 2.4 Mbps) and cdma2000 1xEV-DV (Data and Voice), which supports both data and voice with speeds of up to 3.09 Mbps.

cdma2000 has been introduced in several releases. In this book we describe cdma2000 Release C. We focus on the following 3GPP2 documents:

- 3GPP2 C.S0001-C Introduction to cdma2000 Standards for Spread Spectrum Systems Release C
- 3GPP2 C.S0002-C Physical Layer Standard for cdma2000 Spread Spectrum Systems Release C
- 3GPP2 C.S0003-C Medium Access Control (MAC) Standard for cdma2000 Spread Spectrum Systems Release C
- 3GPP2 C.S0004-C Signaling Link Access Control (LAC) Standard for cdma2000 Spread Spectrum Systems Release C
- 3GPP2 C.S0005-C Upper Layer (Layer 3) Signaling Standard for cdma2000 Spread Spectrum Systems Release C

12.2 cdma2000 Architecture

Figure 12.2 illustrates the basic network architecture of cdmaOne (IS-95) and cdma2000. A mobile station connects to the external network (i.e., Public Switched Telephone Network [PSTN] or Internet) through the base station and core network. The base station consists of two entities: Base Transceiver Station (BTS) and Base Station Controller (BSC). BTS provides the communication services within its coverage area or cell. BSC manages the call handoff and

radio resources of each BTS. In the IS-95 system, the BSC connects to the Mobile Switching Center (MSC) accommodating both voice and data traffic. The voice traffic is routed through the MSC to the external telephone networks (i.e., PSTN), whereas the data traffic is routed to the external data network (i.e., Internet) through the Interworking Function (IWF). IWF provides the access point to the Internet. In a cdma2000 system, there are separate links between the base station and the core network. The link between the BSC and the MSC accommodates voice services while the link between the BSC and the Packet Data Service Node (PDSN) accommodates data services. PDSN supports, establishes, maintains, and terminates IP sessions for the mobile station. The AAA module is responsible for authorization and accounting.

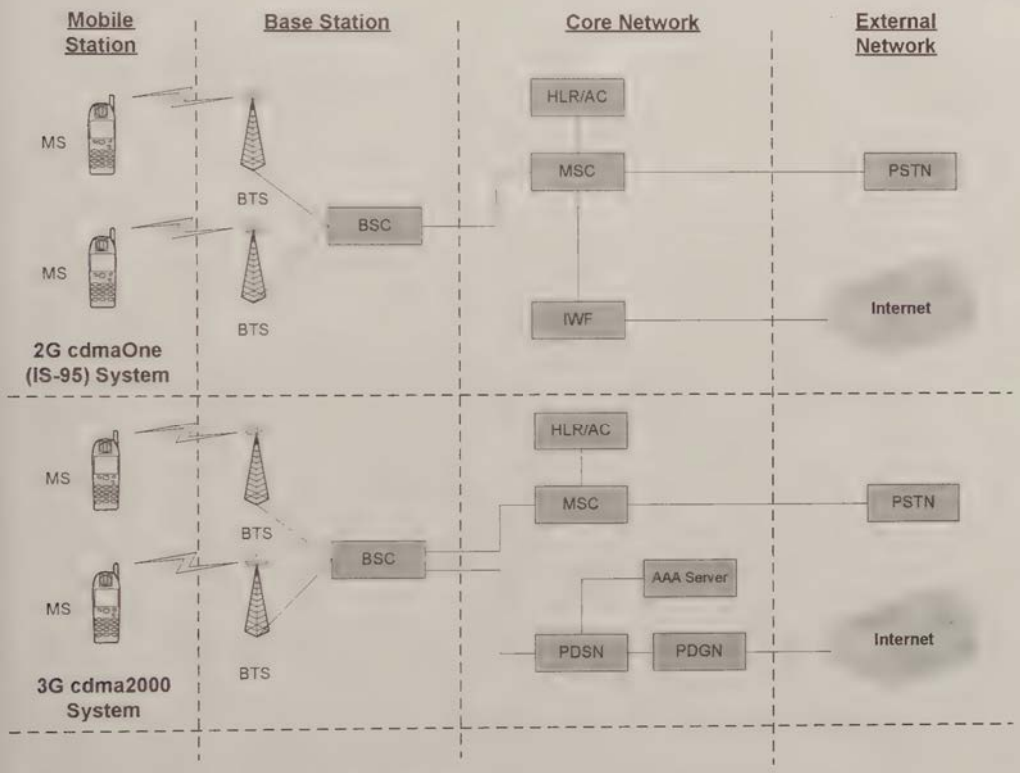


Figure 12.2 cdmaOne and cdma2000 Network Architecture

12.2.1 cdma2000 Air Interface Protocol Architecture

Figure 12.3 illustrates cdma2000 air interface protocol architecture. The air interface protocol architecture is divided into layers corresponding to the Open Systems Interconnection (OSI) protocol layers: 1) Layer 1 or physical layer; 2) Layer 2, which includes the Link Access Control (LAC) sublayer, the Media Access Control (MAC) sublayer, and the Forward Packet Data Channel (F-PDCH) Control Function sublayer; and 3) Layers 3 to 7, which include the upper layer signaling and the voice and data services originated from the users' applications. The F-PDCH Control Function module newly introduced in Revision C contains several key features such as Adaptive Modulation and Coding scheme (AMC) and Hybrid Automatic Repeat request (HARQ). There are also signaling interfaces between the upper layer and the physical layer.

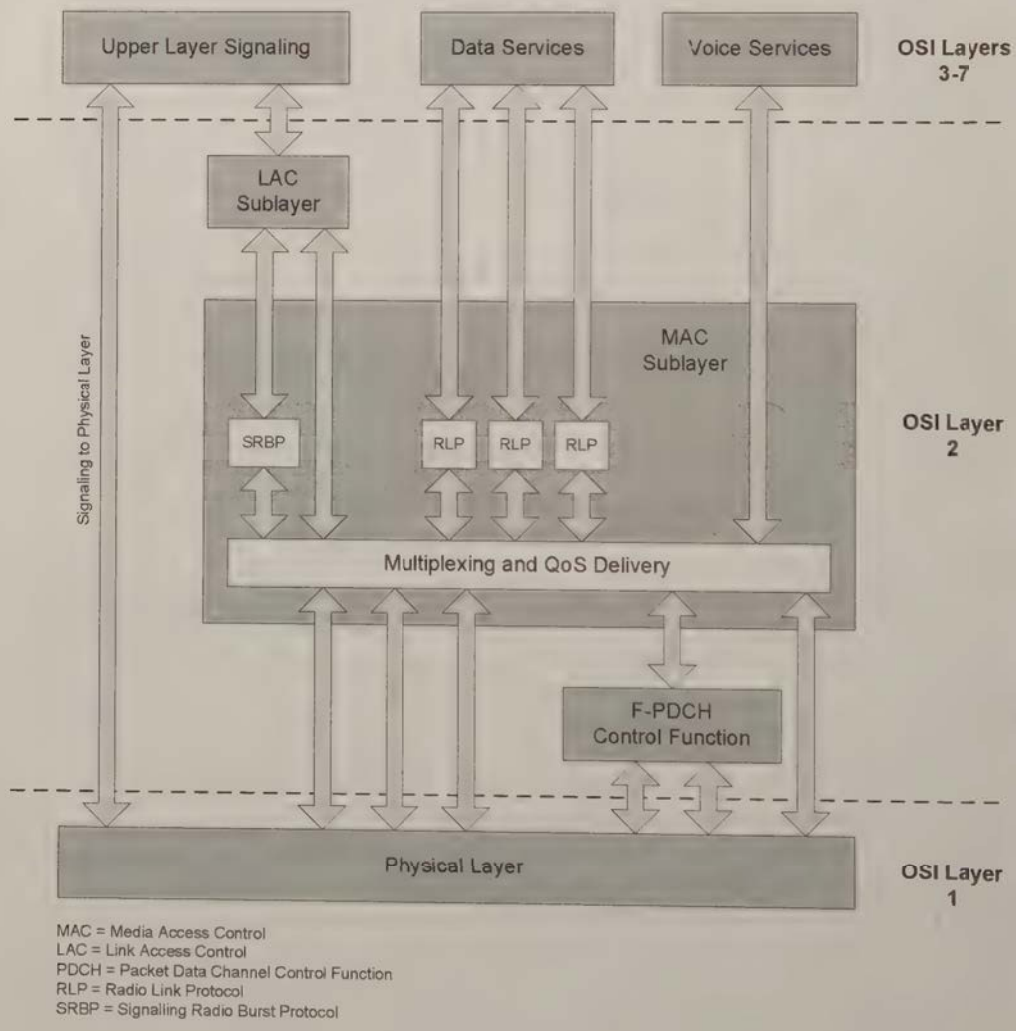


Figure 12.3 cdma2000 Air Interface Protocol Architecture

A more detailed description of cdma2000 air interface protocol architecture at the mobile station side is shown in Figure 12.4.

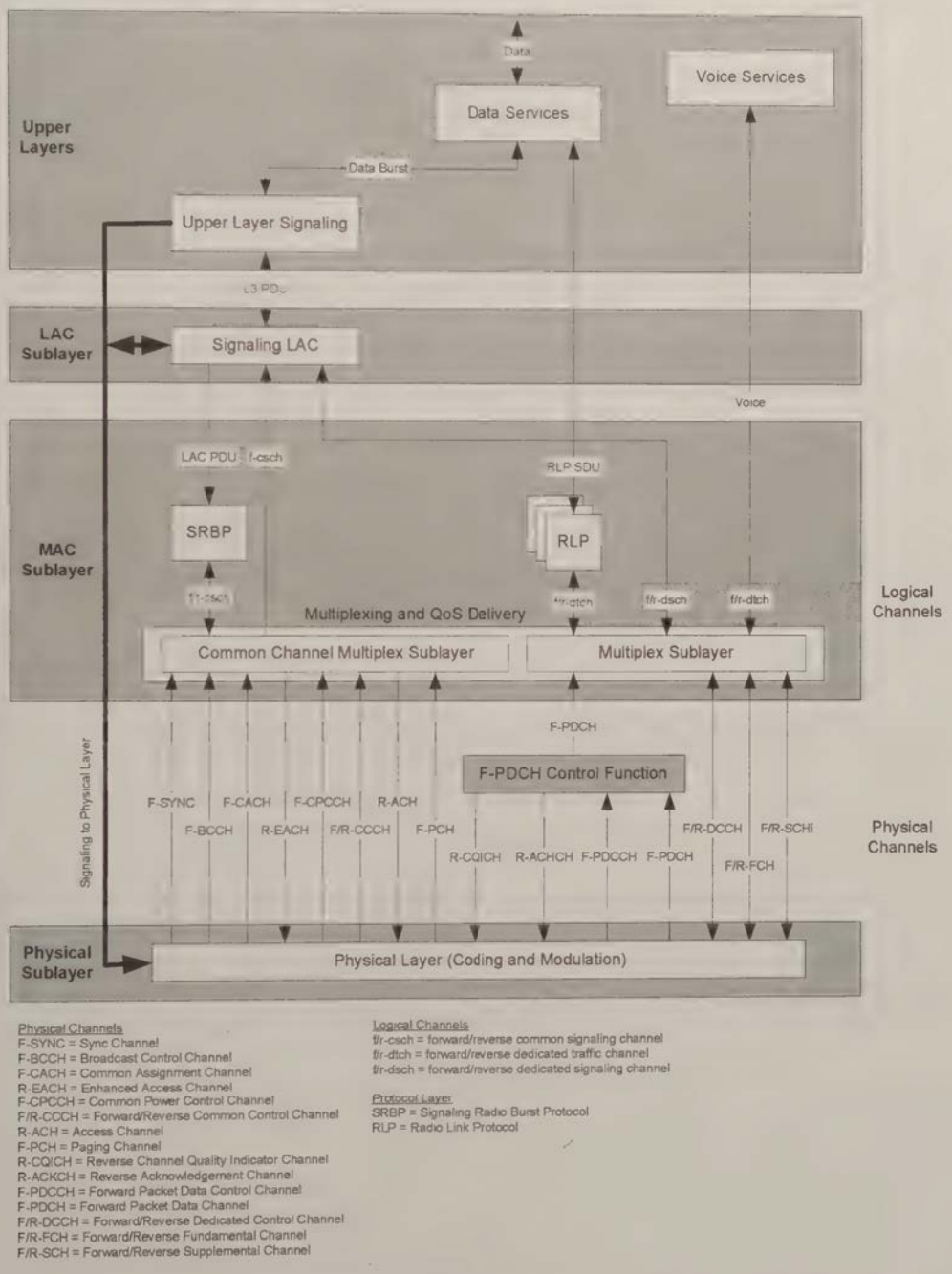


Figure 12.4 Detailed cdma2000 Air Interface Protocol Architecture (Mobile Station Side)

cdma2000 is based on physical and logical channels that carry both data and control packets. The logical channel defines what type of information (i.e., data message, control message) is delivered. Packets from each logical channel are multiplexed and delivered in timely fashion by the MAC to the appropriate physical channels. The MAC delivers these packets based on the QoS requirements of each logical channel. The physical channel defines the radio transport channel based on the radio configuration, which is a combination of encoding, interleaving, frame size, and bit rate. The radio configuration of the physical channel is defined in the physical layer. As shown in Figure 12.4 the connection between the MAC and the physical layers indicates the physical channel to which the connection belongs.

There are two directions on both the logical and physical channels: forward direction (from the base station to the mobile station) and reverse direction (from the mobile station to the base station). These directions are included as the first letter (f = forward, r = reverse) of the logical and physical channel name. A logical channel name consists of three lower case letters and the suffix "ch" (channel). The first letter (i.e., f = forward and r = reverse) indicates the direction of the logical channel. "f" and "r" can be used together if the logical channel has both directions. The second letter (i.e., d = dedicated or c = common) indicates the type of logical channel (dedicate or common [share]). The third letter (i.e., t = traffic or s = signaling) indicates the contents. The first and second letters are separated by a hyphen. Examples of logical channels include f-dtch (forward dedicated traffic channel) and f/r-dsch (forward/reverse dedicated signaling channel). The physical channel name is written in capital letters. The first letter (i.e., F = forward or R = reverse) indicates the direction of the physical channel such as F-PDCH (Forward Packet Data Channel).

12.3 Physical Layer

cdma2000 uses an FDD Code Division Multiple Access (CDMA) network—that is, the transmission from the base station to the mobile station, referred to as forward traffic (i.e., downlink), is done on a different frequency than that of the traffic from the mobile station to the base station, referred to as reverse traffic (i.e., uplink) as shown in Figure 12.5. For each forward and reverse link, cdma2000 employs a combination of Time Division Multiplex (TDM) and Code Division Multiplex (CDM). For cdma2000 1x, the frequency channel width of both the forward and reverse links is 1.25 MHz. These frequency channels are separated by 45 MHz.

As shown in Table 12.1, cdma2000 is assigned various forward and reverse frequencies based on the country of application.

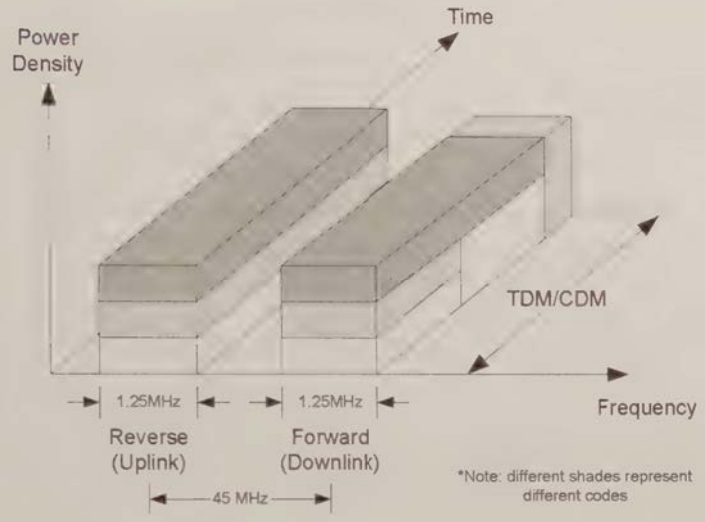


Figure 12.5 Channel Access

Table 12.1 cdma2000 Frequency Bands

Band Class	System	Transmit Frequency Band (MHz)	
		Mobile Station (Reverse Link)	Base Station (Forward Link)
0	North America Cellular	824-849	869-894
1	North America PCS	1850-1910	1930-1990
2	Total Access Communication System	872-915	917-960
3	Japan Total Access Communication System	887-925	832-870
4	Korean PCS	1750-1780	1840-1870
5	Nordic Mobile Telephone	411-484	421-494
6	IMT-2000	1920-1980	2110-2170

Table 12.1 cdma2000 Frequency Bands (Continued)

Band Class	System	Transmit Frequency Band (MHz)	
		Mobile Station (Reverse Link)	Base Station (Forward Link)
7	North America 700	776-794	746-764
8	1800 MHz	1710-1785	1805-1880
9	900 MHz	880-915	925-960

The physical layer delivers the packets received from the MAC layer to the physical channels. The physical layer defines a combination of frames, modulations, and codes used for each physical channel.

For channel access, the physical channel deploys CDMA, in which the information bits are spread by using a number of Pseudo-Noise (PN) chip signals (a multiple of 1.2288 Mcps). The cdma2000 Release C defines two spreading rates: Spreading Rate 1 and Spreading Rate 3. Spreading Rate 1 (referred to as 1x) uses 1.2288 Mcps PN chip signal spread over a 1.25 MHz channel. Spreading Rate 3 (referred to as 3x) has two spreading approaches. The first approach uses 1.2288 Mcps PN chip signal spreading over each of three 1.25 MHz channels (sometimes called Multicarrier Channel). This approach is used in forward CDMA channels. The other approach uses 3.6864 Mcps PN chip signal spreading over a 3.75 MHz channel. The latter approach is used in reverse CDMA channels. Figure 12.6 illustrates the Spreading Rate.

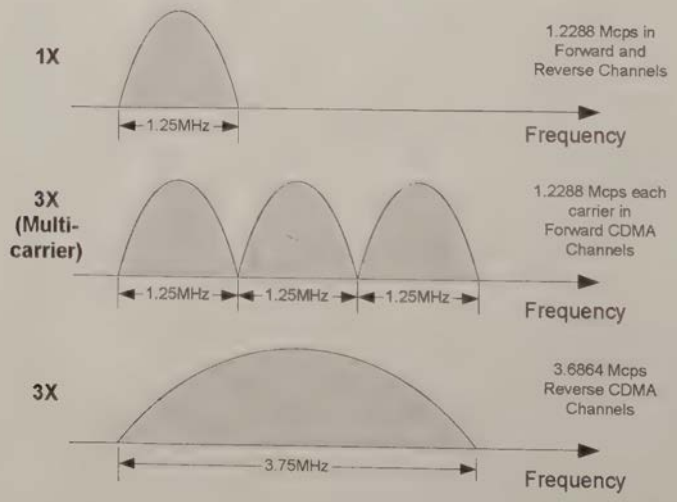


Figure 12.6 Spreading Rate

The CDMA involves two types of codes: long code and Walsh code. The long code (similar to the scrambling code in Universal Mobile Telecommunications System [UMTS]) uses PN sequence to scramble the forward and reverse CDMA channels. On the reverse channel, different long codes are used to identify transmissions from different mobile stations. On the forward channel, the phase of the long code is used to identify the base station transmissions. Unlike coding in UMTS, where the different scrambling codes are used to differentiate between transmissions from different base stations, in cdma2000 each base station uses the same long code but different phases. There are a total of 512 long code phases. The Walsh code (similar to the channelization code in UMTS) is used to identify the physical channels within a mobile station or within a base station. cdma2000 has a total of 128 Walsh codes. The basic concept of Walsh code, which is referred to as channelization code, is described in Chapter 11, Section 11.3.

cdma2000 also defines the radio configurations (RCs) for the forward and reverse CDMA channels. The radio configuration consists of a combination of physical layer parameters such as spreading modulation (i.e., BPSK, QPSK), spreading rate (i.e., 1x, 3x), forward error correction (i.e., 1/2 to 1/4 convolution code, 1/2 to 1/5 turbo code), and data rate. There are six radio configurations (RC1 to RC6) for the reverse CDMA channel and ten radio configurations (RC1 to RC10) for the forward CDMA channel.

12.3.1 Physical Channels

The standard defines the structure of the physical channel in frames. The frame structure varies on each type of physical channel with possible frame sizes of 1.25 ms, 2.5 ms, 5 ms, 10 ms, 20 ms, 40 ms, and 80 ms. The physical channels include the following:

- Forward/Reverse Fundamental Channel (F/R-FCH)
- Forward/Reverse Dedicated Control Channel (F/R-DCCH)
- Forward/Reverse Supplemental Code Channel (F/R-SCCH)
- Forward/Reverse Supplemental Channel (F/R-SCH)
- Paging Channel (F-PCH)
- Quick Paging Channel (F-QPCH)
- Access Channel (R-ACH)
- Forward/Reverse Common Control Channel (F/R-CCCH)
- Forward/Reverse Pilot Channel (F/R-PICH)
- Transmit Diversity Pilot Channel (F-TDPICH)
- Auxiliary Pilot Channel (F-APICH)
- Auxiliary Transmit Diversity Pilot Channel (F-ATDPICH)
- Sync Channel (F-SYNCH)
- Common Power Control Channel (F-CPCCH)
- Common Assignment Channel (F-CACH)
- Enhanced Access Channel (R-EACH)
- Broadcast Control Channel (F-BCCH)
- Forward Packet Data Channel (F-PDCH)
- Forward Packet Data Control Channel (F-PDCCH)

- Reverse Acknowledgment Channel (R-ACKCH)
- Reverse Channel Quality Indicator Channel (R-CQICH)

In the following subsection we introduce some of these physical channels.

12.3.1.1 Pilot Channels

There are pilot channels in both forward and reverse links. In the forward link, pilot channels include Forward Pilot Channel (F-PICH), Transmit Diversity Pilot Channel (F-TDPICH), Auxiliary Pilot Channel (F-APICH) and Auxiliary Transmit Diversity Pilot Channel (F-ATDPICH). Forward Pilot Channel is transmitted by the base station at all times. F-PICH helps the mobile station in the initial cell search process. When a new mobile station joins a cell, it detects the F-PICH transmitted by the base station. The mobile station also measures the forward signal strength from the pilot channel. F-TDPICH has the same function as F-PICH but it is used in transmit diversity. F-APICH and F-ATDPICH are used in beam forming antenna systems. The Reverse Pilot Channel (R-PICH) is only a pilot channel in the reverse link which helps the base station detect the mobile station. R-PICH also includes the Reverse Power Control Subchannnel which controls the power of the forward link.

12.3.1.2 Physical Channels for Voice and Data Traffic

Figure 12.7, which is a part of Figure 12.4, illustrates the physical channels for voice and data traffic. cdma2000 1x defines Forward/Reverse Fundamental Channel (F/R-FCH), Forward/Reverse Supplemental Channel (F/R-SCH), and Forward/Reverse Dedicated Control Channel (F/R-DCCH) to support voice and data traffic. In addition, cdma2000 1xEV introduces the F-PDCH Control Function, which contains new physical channels that support the high-speed forward data transmission. These new physical channels include Forward Packet Data Channel (F-PDCH), Forward Packet Data Control Channel (F-PDCCH), Reverse Acknowledgment Channel (R-ACKCH), and Reverse Channel Quality Indicator Channel (R-CQICH).

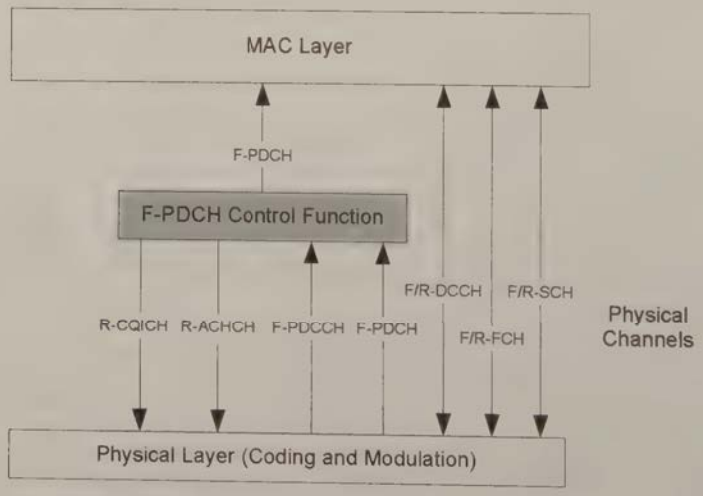


Figure 12.7 Physical Channels for Voice and Data Traffic (mobile station side)

The Forward/Reverse Fundamental Channel (F/R-FCH) can support voice, data, and signaling. The standard defines a flexible data rate that ranges from 750 bps to 14.4 kbps by varying the spreading rate and the associated set of frames for each radio configuration. The Forward/Reverse Dedicated Control Channel (F/R-DCCH) can be used for signaling or burst data transmissions. The Forward/Reverse Supplemental Channel (F/R-SCH) is defined to support high rate data services. F/R-SCH is scheduled dynamically on a frame-by-frame basis. F/R-SCH can deliver data rates up to 32 times the rates of an F/R-FCH. At the base station, the number of F-SCHs is limited by the available transmission power and Walsh codes. At the mobile station, the number of R-SCHs is limited to two.

Forward Packet Data Channel (F-PDCH) provides high-speed forward data transmission. A base station can support up to two F-PDCHs, and each F-PDCH transmits data packets to one mobile station at a time. A mobile station can support one F-PDCH at a time. Forward Packet Data Control Channel (F-PDCCH) provides the transmitting control information (i.e., users' MAC ID, packet size, subpacket ID) for the associated F-PDCH. F-PDCCH can also be used to broadcast the Walsh mask to the mobile stations. A base station can support up to two F-PDCCHs (corresponding to two F-PDCHs). When a mobile station detects its own MAC ID on a F-PDCCH, it will retrieve data packets from the associated F-PDCH. The high forward data rate can be achieved through Adaptive Modulation and Coding (AMC) scheme and flexible Time Division Multiplex/Code Division Multiplex (TDM/CDM). The AMC scheme includes a combination of a number of information bits (i.e., 386, 770, 1538, 2306, 3074 or 3842), the total frame duration (i.e., 1.25 ms., 2.5 ms, or 5 ms), modulation schemes (i.e., QPSK, 8-PSK or 16-QAM), and spreading codes. Table 12.2 shows F-DPCH possible data rates.

Table 12.2 F-DPCH Data Rates (kbps)

		F-PDCH Packet Size (bits) (information bits + 16 quality indicator bits + 6 turbo encoder tail bits)					
		408 bits	**792 bits**	**1560 bits**	**2328 bits**	**3096 bits**	**3864 bits**
Total Frame Duration (ms)	5 ms	82 kbps	158 kbps	312 kbps	466 kbps	619 kbps	773 kbps
	2.5 ms	163 kbps	317 kbps	624 kbps	931 kbps	1238 kbps	1546 kbps
	1.25 ms	326 kbps	634 kbps	1248 kbps	1862 kbps	2477 kbps	3091 kbps

The AMC scheme has flexible choices to achieve the different data rates. TDM/CDM provides packet scheduling of multiple F-PDCHs (up to two F-PDCHs transmitting at the same time) by varying the Walsh Code and scheduling. An example of a TDM/CDM assignment is shown in Figure 12.8 for four mobile stations (MS1 to MS4).

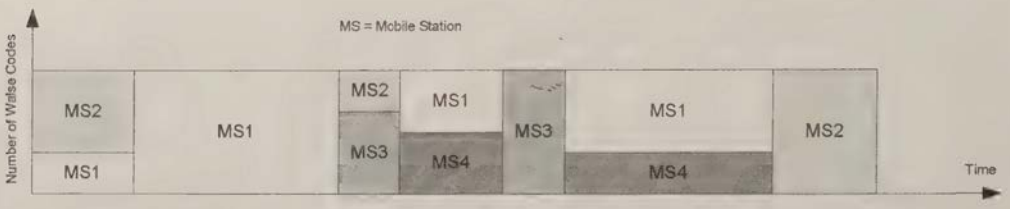


Figure 12.8 Example of a TDM/CDM Assignment

The Reverse Acknowledgment Channel (R-ACKCH) enables Automatic Repeat Request (ARQ) mechanism. After successfully receiving packets from the base station, the mobile station sends an acknowledgment to the base station through the R-ACKCH. The fact that the ARQ mechanism resides at the physical layer speeds up the retransmission process. Furthermore, instead of using the typical ARQ mechanism, cdma2000 1xEV employs a Hybrid ARQ that combines ARQ with Forward Error Correction (FEC). To improve the error correction performance and reduce the number of retransmission attempts, Hybrid ARQ performs FEC decoding on both erroneous packets from the previous transmission and packets from the current transmission.

Reverse Channel Quality Indicator Channel (R-CQICH) is used by the mobile station to indicate to the base station the channel quality measurements. The base station then uses this information to determine the appropriate spreading, modulation, frame size, and scheduling of F-PDCH. It allows the base station to efficiently manage the radio resources.

In summary, the voice and data packets are transmitted from the base station through F-FCH, F-DCCH, F-SCH, and F-PDCH (in case high-speed forward transmission is required). The voice and data packets are transmitted from the mobile station to the base station through F-FCH, F-DCCH, and F-SCH.

12.4 Media Access Control (MAC)

Figure 12.9 illustrates the MAC layer and its interactions with the LAC. cdma2000 supports a generalized model of multimedia services that allows simultaneous support for both voice and data traffic. cdma2000 also includes Quality of Service (QoS) control mechanisms that reside at the MAC layer. These mechanisms balance different QoS requirements of multiple simultaneous multimedia applications. The key functions of the MAC layer are 1) to receive the packets (i.e., voice, data) from the upper layers and 2) to schedule these packets to physical channels in a timely manner based on the connection QoS requirements. This process is done by the MAC through a Multiplexing and QoS Delivery module (see Figure 12.9). Release C standard also defines the signaling between the LAC and the MAC using service primitives. This signaling provides QoS information that can be used by the MAC. The standard also defines the following two modules: Signaling Radio Burst Protocol (SRBP) and Radio Link Protocol (RLP). SRBP is a connectionless protocol for signaling messages. RLP, which is a connection-oriented protocol, provides reasonably reliable transmission over the radio link using a negative-acknowledgment-based data delivery protocol.

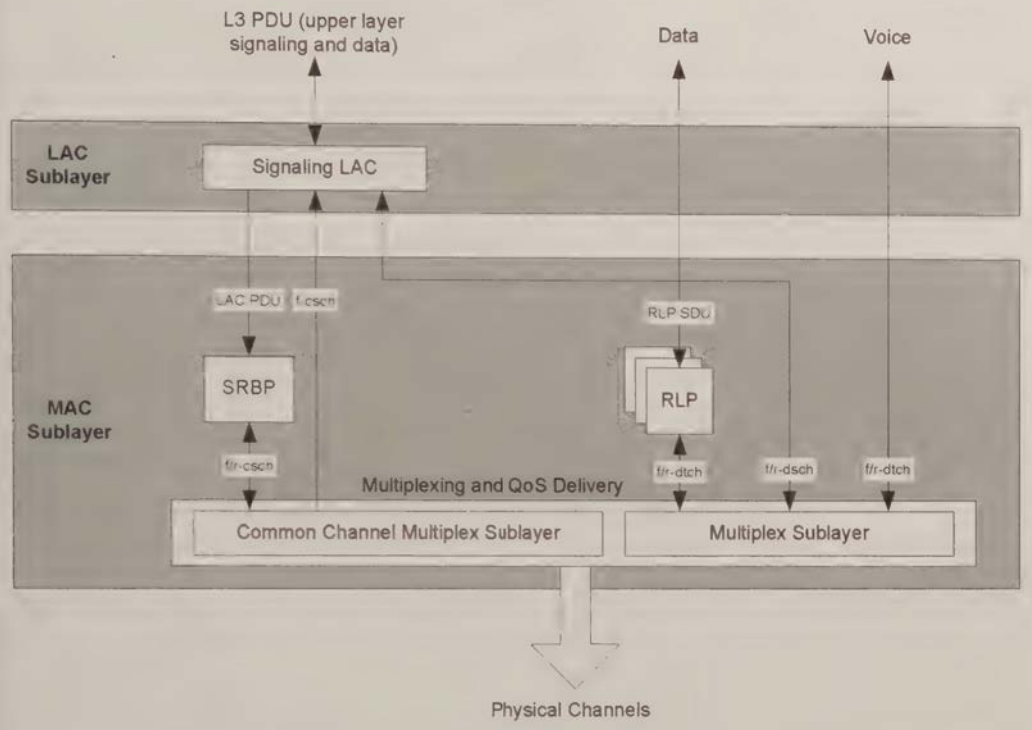


Figure 12.9 MAC Layer

We introduce four key service primitives used in the signaling procedure between the Signaling LAC and the MAC:

- *MAC-SDUReady.Request:* This primitive is sent from the signaling LAC to the MAC when there are packets waiting in the signaling LAC. The primitive includes the following parameters:
  - channel_type: the type of channel required—"5ms FCH/DCCH frame," "20ms FCH/DCCH frame," or "F-PDCH frame"
  - size: the size of packets (bits)
  - scheduling hint: indicates the relative priority service requirement
- *MAC-Availiability.Indication:* This primitive is sent from the MAC to the signaling LAC when the MAC multiplex module is ready to receive the packets from the upper layer and to transmit them to the physical layer. The primitive includes the following parameters:
  - channel_type: the type of channel allowed—"5ms FCH/DCCH frame," "20ms FCH/DCCH frame," or "F-PDCH frame"

- max_size: the maximum number of bits from the signaling LAC that can be fitted in the physical channel based on QoS requirements
- system_time: indicates the time when the physical layer will transmit the packets

- *MAC-Data.Request:* This primitive is sent from the signaling LAC to the MAC. It includes the type of channel required and a packet. The MAC multiplex module will fit this packet to the closest size data block determined by the rate set of the physical channel.
- *MAC-Data.Indication:* This primitive is sent from the MAC to the signaling LAC to indicate the packet transmission in the physical layer.

Figure 12.10 illustrates the signaling and packet transmission process (steps 1 to 5) at the MAC layer.

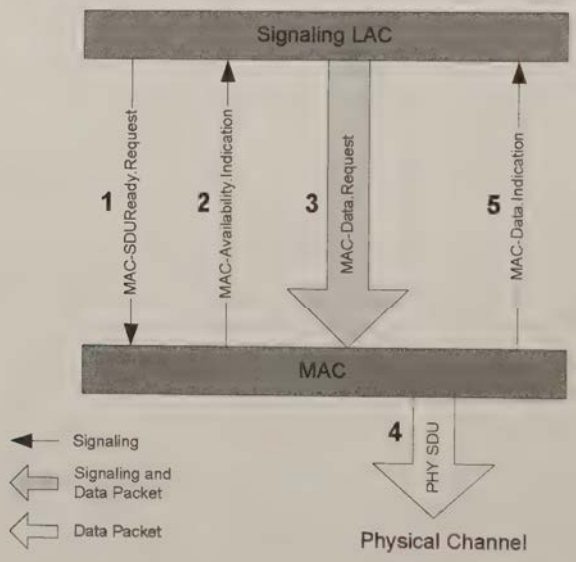


Figure 12.10 Signaling and Packet Transmission Process

12.4.1 Logical Channels

The following logical channels define what type of information (i.e., user data message, control message) is delivered:

- *Forward/Reverse Dedicated Traffic Channel (f/r-dtch):* A point-to-point logical channel that carries voice and data packets and transmits through a dedicated physical channel.

- *Forward/Reverse Dedicated Signaling Channel (f/r-dsch):* A point-to-point logical channel that carries signaling packets from the upper layer to a dedicated physical channel.
- *Forward/Reverse Common Signaling Channel (f/r-csch):* A point-to-multipoint logical channel that carries signaling packets from the upper layer to a common physical channel.

12.4.2 Multiplex and QoS Sublayers

The multiplex sublayer is responsible for transmitting and receiving packets from the physical layer. The multiplex sublayer receives information from the logical channels that comes from various sources (i.e., upper layer signaling, data, and voice services). The transmitting function, under QoS control, solicits information from various packets exchanged with the MAC. This information is used by the multiplex sublayer to determine the relative priority between the traffic supplied by signaling and other services. The exact manner for using this information to deliver over-the-air QoS is not specified by the cdma2000 standard.

12.5 Link Access Control (LAC)

The LAC, which includes several sublayers as depicted in Figure 12.11, performs the following functions:

- Delivery of packets with optional ARQ techniques to provide reliability
- Segmentation of packets to sizes suitable for the MAC and reassembly of such packets coming from the MAC
- Access control through authentication
- Address control to ensure delivery of packets based upon addresses that identify particular mobile stations
- Internal signaling, by exchanging notifications and data with the MAC and the supervisory and configuration entities, resulting from the processing of LAC Sublayer level information

12.6 QoS Support

cdma2000 Release C standard supports voice and high-speed data transmission. Each application has different QoS requirements. As we described in previous sections, cdma2000 defines several QoS mechanisms that reside at different protocol layers (i.e., physical layer, MAC layer, and upper layers). In this section we summarize the QoS mechanisms defined by the standard.

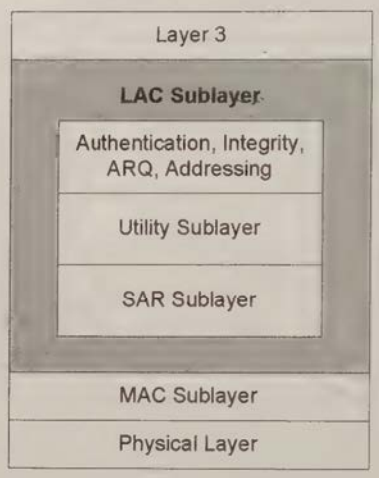


Figure 12.11 LAC Sublayer

12.6.1 Bandwidth Allocation

The standard defines Adaptive Modulation and Coding (AMC) and flexible TDM/CDM. Both techniques provide flexible tools that enable dynamic bandwidth allocation to match with the current traffic and channel conditions. The algorithm that determines the bandwidth allocation is not defined by the standard. The product developers need to develop these algorithms in order to optimize their network resources.

12.6.2 Packet Scheduling

Packet scheduling algorithms indicate when packets from a user or application are allowed to transmit. The standard defines the multiplex and QoS delivery sublayers in the MAC to support packet scheduling algorithms. Multiplex and QoS delivery sublayers can provide service differentiation among logical channels (i.e., voice, data, signaling). The standard also defines the service primitives between the signaling LAC and MAC that enable the transfer of QoS requirement information from the upper layers. The packet scheduling algorithms are not defined by the standard.

CHAPTER 13

Satellite Communication

13.1 Introduction

Communication satellites allow the establishment of communication worldwide in both populated and remote areas, where other ways of communication may be impossible (e.g., oceans and mountains).

Traditionally, satellites have been used for broadcasting television programs. In recent years, the satellite industry has evolved and has started to provide two-way communication. This evolution is possible due to technology, decreasing cost of user's equipment, and its availability in all world regions. These satellite systems are either proprietary or standardized. Hughes Network Systems with its Spaceway program and Gilat Satellite Networks are examples of proprietary systems. In Europe, ETSI (European Telecommunications Standards Institute) has been developing standards for satellite communication. The satellite standards are published under the DVB (Digital Video Broadcasting) project. ETSI is cooperating with the DVB consortium of hundreds of broadcasters, manufacturers, network operators, software developers, regulatory bodies, and others in many countries committed to designing global standards for the delivery of digital television and data services. Companies such as SES-ASTRA, Eutelsat, and Hispasat have been using the DVB standard.

Satellites can orbit the earth in several orbits referred to as GEO (Geosynchronous, or Geostationary Earth Orbit), MEO (Medium, or Middle Earth Orbit), and LEO (Low Earth Orbit). These satellites work in the Ku band (10–17 GHz frequency range) or the Ka band (18–31GHz frequency range).

GEO satellites orbit the earth at 22,300 miles above the earth's surface. They are tied to the earth's rotation and their positions are fixed in relation to earth's surface. This is an advantage since the earth station needs to point its transmitter and receiver to only one location in

space to be able to transmit and receive from the GEO satellite. This makes GEO satellites popular for transmissions of high-speed data, television, and other wideband applications. A disadvantage is the long distance that the signal needs to travel. This results in a long time delay of few hundred millisecond, which causes deterioration in the QoS support provided for interactive applications that require short delays.

MEO satellites orbit the earth between 1,000 and 22,300 miles above the earth's surface. They are not stationary in relation to earth's surface. MEO satellites are used in geographical positioning systems.

LEO satellites orbit the earth between 400 and 1,000 miles above the earth's surface. LEOs are mostly used for data communication such as paging, email, and videoconferencing. LEO satellites do not have a fixed location in space in relation to the earth's surface. They move at very high speeds and to sustain end-to-end communication, they need to communicate with each other. Because they are located relatively close to earth, the earth station transmitter uses significantly less power. Also the travel time for the signal is significantly shorter, a fact that significantly decreases the multimedia application's delay, potentially improving QoS support.

13.1.1 DVB Return Channel System (DVB-RCS)

The DVB family of standards contains GEO satellite communication with various options of uplink (or return) and downlink (or forward) channels. Up to a few years ago, satellites were only able to transfer data unidirectionally from the content sources to the end user equipment, mostly TV sets. However, in recent years bidirectional communication has been introduced with various return channels such as telephones, ISDN, Cable TV, DECT, and LMDS. Here is a list of DVB standards:

- ETS 300 802, Digital Video Broadcasting (DVB); Network-independent protocols for DVB interactive services
- ETSI ES 200 800, Digital Video Broadcasting (DVB); DVB interaction channel for Cable TV distribution systems (CATV)
- TR 101 201, Technical Report Digital Video Broadcasting (DVB); Interaction channel for Satellite Master Antenna TV (SMATV) distribution systems; Guidelines for versions based on satellite and coaxial systems
- EN 301 193, European Standard (Telecommunications series) Digital Video Broadcasting (DVB); Interaction channel through the Digital Enhanced Cordless Telecommunications (DECT)
- EN 301 195, European Standard (Telecommunications series) Digital Video Broadcasting (DVB); Interaction channel through the Global System for Mobile communications (GSM)
- EN 301 199, European Standard (Telecommunications series) Digital Video Broadcasting (DVB); Interaction channel for Local Multi-point Distribution Systems (LMDS)

- ETS 300 801, Digital Video Broadcasting (DVB); Interaction channel through Public Switched Telecommunications Network (PSTN)/Integrated Services Digital Networks (ISDN)
- ETSI EN 301 958 V1.1.1 (2002-03) European Standard (Telecommunications series)
- Digital Video Broadcasting (DVB); Interaction channel for Digital Terrestrial Television (RCT) incorporating Multiple Access OFDM
- TR 101 194, Digital Video Broadcasting (DVB); Guidelines for implementation and usage of the specification of network-independent protocols for DVB interactive services

In this book we focus on the satellite DVB standards that provide two-way communication through the satellite, referred to as DVB-RCS. In these systems the end user has direct access to the satellite using the satellite's uplink and downlink channels. We focus on the following standards and documents:

- ETSI EN 301 790, European Standard (Telecommunications series), Digital Video Broadcasting (DVB); Interaction channel for satellite distribution systems
- ETSI TR 101 790, European Standard (Telecommunications series), Technical Report Digital Video Broadcasting (DVB); Interaction channel for Satellite Distribution Systems; Guidelines for the use of EN 301 790
- TR 101 202, European Standard (Telecommunications series), Digital Video Broadcasting (DVB); Implementation guidelines for Data Broadcasting
- EN 301 192, European Standard (Telecommunications series), Digital Video Broadcasting (DVB); DVB specification for data broadcasting
- ETS 300 802, European Standard (Telecommunications series), Digital Video Broadcasting (DVB); Network-independent protocols for DVB interactive services

The downlink related part of the specifications includes the DVB-Satellite (DVB-S) standard which is used in the typical satellite broadcast systems. For uplink communication, the DVB-RCS standard uses the RCST (Return Channel Satellite Terminal), a satellite terminal that supports interactive services such as SMATV (Satellite Master Antenna Television) as well as data transmission.

DVB-RCS MAC is based upon FDM/TDM, where the uplink and downlink transmissions take place at different frequency ranges. DVB-RCS does not define a specific operating frequency channel to be used, which allows flexible frequency deployment. Both the uplink and downlink channels are time slotted. The MAC specifications allow vendor specific implementations of various QoS supporting algorithms.

Depending on the dish size, DVB-RCS can achieve maximum data speeds as detailed in Table 13.1. The actual data speed depends on the DVB operator equipment and agreements with the end user.

Table 13.1 DVB-RCS Maximum Data Speeds

Dish Size	0.6 Meter	1.0 Meter	1.2 Meter
Return Link Speed	150 kbps	380 kbps	2 Mbps
Forward Link Speed	38 Mbps	38 Mbps	38 Mbps

13.2 Architecture

The DVB-RCS model is shown in Figure 13.1. DVB supports two channels: the Broadcast Channel and the Interaction Channel.

The Broadcast Channel, which is a unidirectional downlink broadcast channel, is identical to the channel defined in the satellite digital video broadcast (DVB-S) standard. The Interaction Channel provides bidirectional interaction communication between the service provider and the end-user. The Interaction Channel consists of a Forward Interaction channel (from the service provider to end-user) and Return Interaction channel (from the end-user to service provide). Typically, the Forward Interaction channel is included in the Broadcast Channel.

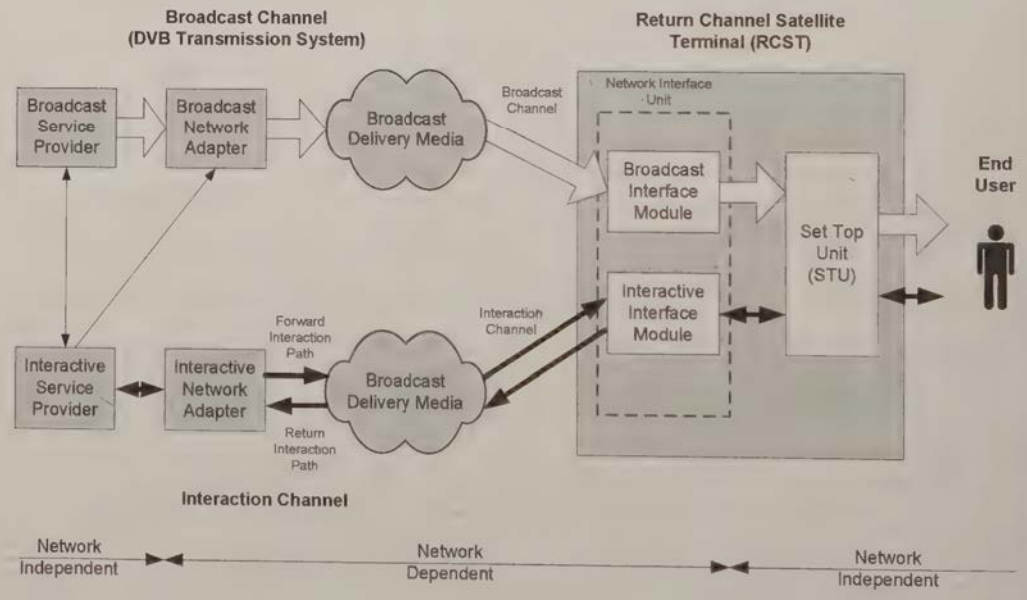


Figure 13.1 DVB-RCS System Model

The RCST provides interface for both Broadcast and Interaction Channels. It is supported by the Network Interface Unit and the Set Top Unit.

A satellite interactive network with several RCST channels is described in Figure 13.2. The NCC (Network Control Center) monitors and controls the operation of the satellite interactive network. The NCC manages the network resources and authorizes and allocates transmis-

sion resources to RCSTs. The system is fed by a few Feeder Stations. The Feeder Station on the forward link is a standard satellite digital video broadcast (DVB-S) on which we multiplex user data, control, and timing signals. The Traffic Gateway receives RCST return signals and provides accounting functions, interactive services, and connections to external public or private service providers. These service providers can be Internet data services, pay-per-view TV, financial services, and corporate networks.

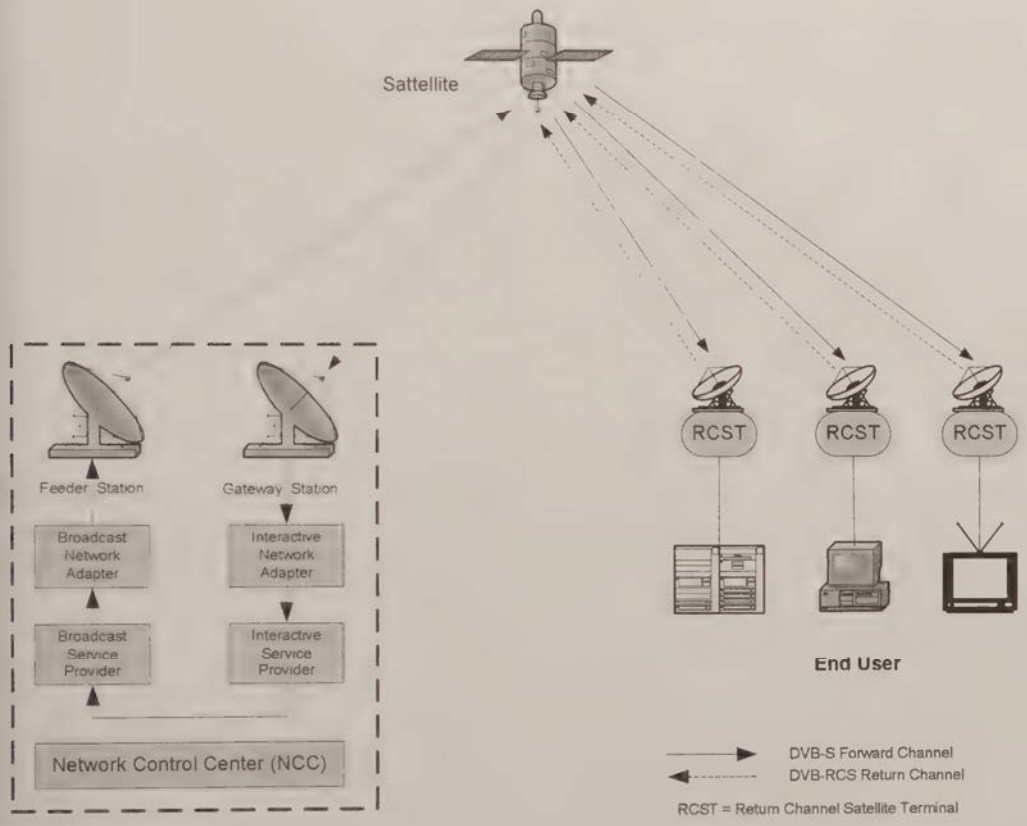


Figure 13.2 Overall Satellite Interactive Network Architecture

The forward link carries signaling information from the NCC and user traffic to RCSTs. The signaling traffic from the NCC to RCSTs, referred to as the Forward Link Signaling, includes the necessary information required to operate the return link. Both the user traffic and the forward link signaling can be carried over different forward link signals. Several RCST configurations are possible depending on the number of forward link receivers present on the RCST.

In the next sections we describe the forward and reverse link technologies that are used in the DVB-RCS standard.

13.3 Forward Link

The forward link or the broadcast channel is based on the DVB-S standard which employs MPEG-2 Transport Stream (TS) defined by ISO/IEC (International Standards Organization/ International Electrotechnical Commission) 13818-1 standard. Multiple data streams (i.e., video, audio, data) are multiplexed on MPEG-2 TS and delivered through the broadcast channel as shown in Figure 13.3. These data streams are categorized into several application areas as follows: DVB data piping, DVB data streaming, DVB multiprotocol encapsulation, DVB data carousel, and DVB object carousel. Each application area has different QoS requirements. Some data streams (i.e., DVB data piping, DVB data stream) are mapped directly onto MPEG-TS. Other data streams (i.e., DVB multiprotocol encapsulation, DVB data carousel, and DVB object carousel) are first mapped through Data Storage Media Command and Control (DSM-CC) and then MPEG-TS. The Forward Link employs Time Division Multiplex (TDM) on a single digital carrier. Before describing each application area, we would like to provide some background of MPEG-2 Transport Stream.

13.3.1 MPEG-2 Transport Stream

MPEG-2 Transport Stream is a transport format for video and audio transmission. Figure 13.4 illustrates a simplified overview of the MPEG-2 process.

The video encoder compresses the video signal and constructs video frames (i.e., I-frame, P-frame, B-frame). Each video frame includes the element stream (ES) header and a series of encoded video frames. The ES header provides information about the content and location of the video blocks required for decoding the video stream. The element streams are packetized and constructed into a packetized element stream (PES). Figure 13.5 shows the PES packet structure. The PES header contains the information necessary to decode the video stream. Important information in PES header that we would like to point out includes: 1) the Decode Time Stamp (DTS), which indicates when to decode the video frame and 2) the Presentation Time Stamp (PTS), which indicates when to display the video frame. PES packets from the different streams are multiplexed into a Transport Stream (TS). Figure 13.6 shows the Transport Stream packet structure. The packet ID (PID) in the TS header identifies the TS payload contents.

The list of PID and its associated values are included in the Program Specific Information (PSI) table. There are several types of PSI tables such as the Program Association Table (PAT), the Program Map Table (PMT), and the Conditional Access Table (CAT). Figure 13.7 illustrates the PSI table structure. Within the MPEG-2 Transport Stream, there are multiple programs (i.e., TV programs). Each program consists of multiple video streams, audio streams, and data streams. The PSI table provides the PID information required to find, identify, and reconstruct the video stream in subsequent Transport Stream packets. First, the receiver scans for the PAT identified by a reserved PID (PID = 0). PAT contains the mapping between the PID value and the associated program pointer of the PMT. For example, as shown in Figure 13.7, PID = 22 points to the PMT of program 1. The PMT contains the mapping between the PID value and the associated stream of the program. For example, as shown in Figure 13.7, PID = 62 identifies the video stream of program 1.

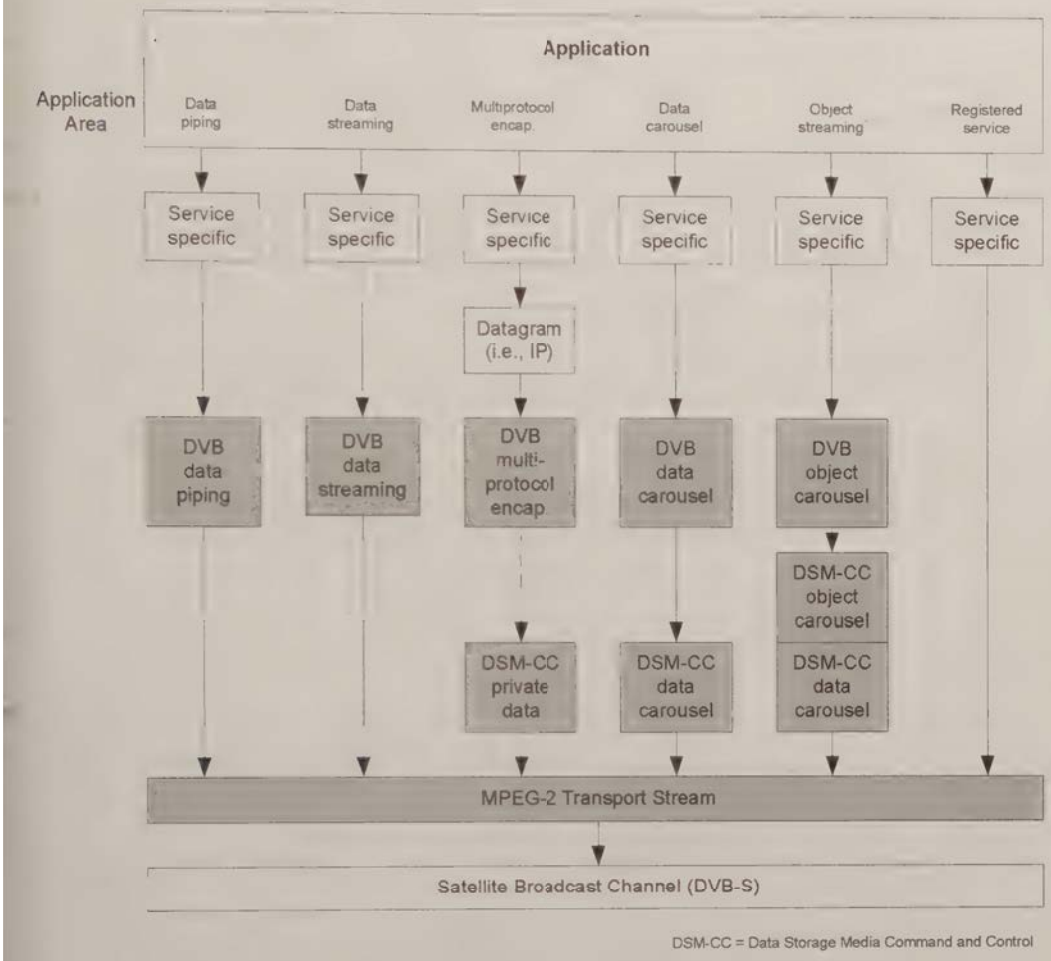


Figure 13.3 Data Broadcast Specification Overview (satellite side)

There are other types of tables such as the Superframe Composition Table (SCT), Frame Composition Table (FCT), and Time Slot Composition Table (TCT) used to define the channel structure. We will describe them later in this chapter.

13.3.2 Data Piping

The data piping mechanism uses an asynchronous (i.e., without timing, such as IP packets) transport mechanism. As shown in Figure 13.8, the data packets are inserted directly into the payload of the MPEG2 transport packets without any fragmentation and reassembly. At the TS header, the payload_unit_start_indicator field may be implemented to include the indication of the start of the data piping packet while the transport_priority field may be implemented to include the end of the packet.

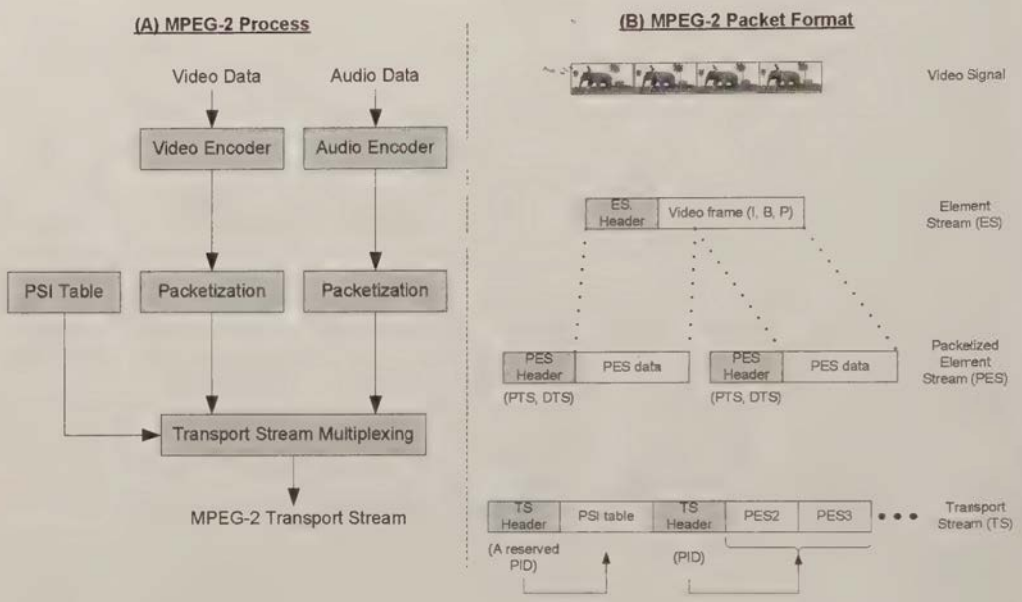


Figure 13.4 MPEG-2 Process Overview

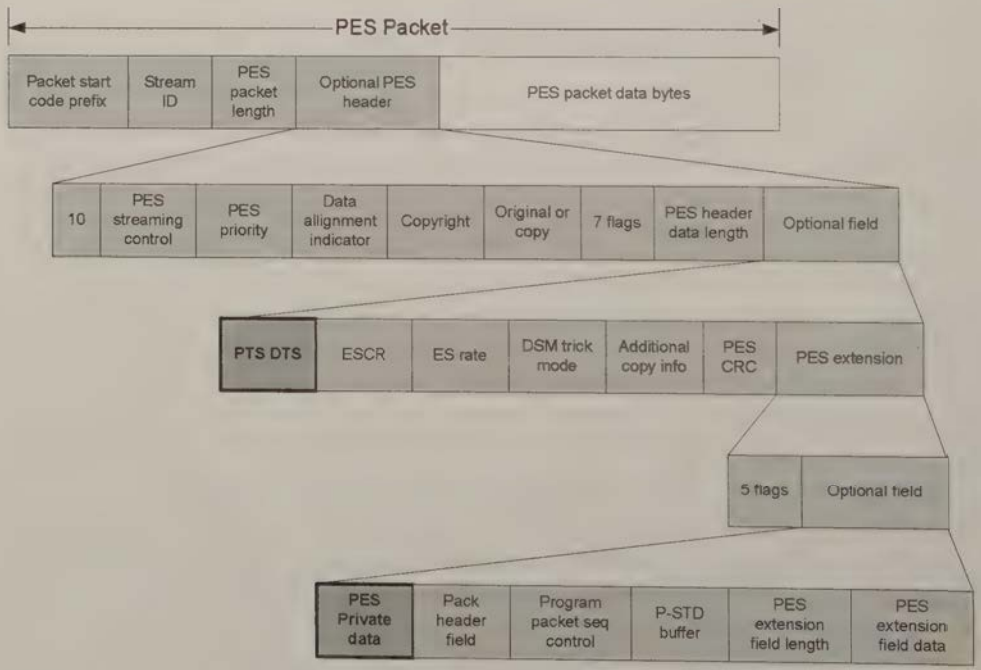


Figure 13.5 PES Packet Structure

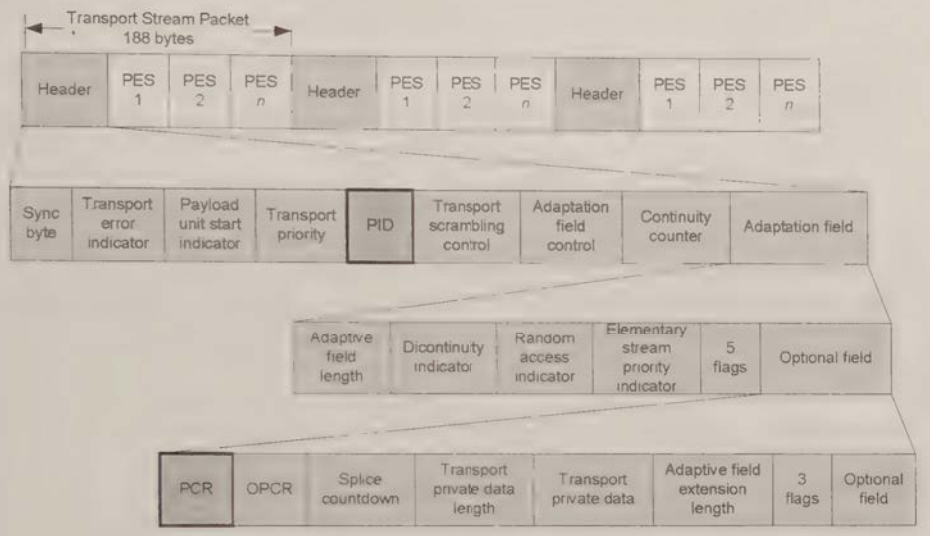


Figure 13.6 Transport Stream Packet Structure

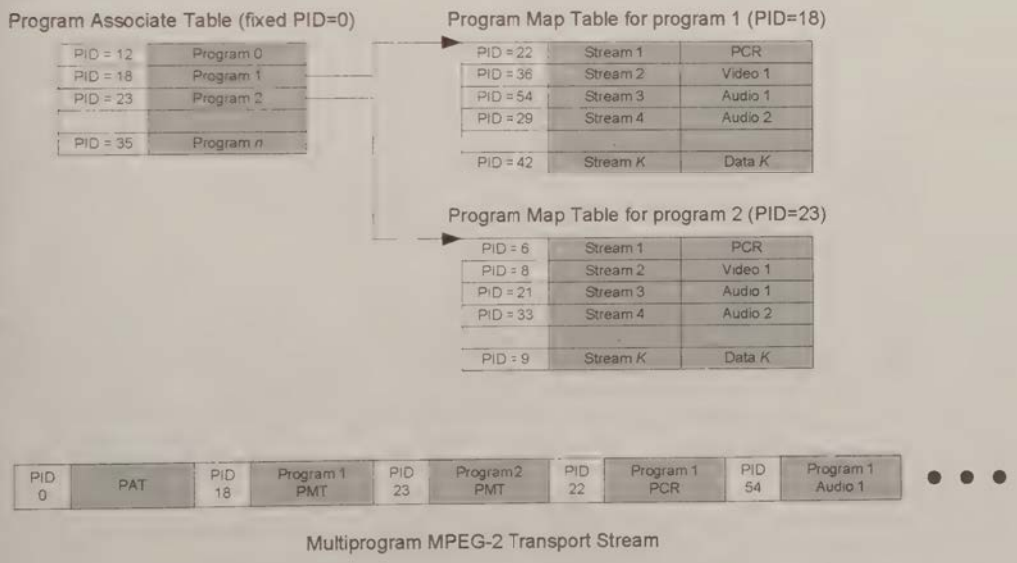


Figure 13.7 Program Specific Information (PSI) Table Structure

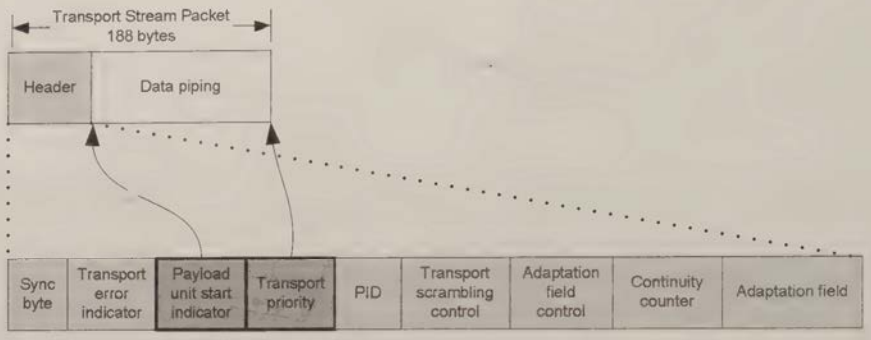


Figure 13.8 Data Piping Packets

13.3.3 Data Streaming

Data streaming mechanism is for streaming-oriented applications which may be asynchronous, synchronous, or synchronized data streams. Asynchronous data streaming transmits data without timing requirements while synchronous data streaming transmits data using a fixed rate transmission clock (i.e., T1, circuit emulation). Synchronized data streaming transmits data with timing related to the different kinds of data streams (i.e., streaming video along with audio where both require time synchronization).

As shown in Figure 13.9, the data streaming packets are inserted into the PES packet payload.

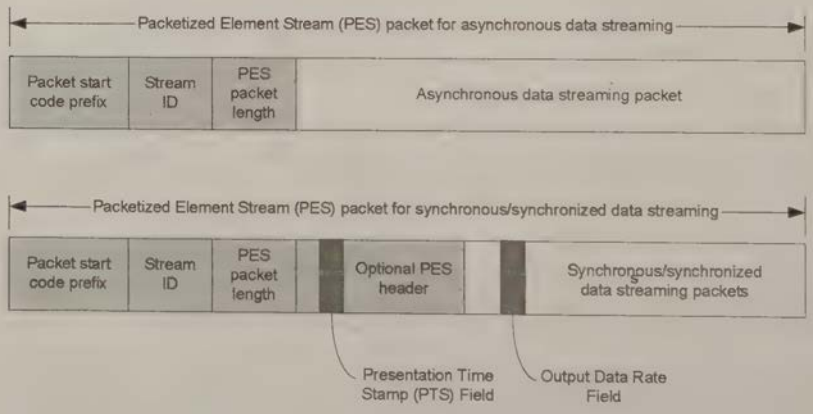


Figure 13.9 Packetized Element Stream (PES) Packets for Asynchronous/Synchronous/Synchronized Data Streaming

The stream ID in the PES packet identifies the type of data streaming contained in the payload. The Presentation Time Stamp (PTS) described in Section 13.3.1 is an optional field in the PES header that includes time stamp information for synchronous and synchronized data streaming.

Packet scheduling algorithms can use the PTS information to determine when to transmit synchronous/synchronized packets. For synchronous data packets, there is a field in the PES payload called output data rate that includes the synchronous data stream required data rate.

13.3.4 Multiprotocol Encapsulation

Multiprotocol encapsulation method is used for transporting packets that originate from different network protocols on top of the MPEG2 Transport Streams in DVB networks. It has been optimized for delivery of IP packets but can be used for other protocols as well. A 48-bit MAC address is used to identify the receiver (i.e., RCST). UDP/IP or TCP/IP traffic will be multiplexed into an MPEG-2 transport stream through DSM-CC sections (defined in ISO/IEC 13818-6) as detailed in Figure 13.10. Using encryption, encapsulation can also provide secure transmission.

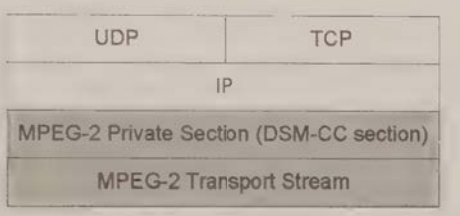


Figure 13.10 Mulitiprotocol Encapsulation for IP Traffic

The DSM-CC (Digital Storage Media Command and Control) facilitates the transmission of a structured group of objects from a broadcast server to clients using directory objects, file objects, and stream objects. It provides tools for controlling the MPEG-2 streams. DSM-CC may be used for controlling the video reception, providing features normally found on Video Cassette Recorders (VCRs) such as fast-forward, rewind, and pause. DSM-CC is designed for lightweight and fast operation considering limited memory devices.

The long delay imposed by the distances of thousands of miles that the signal needs to travel adversely affects the TCP features such as congestion control and packet acknowledgments. TCP's congestion control mechanism assumes that all data loss is due to congestion. Therefore, it wrongly translates the long delays to data loss and thus slows down the transmission of packets and prevents new connections. Moreover, the required TCP acknowledgments can congest the relative small bandwidth available on the uplink channel. Consequently, satellite vendors employ solutions that overcome such TCP problems. Such solutions may employ an intermediate server that acts as the end-user and projects timing parameters to the traffic source such that it will not slow down its transmissions. The intermediate server will encapsulate the packets in "new" packets and will transmit them to the end-user.

13.3.5 Data Carousel

The Data Carousel is a mechanism that allows a server to present a set of packets to a program, which is run by a receiver, by cyclically repeating the contents of the carousel one or more times. An example is the Teletext system in which a set of pages is cyclically broadcasted.

13.4 Return Link

The return link carries transmissions from the RCSTs to the satellite. As shown in Figure 13.11, the return channel is structured into superframes, frames, and time slots.

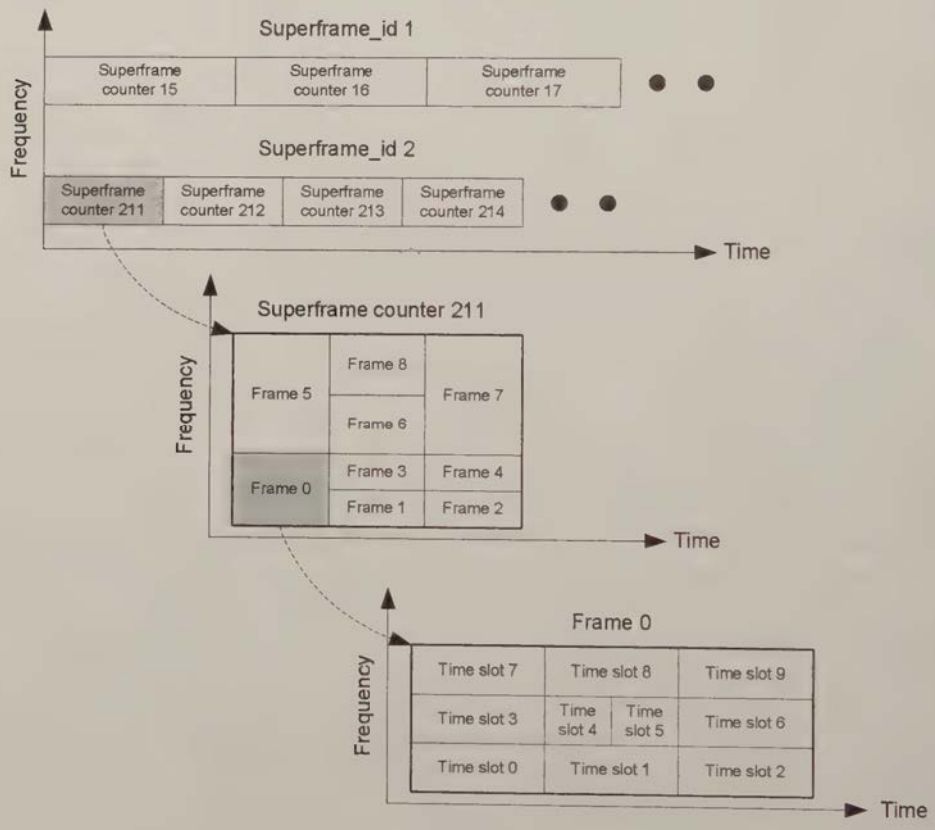


Figure 13.11 Superframes, Frames, and Timeslots

A superframe is defined by a section of frequency range and time duration of the return channel. Each superframe is labeled with a superframe_counter. A superframe consists of frames identified by frame_numbers. A frame consists of a time slot identified by timeslot_number. For channel allocation purposes, each time slot is uniquely identified by Superframe_id, Superframe_counter, Frame_number, and Timeslot_number. The superframe, frame, and time

slot structure of the satellite system as well as their identifications are indicated in the Superframe Composition Table (SCT), the Frame Composition Table (FCT), and the Time Slot Composition Table (TCT), which are broadcasted by the satellite.

All RCST transmissions are governed and controlled by the NCC. Before the RCST can send data, it needs to join the network (logon) and inform the NCC about its configuration. The logon process occurs on a frequency channel that is defined by the NCC and transmitted on the Forward Link.

The Return Link supports four types of traffic: traffic (TRF), acquisition (ACQ), synchronization (SYNC), and common signaling channel (CSC).

TRF is used for carrying data from the RCST to the Gateway Station. This traffic can include ATM based cells or MPEG-2 packets. Synchronization and Acquisition traffic is used to position RCST transmissions during and after the logon process. A SYNC is used by an RCST to synchronize and send control information to the system. An ACQ can be used to achieve synchronization prior to operational use of the network by the RCST. The CSC packets are only used by the RCST to identify itself to the system during the logon process, as well as other set up information, such as determining the frequencies.

13.4.1 Return Link Channel Access

Because of the multipoint-to-point transmissions on the return link, the RCSTs employ a multiple access mechanism denoted Multifrequency Time Division Multiple Access (MF-TDMA). MF-TDMA employs a combination of FDMA and TDMA. In every superframe, the NCC broadcasts a Terminal Burst Time Plan (TBTP) which indicates the frequency, the bandwidth, the start time, and the duration for each RCST that is allowed to transmit data. There are two MF-TDMA schemes: fixed-slot MF-TDMA and dynamic-slot MF-TDMA. In fixed-slot MF-TDMA, the bandwidth and duration of the time slots assigned to an RCST are fixed while in dynamic-slot MF-TDMA, the bandwidth and duration of the time slots are variable. Dynamic-Slot MF-TDMA is optional in DVB systems. Figure 13.12 illustrates a channel access assignment diagram for a specific RCST.

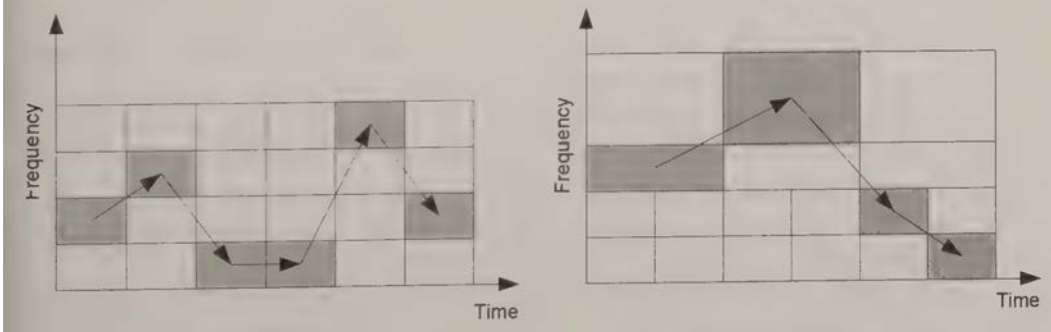


Figure 13.12 Channel Access Assignment Diagram for a Specific RCST

The channel assignment is based on the application's bandwidth demand and QoS requirements. The channel assignment process can be achieved through a request-grant process where the RCST requests the bandwidth and the NCC grants the bandwidth. As shown in Figure 13.13, the standard defines capacity requests as well as signaling methods. The standard does not define the algorithm that determines the bandwidth allocation of each RCST.

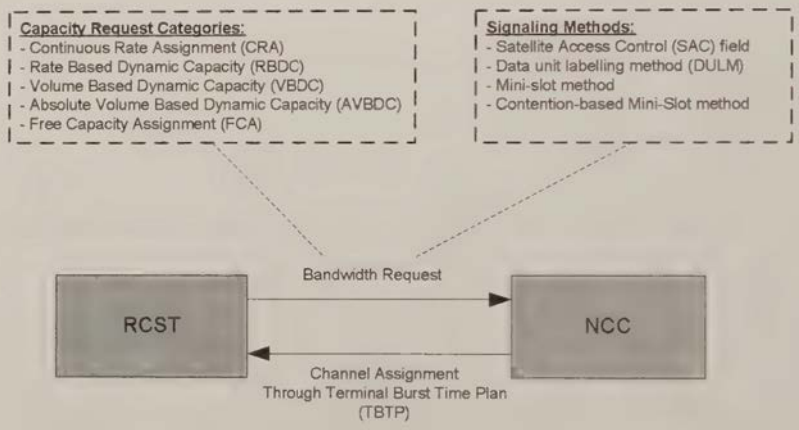


Figure 13.13 Capacity Request-Grant Process

Each application (identified by the Channel_ID) on a RCST requests bandwidth individually. The per-connection capacity request is categorized into the following five categories:

- Continuous Rate Assignment (CRA) indicates the fixed minimum bandwidth requirement per superframe. CRA is suitable for applications that require a fixed minimum guarantee rate with minimum delay and delay jitter such as constant bit rate (CBR) applications (circuit emulation).
- Rate-Based Dynamic Capacity (RBDC) indicates the dynamic bandwidth requirement per superframe. The current RBDC request will override all previous RBDC requests. To prevent a hanging capacity assignment, RBDC has a predetermined time-out period associated with it. If the time-out period expires, RBDC is set to zero. RBDC is suitable for variable bit rate (VBR) applications. Practically, the combination of CRA and RBDC can be used. CRA provides the fixed minimum bandwidth while RBDC provides dynamic bandwidth on the top of the minimum bandwidth.
- Volume-Based Dynamic Capacity (VBDC) indicates the volume bandwidth requirement per superframe. These requests are cumulative (i.e., each request increments on previous requests). At the end of each superframe, the cumulative amount of bandwidth is deducted by the amount of bandwidth already assigned in the superframe to the specific RCST. VBDC is suitable for delay tolerant applications.

- Absolute Volume-Based Dynamic Capacity (AVBDC) is similar to VBDC with the difference that AVBDC is not cumulative. It indicates the absolute value of the volume bandwidth. Therefore, the current AVBDC will override all previous AVBDCs. AVBDC is used in cases where VBDC might be lost during the request process.
- Free Capacity Assignment (FCA) uses the available bandwidth assignment. FCA is not mapped to any traffic category. The available bandwidth assignment is considered as bonus bandwidth used to reduce traffic delays.

The standard defines the following signaling methods that can be used for capacity requests:

- *Satellite Access Control (SAC) field:* A SYNC packet used for synchronization contains an optional SAC field. This field includes the connection capacity request. The SYNC packet can be used in contention mode where multiple RCSTs transmit SYNC packets at the same time.
- *Data Unit Labeling Method (DULM):* This method allows RCSTs to transmit control and management information to the NCC piggybacked to the data packets already sent during the assigned periods for TRF traffic.
- *Mini-slot Method:* This method is based on a periodic assignment to already logged-on RCSTs for packets that use less than full traffic time slots. It carries control and management information and is used also for maintaining RCST synchronization. This mechanism is supported by the SAC used in SYNC packets.
- *Contention-based Mini-slot Method:* This method can be applied such that a group of RCSTs can access a Mini-Slot on a contention basis. This mechanism is supported by the SAC request used in SYNC packets. The access is based on Slotted Aloha, in which the RCST transmits at the beginning of the time slot and if it is not successful it backs off and retransmits in another time slot.

13.5 Quality of Service Support

Figure 13.14 shows DVB-RCS QoS architecture. The standard defines some basic QoS mechanisms such as classification, channel access, and capacity request signaling.

13.5.1 Classification

Before packets from a specific application can be transmitted by the RCST, a connection needs to be established between the application and the NCC. Each application will be identified by the Channel_ID. DVB-RCS uses per-flow classification which enables per-flow QoS services. The signaling processes involved in the connection setup, modification, and termination are expected to be clarified in the next revision of the standard.

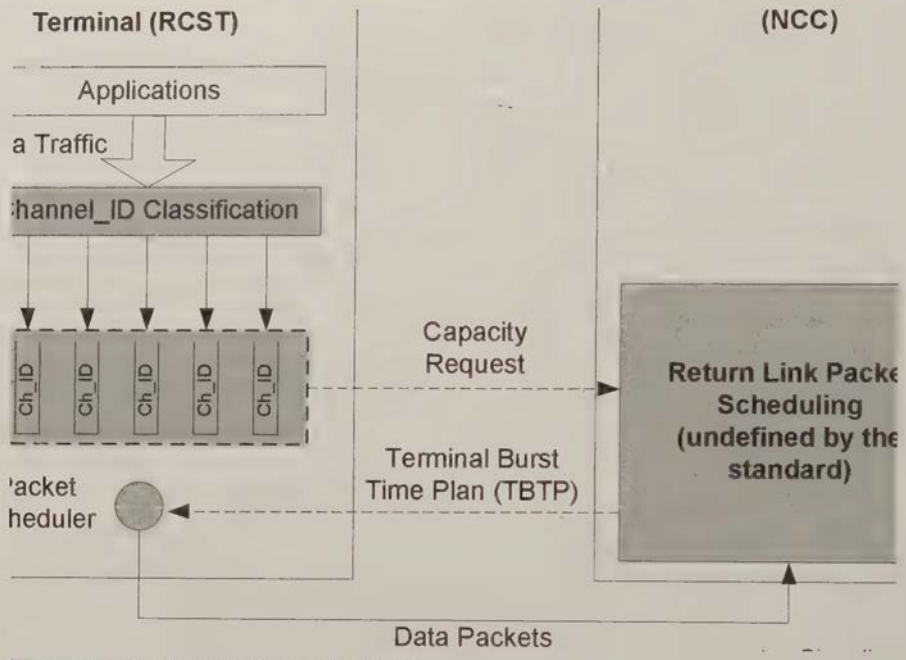


Figure 13.14 DVB-RCS QoS Architecture

13.5.2 Capacity Request Signaling and Channel Access

The standard defines the signaling method for capacity requests as well as the types of capacity requests. As described in Section 13.4.1 each type of capacity request which is per connection basis, supports different types of applications with different QoS requirements.

As described in Section 13.4.1, the return link employs MF-TDMA. Each RCST is allowed to transmit packets in a specific frequency and for a specific amount of time as defined in the Terminal Burst Time Plan (TBTP) as described in Section 13.4.1. TBTP is sent from the NCC to the RCST in every superframe. The TBTP mechanism enables dynamic bandwidth allocation which can provide QoS support for each application. The scheduling algorithm that determines the TBTP as a function of the application's QoS requirements as well as the available system resources is not included in the standard.

APPENDIX

Acronyms and Abbreviations

Part 1: Multimedia Application and Quality of Service (QoS)

CBR	Constant Bit Rate
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DiffServ	Differentiated Service
DSCP	Differential Service Code Point
EMS	Enhanced Messaging Service
GPS	Global Positioning System
IntServ	Integrated Service
MMS	Multimedia Messaging Service
MOS	Mean Opinion Score
QoS	Quality of Service
RSVP	Resource Reservation Protocol
SBM	Subnet Bandwidth Manager
SMS	Short Message Service

TDMA	Time Division Multiple Access
TOS	Type Of Service
VBR	Variable Bit Rate
VOD	Video On Demand
VoIP	Voice over IP
WAP	Wireless Application Protocol
WFQ	Weight Fair Queue

Part 2: Wireless Local Area Networks

ACF	Association Control Function
ACH	Access Feedback Channel
AIFS	Arbitration Interframe Space
AP	Access Point
ARQ	Automatic Repeat Request
ASCH	Association Control Channel
BC	Broadcast
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BSS	Basic Service Set
CC	Controlled Contention
CCA	Clear Channel Assessment
CCI	Controlled Contention Interval
CFP	Contention-Free Period
CM	Centralized Mode
CP	Contention Period, Connection Point
CTS	Clear To Send
CW	Contention Window
DCC	DLC Connection Control
DCCH	Dedicated Control Channel
DCF	Distributed Coordination Function
DFS	Dynamic Frequency Selection
DIFS	DCF Interframe Space
DiL	Direct Link
DL	DownLink
DLC	Data Link Control

DM	Direct Mode
DS	Distribution System
DSSS	Direct Sequence Spread Spectrum
EC	Error Control
EDCF	Enhanced DCF
EIFS	Extended Interframe Space
ESS	Extended Service Set
FCCH	Frame Control Channel
FCH	Frame Channel
FHSS	Frequency Hopping Spread Spectrum
HC	Hybrid Coordinator
HCF	Hybrid Coordination Function
IBSS	Independent Basic Service Set
IFS	Interframe Space
LCCH	Link Control Channel
LCH	Long Transport Channel
MT	Mobile Terminal
NAV	Network Allocation Vector
OFDM	Orthogonal Frequency Division Multiplexing
PCF	Point Coordination Function
PF	Persistence Factor
PIFS	PCF Interframe Space
PLCP	Physical Layer Convergence Protocol
QSTA	QoS Station
RA	Random Access
RBCH	RLC Broadcast Channel
RCH	Random Access Channel
RFCH	Random Access Feedback Channel
RG	Resource Grants

RLC	Radio Link Control
RR	Resource Request
RRC	Radio Resource Control
RTS	Request To Send
SCH	Short Transport Channel
SIFS	Short Interframe Space
TC	Traffic Category
TS	Traffic Stream
TSPEC	Traffic Specifications
TXOP	Transmission Opportunity
UBCH	User Broadcast Channel
UDCH	User Data Channel
UL	Uplink
UMCH	User Multicast Channel
UWB	Ultra Wide Band

Part 3: Wireless Metropolitan Area Networks

BE	Best Effort
BS	Base Station
CID	Connection Identifier
CPS	Common Part Sublayer
CS	Convergence Sublayer
DCD	Downlink Channel Descriptor
DIUC	Downlink Interval Usage Code
GPC	Grant Per Connection
GPSS	Grant Per Subscriber Station
IE	Information Element
IUC	Interval Usage Code
nrtPS	Non-Real-Time Polling Service
PMP	Point to Multipoint

rtPS	Real-Time Polling Service
SI	Slip Indicator
SS	Subscriber Station
UCD	Uplink Channel Descriptor
UGS	Unsolicited Grant Service
UIUC	Uplink Interval Usage Code

Part 4: Wireless Personal Area Networks

ACL	Asynchronous Connection-Less
CAC	Channel Access Code
CAP	Contention Access Period
CFP	Contention-Free Period
CTA	Channel Time Allocation
CTR	Channel Time Request
DAC	Device Access Code
FHS	Frequency Hop Synchronization
GTS	Guaranteed Time Slot
HCI	Host Control Interface
HID	Human Interface Device
IAC	Inquiry Access Code
L2CAP	Logical Link Control and Adaptation Protocol
LC	Link Control
LM	Link Manager
PNC	PicoNet Coordinator
PNID	PicoNet ID
MTS	Management Time Slot
SCO	Synchronous Connection-Oriented
SDP	Service Discovery Protocol

UA	User Asynchronous
UI	User Isochronous
US	User Synchronous

Part 5: 2.5G and 3G Networks

GPRS, UMTS, cdma2000

3GPP	3G Partnership Project
3GPP2	3G Partnership Project 2
AAA	Authorization And Accounting
AMC	Adaptive Modulation and Coding
AMR	Adaptive Multirate
ARIB	Association of Radio Industries and Businesses
ARQ	Automatic Repeat Request
ASC	Access Service Classes
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BMC	Broadcast/Multicast Control
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CCCH	Common Control Channel
CCH	Control Channel
CCITT	Consultative Committee for International Telephony and Telegraphy
CDMA	Code Division Multiple Access
CPAGCH	Compact Packet Access Grant Channel
CPBCCH	Compact Packet Broadcast Control Channel
CPCH	Common Packet Channel
CPNCH	Compact Packet Notification Channel
CPPCH	Compact Packet Paging Channel
CPRACH	Compact Packet Random Access Channel
CSCF	Call State Control Function
CTCH	Common Traffic Channel
CWTS	China Wireless Telecommunication Standard Group
DBPSCH	Dedicated Basic Physical Subchannel
DCCH	Dedicated Control Channel

DCH	Dedicated Channel
DL	Data Link
DSCH	Downlink Shared Channel
DTCH	Dedicated Traffic Channel
DTM	Dual Transfer Mode
EDGE	Enhanced Data Rate for Global Evolution
EGPRS	Enhanced GPRS
ETSI	European Telecommunications Standards Institute
FACH	Forward Access Channel
F-APICH	Forward Dedicated Auxiliary Pilot Channel
F-ATDPICH	Forward Auxiliary Transmit Diversity Pilot Channel
F-BCCH	Forward Broadcast Control Channel
F-CACH	Forward Common Assignment Channel
F-CPCCH	Forward Common Power Control Channel
F-PCH	Forward Paging Channel
F-PDCCH	Forward Packet Data Control Channel
F-PDCH	Forward Packet Date Channel
F-QPCH	Forward Quick Paging Channel
FR	Full Rate
F/R-CCCH	Forward/Reverse Common Control Channel
F/R-DCCH	Forward/Reverse Dedicated Control Channel
F/R-FCH	Forward/Reverse Fundamental Channel
F/R-PICH	Forward/Reverse Pilot Channel
F/R-SCCH	Forward/Reverse Supplemental Code Channel
F/R-SCH	Forward/Reverse Supplemental Channel
F-SYNCH	Forward Synchronous Channel
F-TDPICH	Forward Transmit Diversity Pilot Channel
GERAN	GSM/EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
G-RNTI	GERAN Radio Network Temporary Identity
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HR	Half Rate
HS	High-Speed

HSCSD	High-Speed Circuit Switched Data
HS-DSCH	High-Speed Downlink Shared Channel
HSDPA	High-Speed Downlink Packet Access
HSPDA	High-Speed Download Packet Access
HSS	Home Subscriber Server
IMS	Internet Multimedia Subsystem
IMT-2000	International Mobile Telecommunication–2000
ITU	International Telecommunications Union
LAC	Link Access Control
MAC	Medium Access Control
MGCF	Media Gateway Control Function
MGW	Media Gateway
MRF	Multimedia Resource Function
MS	Mobile Station
MSC	Mobile Switching Center
OVSF	Orthogonal Variable Spreading Factor
PACCH	Packet Associated Control Channel
PAGCH	Packet Access Grant Channel
PBCCH	Packet Broadcast Control Channel
PCCCH	Packet Common Control Channel
PCH	Paging Channel
PCM	Pulse Code Modulation
PDCCH	Packet Dedicated Control Channel
PDCH	Packet Data Channel
PDCHCF	Packet Data Channel Control Function
PDCP	Packet Data Convergence Protocol
PDP	Packet Data Protocol
PDSN	Packet Data Serving Node
PDTCH	Packet Data Traffic Channel
PNCH	Packet Notification Channel
PPCH	Packet Paging Channel
PRACH	Packet Random Access Channel
PSTN	Public Switched Telephone Network
PTCCH/D	Packet Timing Advance Control Channel/Downlink
PTCCH/U	Packet Timing Advance Control Channel/Uplink

PTM	Point-To-Multipoint
PTM-M	Point-To-Multipoint–Multicast
PTP	Point-To-Point
QoS	Quality of Service
RACH	Random Access Channel
R-ACH	Reverse Access Channel
R-ACKCH	Reverse Acknowledgment Channel
RAN	Radio Access Network
RCN	Radio Network Controller
R-CQICH	Reverse Channel Quality Indicator Channel
R-EACH	Reverse Enhanced Access Channel
RLC	Radio Link Control
RLP	Radio Link Protocol
RNC	Radio Network Controller
RR	Radio Resource
RRC	Radio Resource Control
R-SGW	Roaming Signaling Gateway
RX	Receive
SBPSCH	Shared Basic Physical Subchannel
SF	Spread Factor
SGSN	Serving GPRS Support Node
SHCCH	Shared Channel Control Channel
SRBP	Signaling Radio Burst Protocol
SS7	Signaling System No. 7
TBF	Temporary Block Flow
TCH	Traffic Channel
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TFC	Transport Format Combination
TFCS	Transport Format Combination Set
TFI	Transport Format Indicator, Temporary Flow Identity
TIA/EIA	Telecommunications Industry Alliance/Electronics Industries
TLLI	Temporary Logical Link Identifier
TTA	Telecommunication Technology Association
TTI	Transmission Time Interval
T-SGW	Transport Signaling Gateway

TX	Transmit
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USCH	Uplink Shared Channel
USF	Uplink State Flag
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wide CDMA or Wide Code Division Multiple Access

Satellite Communication

ACQ	Acquisition
AVBDC	Absolute Volume Based Dynamic Capacity
CRA	Continuous Rate Assignment
CSC	Common Signaling Channel
DSM-CC	Digital Storage Media Command and Control
DTS	Decode Time Stamp
DULM	Data Unit Labeling Method
DVB	Digital Video Broadcasting Project
DVB-S	Digital Video Broadcast by Satellite
FCA	Free Capacity Assignment
GEO	Geosynchronous or Geostationary Earth Orbit
ISO	International Standards Organization
LEO	Low Earth Orbit
MEO	Medium or Middle Earth Orbit
NCC	Network Control Center
PAT	Program Association Table
PES	Packetized Element Stream
PID	Packet ID

PMT	Program Map Table
PSI	Program-Specific Information
PTS	Presentation Time Stamp
QPSK	Quadrature Phase Shift Keying
RBDC	Rate-Based Dynamic Capacity
RCST	Return Channel Satellite Terminal
SAC	Satellite Access Control
SMATV	Satellite Master Antenna Television
SYNC	Synchronization
TBTP	Terminal Burst Time Plan
TRF	Traffic
TS	Traffic Stream
VBDC	Volume-Based Dynamic Capacity



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INDEX

A

Abbreviations, 307–317
Absolute Volume-Based Dynamic Capacity (AVB-DC), 305
Access Feedback Channel (ACH), 99
Acknowledged mode, Error Control (EC), 91
Acronyms, 307–317
ActiveQoSParamSet, 134
Ad hoc network, 64–65
Adaptation, 30
Adaptive data burst profiles, 124
Adaptive Modulation and Coding (AMC), 285, 290
Ad-hoc network, 106–107
AdmittedQoSParamSet, 134
Advanced Mobile Phone Service (AMPS), 275
Air interface protocol architecture, cdma2000, 278–280
A-node management, 106, 107
Application, and multimedia application performance, 21
Application requirements, multimedia, 29–35
  adaptive and nonadaptive characteristics, 30
  application criticality, 31
  examples of, 32–35
  interactive voice, 32–34
  interactive/noninteractive applications, 29–30
  qualitative expression, 32
  quantitative expression, 31
  representation of, 31–32
  tolerance/intolerance, 30
  video applications, 34–35
Architecture:
  cdma2000, 276–280
  DVB Return Channel System (DVB-RCS), 294–295
  GPRS Release 5 (GPRS Rel-5), 194–204
  HiperLAN, 86–88
    network topology, 86–87
    protocol stack, 87–88
  HomeRF, 106–108
    network topology, 106–108
    protocol stack, 108
  IEEE 802.11, 64–75
  IEEE 802.16, 120–121
  IEEE 802.15.3, 166–169
  IEEE 802.15.4, 180–182
  Quality of Service (QoS), 55–57
  Universal Mobile Telecommunications System (UMTS), 234–236
ARQ (Automatic Repeat Request) mechanism, 137
Association Control Channel (ASCH), 99–100
Association Control Function (ACF), 91
Association of Radio Industries and Businesses (ARIB), 191
Asynchronous data device (A-node), 105, 106
AT&T, 4, 105
Atlantis: The Lost Empire (Disney), 9
Automated teller machine (ATM), 6
Automotive Multimedia Interface Collaboration (AMI-C), 14-15
Auxiliary Pilot Channel (F-APICH), 284
Auxiliary Transmit Diversity Pilot Channel (F-ATD-PICH), 284

B

Bandwidth:
  interactive voice, 32
  management, 36
  median policies, xiii
  over-provisioning, 36
Base Station Controller (BSC), 276–277
Base Station System (BSS), 195–196
Base Transceiver Station (BTS), 276–277
BCCH, *See* Broadcast Control Channel (BCCH)
Bluetooth, 22, 143–164
BMW, Mayday system, 13

Broadcast Channel (BCH), 99
Broadcast channels, 210
Broadcast Control Channel (BCCH), 95, 210
Broadcast/Multicast Control (BMC), 260
Burstiness, 26

C
Cable television, 7
Capacity request-grant process, 304–305
Carrier sense multiple access with collision avoidance (CSMA/CA) mechanism, 70, 171, 184, 191
Cayman Systems, 105
cdma2000, 275–290
  air interface protocol architecture, 278–280
  architecture, 276–280
  cdma2000 1x, 275
  cdma2000 1xEV-DO (Data Only), 276
  cdma2000 1xEV-DV (Data and Voice), 276
  cdma2000 3x, 275
  defined, 275
  evolution, 276
  frequency bands, 281
  link access control (LAC), 289
  logical channels, 288–289
    Forward/Reverse Common Signaling Channel (f/r-csch), 289
    Forward/Reverse Dedicated Signaling Channel (f/r-dsch), 289
    Forward/Reverse Dedicated Traffic Channel (f/r-dtch), 288
  Media Access Control (MAC), 286–289
    MAC layer, 287
    MAC-Availiability.Indication, 287–288
    MAC-Data.Indication, 288
    MAC-Data.Request, 288
    MAC-SDUReady.Request, 287
  multiplex sublayer, 289
  phases, 275
  physical channels, 283–286
    pilot channels, 284
    for voice and data traffic, 284–286
  physical layer, 280–283
  QoS sublayer, 289
  QoS support, 289–290
    bandwidth allocation, 290
    packet scheduling, 290
  Release C documentation, 276
  Spreading Rate 1/Spreading Rate 3, 282
Cellular networks, xiv
Central processing unit (CPU), 4
Centralized file sharing, 7–8
Channel time allocation (CTA), 172
Channel time request (CTR) command, 173, 176
Child piconet, 175
China Wireless Telecommunication Standard Group (CWTS), 191
Circuit Switching (CS) domain, Core Network (CN), 195
Cisco Systems, 4, 61
Classes A, B, C domain of operation, 196
Clear To Send (CTS) packet, 71
Clubphoto, 8
Cmode, 6
Coca-Cola, 6
Code Division Multiple Access (CDMA), 15
Collision-based channel access, 44–45
Collision-free channel access, 45–46
  polling, 45
  TDMA (Time Division Multiple Access), 45–46
Collocation, 66–67
Common signaling channel (CSC), 303
Communication puzzle, xv
Communication system, 22
Compact Packet Access Grant Channel (CPAGCH), 210
Compact Packet Broadcast Control Channel (CPBCCH), 210
Compact Packet Notification Channel (CPNCH), 210
Compact Packet Paging Channel (CPPCH), 210
Compact Packet Random Access Channel (CPRACH), 210
Compaq, 105
Complementary Code Keying (CCK) modulation, 63
Conditional Access Table (CAT), 296
Connection Identifiers (CIDs), 124
Constant bit rate (CBR), 25
Contention period, HomeRF, 109
Contention-based Mini-slot Method, 305
Contention-Free Period (CFP), 72
  HomeRF, 109
Continuous Rate Assignment (CRA), 304
Control channels, GPRS Release 5 (GPRS Rel-5), 209–210
Controlled Load Integrated Services, 35
Core Network (CN), 194–195
  Circuit Switching (CS) domain, 195
  Packet Switching (PS) domain, 195
CS domain of operation, 196
CS/PS domain of operation, 196
Cybiko, 8

D
Daimler-Chrysler, 14
Data Link Control (DLC) layer, 90–102
  convergence layer (CL), 102
  Error Control (EC), 90, 91–92
    acknowledged mode, 91
    repetition mode, 92
    unacknowledged mode, 92
  logic channels, 93, 95–99
    Association Control Channel (ASCH), 99–100
    Broadcast Control Channel (BCCH), 95
    Dedicated Control Channel (DCCH), 97–98
    Frame Control Channel (FCCH), 95–96
    Link Control Channel (LCCH), 99
    Random Access Feedback Channel (RFCH),

96
RLC Broadcast Channel (RBCH), 96–97
User Broadcast Channel (UBCH), 97
User Data Channel (UDCH), 98
User Multicast Channel (UMCH), 97
Media Access Control (MAC), 90, 92–94
logical channels, 93
MAC frame structure, 92–93
transport channels, 93
QoS support, 102–103
channel access, 102
classification, 102
packet scheduling, 103
Radio Link Control (RLC), 90, 91
resource request (RR) and resource grant (RG), 100–102
polling resource request, 101
unpolling resource requests, 101–102
transport channels, 99–100
Access Feedback Channel (ACH), 99
Broadcast Channel (BCH), 99
Frame Channel (FCH), 99
Long Transport Channel (LCH), 100
Random Access Channel (RCH), 100
Short Transport Channel (SCH), 100
Data Storage Media Command and Control (DSM-CC), 296
Data Unit Labeling Method (DULM), 305
DCF Interframe Space (DIFS), 70–71
Decode Time Stamp (DTS), 296
Dedicated Basic Physical Sub Channel (DBPSCH), 204, 210, 211, 217
Dedicated Control Channel (DCCH), 97–98
Delay, 26–27
interactive voice, 33
as quantitative expression of application requirements, 31
Delay jitter, as quantitative expression of application requirements, 31
Delay jitter, interactive voice, 33
Delay variation, 27–28
Delay-tolerant adaptive applications, 30
Delete jitter, 27–28
Destination processing delay, 26
Device architecture, and consumer experience, 4
Device Management Entity (DME), 169
Dialpad, 9
Differentiated Services (DiffServ), 35
DIFS, 111
Digital audio files, 7
Direct Sequence Spread Spectrum (DSSS), 62
DirecTV, 5
DirecWay Hughes Satellites, 12
Dish Networks, 5
Disney, 8
Distortion tolerance/intolerance, 30
DLC Connection Control (DCC), 91
DLC layer, *See* Data Link Control (DLC) layer
DLC User Connection ID (DUC ID), 94
D-Link, 61
DoCoMo, 4, 6
iConvenience, 7
Downlink data transmission, 215
DSCP (Internet protocol differential service code point), 42
DSM-CC (Digital Storage Media Command and Control), 301
DVB (Digital Video Broadcasting) project, 291
DVB Return Channel System (DVB-RCS), 292–294
architecture, 294–295
Forward Link, 296–302
Data Carousel, 302
data piping, 297–300
data streaming, 300–301
MPEG-2 transport stream, 296–297
multiprotocol encapsulation, 301
maximum speeds, 293–294
QoS support, 305–306
capacity request signaling and channel access, 306
classification, 305
Return Link, 302–305
acquisition (ACQ), 303
capacity request-grant process, 304–305
channel access, 303–305
common signaling channel (CSC), 303
Frame Composition Table (FCT), 303
frames, 302
signaling methods for capacity requests, 305
Superframe Composition Table (SCT), 303
superframes, 302
synchronization (SYNC), 303
Time Slot Composition Table (TCT), 303
time slots, 302–303
traffic (TRF), 303
Dynamic Frequency Selection (DFS), 138
Dynamic time slot assignment, 45

E

E911 services, 11
Endeavors, 5
End-to-end delay diagram, 26–27
Enhanced Data rate for Global Evolution (EDGE), 18, 193
Enhanced Distributed Coordination Function (EDCF), 79–80
Enhanced Messaging Service (EMS), 8, 16–17
Entertainment applications, 7
Ericsson, 4, 9
Error Control (EC), 90, 91–92
acknowledged mode, 91
repetition mode, 92
unacknowledged mode, 92
Error rate, 28
ETSI (European Telecommunications Standards Institute), xiv, 291

European Telecommunication Standard Group (ETSI), 191
European Telecommunications Standards Institute (ETSI), 191
Eutelsat, 291
Extended Interframe Space (EIFS), 70
eZmeeting, 5

F
Fast Associated Control Channel (FACCH), 210
FCH IEs (FCCH), 103
FGDC (Federal Geographic Data Committee), 11
5-tuplet IP header, 43
Ford Motor Company, 12, 14
Forward Link, 275, 296–302
  Data Carousel, 302
  data piping, 297–300
  data streaming, 300–301
  MPEG-2 transport stream, 296–297
  multiprotocol encapsulation, 301
Forward Link Signaling, 295
Forward Packet Data Channel (F-PDCH), 284–285
Forward Packet Data Control Channel (F-PDCCH), 284–285
Forward Pilot Channel (F-PICH), 284
Forward/Reverse Dedicated Control Channel (F/R-DCCH), 284–285
Forward/Reverse Fundamental Channel (F/R-FCH), 285
Forward/Reverse Supplemental Channel (F/R-SCH), 284–285
Frame Channel (FCH), 99
Frame Composition Table (FCT), 297, 303
Frame Control Channel (FCCH), 95–96
Frame convergence sublayer (FCSL), 168
Free Capacity Assignment (FCA), 305
Frequency Division Duplex (FDD), 232, 275
Frequency Hopping Spread Spectrum (FHSS), 62, 109
Full Function Device (FFD), 180–181

G
GameBoy, 8
GameWorld Technologies, "Women Are Smarter?" game, 15
Gateway GPRS Support Node (GGSN), 195
General Motors, 12, 14
  OnStar System, 13
General Packet Radio Service (GPRS), 18, 191–229
  defined, 191
  Enhanced Data rate for Global Evolution (EDGE), 193
  releases of, 193
GEO (Geosynchronous, or Geostationary Earth Orbit) satellites, 291–292
GERAN (GSM/EDGE Radio Access Network), 194, 196
Gilat Satellite Networks, 291
Gladiator (JAMDAT Mobile), 8–9
Global networks, 3–4
Global System for Mobile Communications (GSM), 15
GPRS Release 5 (GPRS Rel-5):
  architecture, 194–204
  channel access/resource allocation, 214–215
    downlink data transmission, 215
    slotted Aloha method, 214
    Time Division Multiple Access (TDMA) method, 214
    uplink data transmission, 215
  control channels, 209–210
  Core Network (CN), 194–195
    Circuit Switching (CS) domain, 195
    Packet Switching (PS) domain, 195
  GERAN (GSM/EDGE Radio Access Network), 194, 196
  logical channels, 209
  MAC-DTM state, 217
  MAC-Idle state, 217
  MAC-Shared state, 217
  Mobile Station (MS), 194
  packet traffic channels, 211
  physical channel, 204–208
    assignment example, 205
    defined, 204
    hyperframes, 206
    multiframes, 206
    Packet Data Channel (PDCH), 206–207
    packet traffic channels, 211
    radio block, 206–207
    superframes, 206
    TDMA frames, 206
    time slots, 206
  protocol architecture, 202–204
  QoS mechanisms in radio bearer service, 228–229
    classification, 228–229
    packet scheduling, 229
  QoS profile in GPRS bearer service, 224–227
    delay parameter, 225
    PDP context procedures, 226–227
    reliability parameter, 225
    service precedence/priority parameter, 224
    throughput parameter, 226
  QoS support, 222–229
  Radio Access Network (RAN), 194
  radio interface protocol architecture, 197–201
    data link, 198, 200
    Media Access Control (MAC), 198, 200
    Packet Data Convergence Protocol (PDCP), 198, 199, 211–217
    physical layer, 200–201
    Radio Link Control (RLC), 199–200, 215–217
    Radio Resource Control (RRC), 198–199
    Radio Resource (RR), 198, 199
  Radio Resource Control (RRC), 218–222
    modes of operation, 219–220
  Radio Resource (RR), 218–222

dedicated mode, 220
dual transfer mode (DTM), 221
modes of operation, 220–222
packet idle mode, 220
packet transfer mode, 220–221
RAN, 194
specification of, 193–194
Temporary Block Flows (TBFs):
establishment of, 211–214
mobile station initiation of TBF establishment, 211–214
transition between modes, 221–222
UTRAN (UMTS Terrestrial Radio Access Network), 196
GPS (Global Positioning System), 9–11
Groove, 5
GTSkl, 187
GTSLength, 187
GTSStartSlot, 187
Guaranteed Integrated Services (IntServ), 35
Guaranteed time slot (GTS), 166, 168, 171, 173, 183, 185
establishment procedure, 186
primitives, 185–186
private GTS, 175

H

HDTV, 34
High-Speed Download Packet Access (HSDPA) technology, 231
HiperAccess, 119
HiperLAN, 85–103
architecture, 86–88
network topology, 86–87
protocol stack, 87–88
convergence layer (CL), 102
Data Link Control (DLC) layer, 90–102
Error Control (EC), 90, 91–92
logic channel, 95–99
Media Access Control (MAC), 90, 92–94
Radio Link Control (RLC), 90, 91
resource request (RR) and resource grant (RG), 100–102
transport channels, 99–100
defined, 85
history of, 85
physical layer, 88–89
predecessor, 85
QoS support, 102–103
Hispasat, 291
Home Location Register (HLR), 16
Home Subscriber Server (HSS), 195
HomeRF, 105–115
A-node management, 106, 107
architecture, 106–108
network topology, 106–108
protocol stack, 108
asynchronous data device (A-node), 106
asynchronous data service, 105
Connection Points (CPs), 106
contention period, 109
contention-free period, 109
data services defined by, 105
defined, 105
I-node management, 106, 108
isochronous data device (I-node), 105, 106
Media Access Control (MAC), 109–113
channel access, 109–110
contention-based CSMA/CA with priority access and time reservation, 110–111
reserved time TDMA with retransmission option, 111–113
operation, 111–112
physical layer, 109
priority asynchronous data service, 105
QoS support, 113–115
asynchronous data service, 114–115
isochronous data service, 113–114
priority asynchronous data service, 114
S-node management, 106, 108
standard, 106
streaming data device (S-node), 106
HomeRF Working Group (HRFWG), 105
Host machine, and multimedia application performance, 21
Hughes Network Systems, Spaceway program, 3, 291
Hybrid Coordination Function (HCF), 78–79, 80
Hyperframes, 206

I

iConvenience, 7
IEEE 802.11, 22, 61–83
architecture, 64–75
defined, 61–62
IEEE 802.11e (QoS extension), 75–83
channel access and packet scheduling, 78–82
QoS in HCF, 81–82
QoS signaling, 82–83
queue state indicator signaling, 83
traffic category, 76–77
traffic classification, 76–78
traffic specification signaling, 83
traffic stream, 77–78
Media Access Control (MAC), 69–72
architecture, 69
Distributed Coordination Function (DCF), 70–71
Point Coordination Function (PCF), 72
network topologies, 64–68
ad hoc network, 64–65
collocation, 66–67
infrastructure network, 65–66
protocol stack, 67–68
physical layer, 68
physical layer convergence protocol (PLCP), 72
QoS support, 73–75

QoS in IEEE 802.11 DCF, 73
QoS in IEEE 802.11 PCF, 74–75
standard supplements, 63–64
standards, 62
IEEE 802.15, 165–187
IEEE 802.16, 119–139
adaptive data burst profiles, 124
architecture, 120–121
IEEE 802.16a, 137–139
MAC discussions, 139
IEEE 802.16.1, 120–121
MAC Common Part Sublayer (CPS), 121
Media Access Control (MAC), 124–132
bandwidth allocation, 130
bandwidth request mechanism, 128–129
Best Effort (BE) Service, 131
channel access, 124–128
contention resolution, 128
downlink subframe, 125
network entry and initialization, 132
Non-Real-Time Polling Service (nrtPS), 131
Real-Time Polling Service (rtPS), 131
service flow scheduling service, 130–132
Unsolicited Grant Service (UGS), 130–131
uplink subframe, 125–128
network topology, 120–121
physical layer, 121–123
protocol stack, 121
QoS support, 132–137
channel access, 134
classification module, 134
mechanisms, 134–137
packet scheduling, 135–136
provision, 133
Security Sublayer, 121
Service Specific Convergence Sublayer (CS), 121
IEEE 802.15.1, 165
IEEE 802.15.3, 165–179
architecture, 166–169
network topology, 166–168
protocol stack, 168–169
channel definition and channel access, 171–174
contention access period (CAP), 171–172
contention-free period (CFP), 172–174
Media Access Control (MAC), 170–176
physical layer, 169–170
piconet:
child piconet, 175
neighbor piconet, 176
starting, 174–176
QoS support, 176–179
architecture, 179
classification, 178
contention access period (CAP), 176
contention-free period (CFP), 176–178
IEEE 802.15.4, 179–187
architecture, 180–182
network topology, 180–181
protocol stack, 182
focus of, 179
frequency band, 182
Media Access Control (MAC), 183–185
physical layer, 182
QoS support, 185–187
IEEE (Institute of Electrical and Electronics Engineers), xiv
IEEE (Institute of Electrical and Electronics Engineers) 802 user priority, 41
IMT2000-Mc (IMT-CDMA Multicarrier), *See* cdma 2000
IMT-2000 (International Mobile Telecommunication-2000), 275
Infrastructure network, 65–66
I-node management, 106, 108
Integrated Emergency Medicine Network (IEMN) system, 12
Intel, 105
Interactive video applications, 34
Interactive voice, 32–34
bandwidth, 32
delay, 33
delay jitter, 33
speech coding standards, 32–33
Interframe Space (IFS), 70–71, 110
Internet, 4–5
Internet Engineering Task Force (IETF), 42
Internet Multimedia Subsystem (IMS), 197
Interworking Function (IWF), 277
In-traffic mechanisms, 39
IPTOS (Internet protocol type service), 42
iRadio project, Motorola, 14
Isochronous data service, HomeRF, 105
ISO/IEC (International Standards Organization/International Electrotechnical Commission) 13818-1 standard, 296
ITU (International Telecommunication Union), xiv

J

JAMDAT Mobile, Gladiator game, 8–9

K

Kazaa Media Desktop, 8

L

Laan & Spar Bank (Denmark), 6
Latency tolerance/intolerance, 30
Lawson stores, 7
LEO (Low Earth Orbit) satellites, 291–292
Link Control Channel (LCCH), 99
Linksys, 4, 61
Location-based services, 9–11
Logic channels, Data Link Control (DLC) layer, 93
Logical channels:
cdma2000, 288–289
GPRS Release 5 (GPRS Rel-5), 209
Long Transport Channel (LCH), 100
Loss, as quantitative expression of application re-

quirements, 31
Loss rate, 28
Low-Rate Wireless Personal Area Network (LR-WPAN), 179, 180, 185
intermittent data, 185
periodic data, 185
repetitive low-latency data, 185
LR-WPAN, *See* Low-Rate Wireless Personal Area Network (LR-WPAN)

M

MAC, *See* Media Access Control (MAC)
MAC Identification number (MAC ID), 91
MAC-DTM state, 217
Machine-to-machine application, 29
MAC-Idle state, 217
MAC-Shared state, 217
Managed Network, 107
Management time slots (MTSs), 171, 173–174
Mapping between priority and services, example of, 42
Mayday system, BMW, 13
Media Access Control (MAC), 85
cdma2000, 286–289
Data Link Control (DLC) layer, 90, 92–94
HomeRF, 109–113
IEEE 802.11, 69–72
IEEE 802.16, 124–132
IEEE 802.15.4, 183–185
Universal Mobile Telecommunications System (UMTS), 253–259
MEO (Medium, or Middle Earth Orbit) satellites, 291–292
Mercedes Benz, iDrive system, 13
MExE (Mobile Execution Environment), 18
MF-TDMA, *See* Multifrequency Time Division Multiple Access (MF-TDMA)
Microsoft, 3
ASF, 34
Media Player, 5
MIDI, 17
Mini-slot method, 305
MMS, *See* Multimedia Messaging Service (MMS)
Mobile Games Interoperability Forum (MGIF), 9
Mobile Station (MS), 194
Mobile Switching Center (MSC), 195, 277
Monsters Inc. (Disney/Pixar), 9
Morpheus, 8
Motorola, 9, 105
iRadio project, 14
MP3, 7, 17
MPEG 4, 17
MPEG-2 Transport Stream (TS), 296
MSC, *See* Mobile Switching Center (MSC)
MSN Messenger, 9
MTSs, *See* Management time slots (MTSs)
Multiframes, 206
Multifrequency Time Division Multiple Access (MF-TDMA), 303
Multimedia applications, 3–20
application requirements, 29–35
adaptive and nonadaptive characteristics, 30
application criticality, 31
examples of, 32–35
interactive voice, 32–34
interactive/noninteractive applications, 29–30
qualitative expression, 32
quantitative expression, 31
representation of, 31–32
tolerance/intolerance, 30
video applications, 34–35
business applications, 12
digital money transactions, 6–7
email and multimedia messaging, 8
entertainment, 7
evolution of, 3–5
file sharing, 7–8
location-based services, 9–11
peer-to-peer computing, 5–6
personal area device connectivity, 12–13
picture sharing, 7–8
protocols, 15–20
Enhanced Messaging Service (EMS), 8, 16–17
Multimedia Messaging Service (MMS), 8, 17–18
Short Message Service (SMS), 8, 15–16
Wireless Application Protocol (WAP), 18–20
Telematics, 13–15
telemedicine, 12–13
video and audio streaming, 5
voice and telephony, 9
wireless gaming, 8–9
Multimedia Messaging Service (MMS), 8, 17–18
Multimedia Mobile Access Communications (MMAC), 85
Multiprotocol encapsulation, 301

N

National Semiconductor, 105
NCC (Network Control Center), 294
Neighbor piconet, 176
Net2Phone, 9
Network Allocation Vector (NAV), 71
Network, and multimedia application performance, 21
Network applications, 21
Network delay, 26
Network topology:
HiperLAN, 86–87
HomeRF, 106–108
IEEE 802.11, 64–68
IEEE 802.16, 120–121
IEEE 802.15.3, 166–168
Nintendo, 8
Nokia, 9
Non-Real-Time Polling Service (nrtPS), 131

O

OFDM (Orthogonal Frequency Division Multiplexing), 138
OFDMA (Orthogonal Frequency Division Multiple Access), 138
ofoto, 8
Omnitel, 4
OnStar System, General Motors, 13
Open System Interconnection (OSI) layers, 41
Orange, 4
Orthogonal Frequency Division Multiplexing (OFDM), 63
Out-of-traffic mechanisms, 39
Output queuing delay, 26

P

p2p computing, 5–6
Packet Access Grant Channel (PAGCH), 210
Packet Associated Control Channel (PACCH), 210
Packet Broadcast Control Channel (PBCCH), 209, 210
Packet Common Control Channels (PCCCHs), 209
Packet Data Channel (PDCH), 206–207
Packet Data Convergence Protocol (PDCP), 259
Packet Data Service Node (PDSN), 277
Packet Data Traffic Channel (PDTCH), 211
Packet Notification Channel (PNCH), 210
Packet Paging Channel (PPCH), 210
Packet Random Access Channel (PRACH), 210
Packet Switching (PS) domain, Core Network (CN), 195
Packet Timing Advance Control Channels (PTCCHs), 210
Packet Timing Advance Control Channel/Downlink (PTCCH/D), 210
Packet Timing Advance Control Channel/Uplink (PTCCH/U), 210
Packet traffic channels, 211
PacketVideo, 5
PCF Interframe Space (PIFS), 70–71
PCMCIA (PC Memory Card Fed S&L International Association) cards, 62
People-to-machine application, 29
People-to-people application, 29
Physical channel(s):
  cdma2000, 283–286
  GPRS Release 5 (GPRS Rel-5), 204–208
Physical layer:
  cdma2000, 280–283
  HiperLAN, 88–89
  HomeRF, 109
  IEEE 802.11, 68
  IEEE 802.15.3, 169-170
  IEEE 802.15.4, 182
  IEEE 802.16.1, 121-123
  radio interface protocol architecture, 200–201
  UMTS, 236–253
Physical Layer (PHY) specifications, 62
Piconet:
  child piconet, 175
  neighbor piconet, 176
  starting, 174–176
Piconet Coordinator (PNC), 167, 169–170
Piconet ID (PNID), 167
Presentation Time Stamp (PTS), 296, 300–301
Private GTS, 175
Program Map Table (PMT), 296
Program Specific Information (PSI) table, 296, 298
Propagation delay, 26
Protocol architecture, GPRS Release 5 (GPRS Rel-5), 202–204
Protocol delay, 26
ProvisionedQoSParamSet, 134
Proxim, 105
PS domain of operation, 196
Public Switched Telephone Network (PSTN), 276–277

Q

QoS, *See* Quality of Service (QoS)
QoS support:
  cdma2000, 289–290
  Data Link Control (DLC) layer, 102–103
  DVB Return Channel System (DVB-RCS), 305–306
  HiperLAN, 102–103
  HomeRF, 113–115
  IEEE 802.11, 73–75
  IEEE 802.16, 132–137
  IEEE 802.15.3, 176–179
  IEEE 802.15.4, 185–187
  Universal Mobile Telecommunications System (UMTS), 264–273
Quadrature Amplitude Modulation (QAM) with Trellis Coded Modulation (TCM), 166
Quality of Service (QoS), 4
  admission control, 54–55
    explicit, 54
    implicit, 54
    location of mechanism, 54–55
  architecture, 55–57
    for ad hoc wireless networks, 56–57
    for infrastructure wireless networks, 55–56
  channel access mechanism, 44–45
    collision-based channel access, 44–45
    collision-free channel access, 45–46
  fundamentals, 21–37
  mechanisms, 39–57
    application/user classification, 44
    bandwidth management mechanisms, 39
    classifications, 39–44
    data link layer classification, 41–42
    network layer classification, 42–43
    traffic handling mechanisms, 39
    transport layer classification, 43–44
  model, 23

packet scheduling mechanisms, 46–48
First In First Out (FIFO), 47–48
flat packet scheduling, 47
hierarchical packet scheduling, 46
interstation packet scheduling, 46
intrastation packet scheduling, 46
strict priority, 48–49
Weight Fair Queue (WFQ), 49–50
parameters, 24–28
delay, 26–27
delay variation, 27–28
loss/error rate, 28
throughput, 24–26
resource reservation signaling mechanisms, 53–54
Resource Reservation Protocol (RSVP), 53–54
services, 35–36
best effort services, 36
per-class QoS services, 36
per-flow QoS services, 36
qualitative (differentiated) services, 36
quantitative (guaranteed) services, 35
realization of, 36–37
traffic policing mechanism, 50–53
leaky bucket mechanism, 50–51
token bucket mechanism, 51–53
use of term, 22
QuickTime, 5, 34

R

Radio Access Network (RAN), 194
Radio block, 206–207
Radio interface protocol architecture, 197–201
data link, 198, 200
Media Access Control (MAC), 198, 200
Packet Data Convergence Protocol (PDCP), 198, 199, 211–217
physical layer, 200–201
Radio Link Control (RLC), 199–200, 215–217
Radio Resource Control (RRC), 198–199
Radio Resource (RR), 198, 199
Radio Link Control (RLC), 90, 91
Radio Link Protocol (RLP), 286
Radio Resource Control (RRC), 91, 260–264
CELL_DCH RRC state, 262
CELL_FACH RRC state, 262
CELL_PCH state, 262
connection establishment procedure, 263
functions performed by, 260–261
procedures, 262–263
radio bearer establishment procedure, 263–264
states, 261–262
URA_PCH state, 262
Radio Resource (RR), 218–222
dedicated mode, 220
dual transfer mode (DTM), 221
modes of operation, 220–222
packet idle mode, 220
packet transfer mode, 220–221
Random Access Channel (RCH), 100
Random Access Feedback Channel (RFCH), 96
Rat Race (nGame), 9
Rate adaptive applications, 30
Rate-Based Dynamic Capacity (RBDC), 304
RealAudio, 7
Real-Time Polling Service (rtPS), 131
RealVideo, 5
Reduced Function Device (RFD), 180–181
Remote Communities Services Telecentre (RCST) project, 12
Remote surgery, 31
Renault, 14
Repetition mode, Error Control (EC), 92
Request To Send (RTS) packet, 71
Resource Grants (RGs), 95
Retransmission interframe space (RIFS), 171--172
Return Link, 302–305
acquisition (ACQ), 303
capacity request-grant process, 304–305
channel access, 303–305
common signaling channel (CSC), 303
Frame Composition Table (FCT), 303
frames, 302
signaling methods for capacity requests, 305
Superframe Composition Table (SCT), 303
superframes, 302
synchronization (SYNC), 303
Time Slot Composition Table (TCT), 303
time slots, 302–303
traffic (TRF), 303
Reverse Acknowledgment Channel (R-ACKCH), 284, 286
Reverse Channel Quality Indicator Channel (R-CQICH), 284, 286
RLC, *See* Radio Link Control (RLC):
RLC Broadcast Channel (RBCH), 96–97
RR, *See* Radio Resource (RR)
RRC, *See* Radio Resource Control (RRC)

S

Satellite, 22
Satellite Access Control (SAC) field, 305
Satellite communication, 291–306
DVB Return Channel System (DVB-RCS), 292–294
architecture, 294–295
forward link, 296–302
maximum speeds, 293–294
QoS support, 305–306
return link, 302–305
GEO (Geosynchronous, or Geostationary Earth Orbit) satellites, 291–292
LEO (Low Earth Orbit) satellites, 291–292
MEO (Medium, or Middle Earth Orbit) satellites, 291–292
Satellite networks, xiv
SCT, *See* Superframe Composition Table (SCT)

Sega, 8
Service Access Point (SAPs), 169
Service Data Unit (SDU), 102
Serving GPRS Support Node (SGSN), 195
SES-ASTRA, 291
Shared Basic Physical Sub Channel (SBPSCH), 204, 211, 217
Shell, 12
Short Interframe Space (SIFS), 70, 111, 171–172
Short Message Service Center (SMSC), 16
Short Message Service (SMS), 8, 15–16
Short Transport Channel (SCH), 100
Siemens, 9, 105
SIFS, *See* Short Interframe Space (SIFS)
Signaling Radio Burst Protocol (SRBP), 286
Slotted Aloha method, 214
Slow Associated Control Channel (SACCH), 210
SMS, *See* Short Message Service (SMS)
S-node management, 106, 108
Source-processing delay, 26
Spaceway program, Hughes Network Systems, 291
Spar Nord Bank, 6
Speech coding standards, interactive voice, 32–33
SpotLife, 8
Stand-alone Dedicated Control Channel (SDCCH), 210
Standard Committee T1 Telecommunications (T1), 191
Static time slot assignment, 45
StoragePoint, 8
Streaming data device (S-node), HomeRF, 106
Streaming video applications, 29, 35
Superframe Composition Table (SCT), 297, 303
Superframes, 206, 302
Synchronized Multimedia Integration Language (SMIL), 18

T

TCT, *See* Time Slot Composition Table (TCT)
TDMA frames, 206
Telecommunication Technology Association (TTA), 191
Telematics, 3, 13–15
  automotive, 13–15
Telemedicine, 12–13, 31
Telestat, 12
Temporary Block Flows (TBFs):
  establishment of, 211–214
  mobile station initiation of TBF establishment, 211–214
Terminal Burst Time Plan (TBTP), 303, 306
Texaco, 12
Third Generation Partnership Project 2 (3GPP2), 275
3Com, 4, 61
3G Universal Mobile Telecommunications System (UMTS) technology, 191, 196
  evolution toward, 191–192
Throughput, 24–26
  burstiness, 26
  constant bit rate (CBR), 25
  as quantitative expression of application requirements, 31
  variable bit rate (VBR), 25
Time Division Duplex (TDD), 232
Time Division Multiple Access (TDMA), 15, 214
Time Division Multiplex (TDM), 296
Time Division Multiplex/Code Division Multiplex (TDM/CDM), 285
Time Division-Code Division Multiple Access (TD-CDMA), 232–233
Time Slot Composition Table (TCT), 297, 303
Time slots, 206
Toyota, 14
Transmission delay, 26
Transmit Diversity Pilot Channel (F-TDPICH), 284
Transport channels, Data Link Control (DLC) layer, 99–100
Triad RealVideo, 34
2G Global System for Mobile Communications (GSM) technology, 191, 192
  phases, 192

U

UL-MAP, *See* Uplink Map Message (UL-MAP)
Ultra Wide Band (UWB), 166
UMTS, *See* Universal Mobile Telecommunications System (UMTS)
Unacknowledged mode, Error Control (EC), 92
Universal Mobile Telecommunications System (UMTS), 18, 231–273, 283
  architecture, 234–236
  Broadcast/Multicast Control (BMC), 260
  defined, 231
  evolution, 231–232
  geographical coverage, 233
  Media Access Control (MAC), 253–259
  Packet Data Convergence Protocol (PDCP), 259
  physical layer, 236–253
  QoS support, 264–273
    admission/capability control, 266
    Background class, 267–270
    bandwidth allocation, 271
    classification function, 267
    control plane QoS management functions, 266
    Conversational class, 267–270
    Interactive class, 267–270
    mapping function, 267
    mechanisms in the radio bearer service, 270–273
    priority handling, 271
    QoS architecture, 265
    QoS classes, 267–270
    resource manager, 267
    service manager, 266
    Streaming class, 267–270
    subscription control, 266

traffic conditioner, 267
translation function, 266
user plane QoS management functions, 267
Radio Link Control (RLC), 259
Radio Resource Control (RRC), 260–264
CELL_DCH RRC state, 262
CELL_FACH RRC state, 262
CELL_PCH state, 262
connection establishment procedure, 263
functions performed by, 260–261
procedures, 262–263
radio bearer establishment procedure, 263–264
states, 261–262
URA_PCH state, 262
release 5 documentation, 233–234
UTRAN (UMTS Terrestrial Radio Access Network), 232–233
Universal Mobile Telecommunications System (UMTS) technology, 191
Uplink data transmission, 215
Uplink Map Message (UL-MAP), 124–125, 135
Uplink Stage Flag (USF), 204, 207
U.S. National Spatial Data Infrastructure, 11
User Broadcast Channel (UBCH), 97
User Data Channel (UDCH), 98
User device miniaturization, xiii
User Multicast Channel (UMCH), 97
Users, and multimedia application performance, 21
USF, *See* Uplink Stage Flag (USF)
UTRAN (UMTS Terrestrial Radio Access Network), 196, 232–233

V

Variable bit rate (VBR), 25
Video and audio streaming, 5
Video applications, 34–35
interactive, 34
streaming, 35
Video Cassette Recorders (VCRs), 301
Video codec bandwidth requirements, 34
Video on Demand, 34
Vodafone, 4
VoIP (voice over Internet protocol), 6, 9, 33
delay guidelines for, 33
delay jitter guidelines for, 33
Volume-Based Dynamic Capacity (VBDC), 304

W

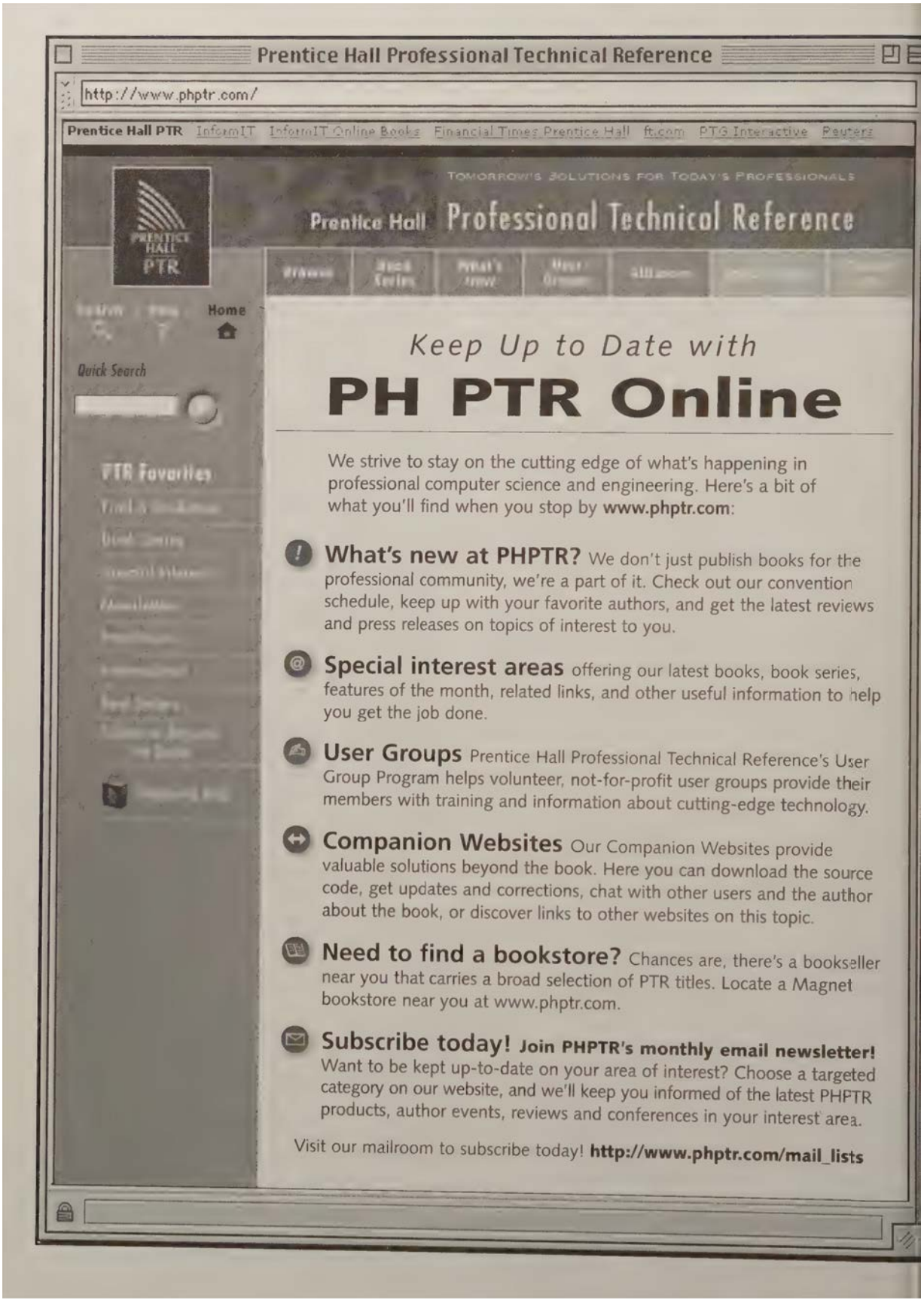
Wal-Mart, 12
Walsh code, 283
WAP, *See* Wireless Application Protocol (WAP)
WCDMA (Wideband CDMA), 232
Wide Code Division Multiple Access (WCDMA) technology, 191
Wideband Code Division Multiple Access (WCDMA), 232
Wireless Application Protocol (WAP), 18–20
External Functionality Interface (EFI) service, 19
programming model, 20
proxy model, 19–20
and Pull Model, 19
and Push Model, 19
Wireless communication:
availability of, 3–4
and changing world, xiii
Wireless Ethernet Compatibility Alliance (WECA), 62
Wireless Fidelity (Wi-Fi), 62
Wireless LAN Medium Access Control (MAC), 62
Wireless local area networks (WLANs), xiv, 4, 7, 22, 59–115
HiperLan, 85–103
HomeRF, 105–115
IEEE 802.11, 61–83
Wireless MAN(TM), 119
Wireless media compared to wired media, 62
Wireless metropolitan area networks (WMANs), xiv, 117–139
Wireless networks, xiii, xiv
applications, 4
Wireless personal area networks (WPANs), xiv, 4, 6, 141–187
Bluetooth, 143–164
IEEE 802.15, 165–187
WLANs, *See* Wireless local area networks (WLANs)
WMANs, *See* Wireless metropolitan area networks (WMANs)
WPANs, *See* Wireless personal area networks (WPANs)
WTA (Wireless Telephony Application), 19

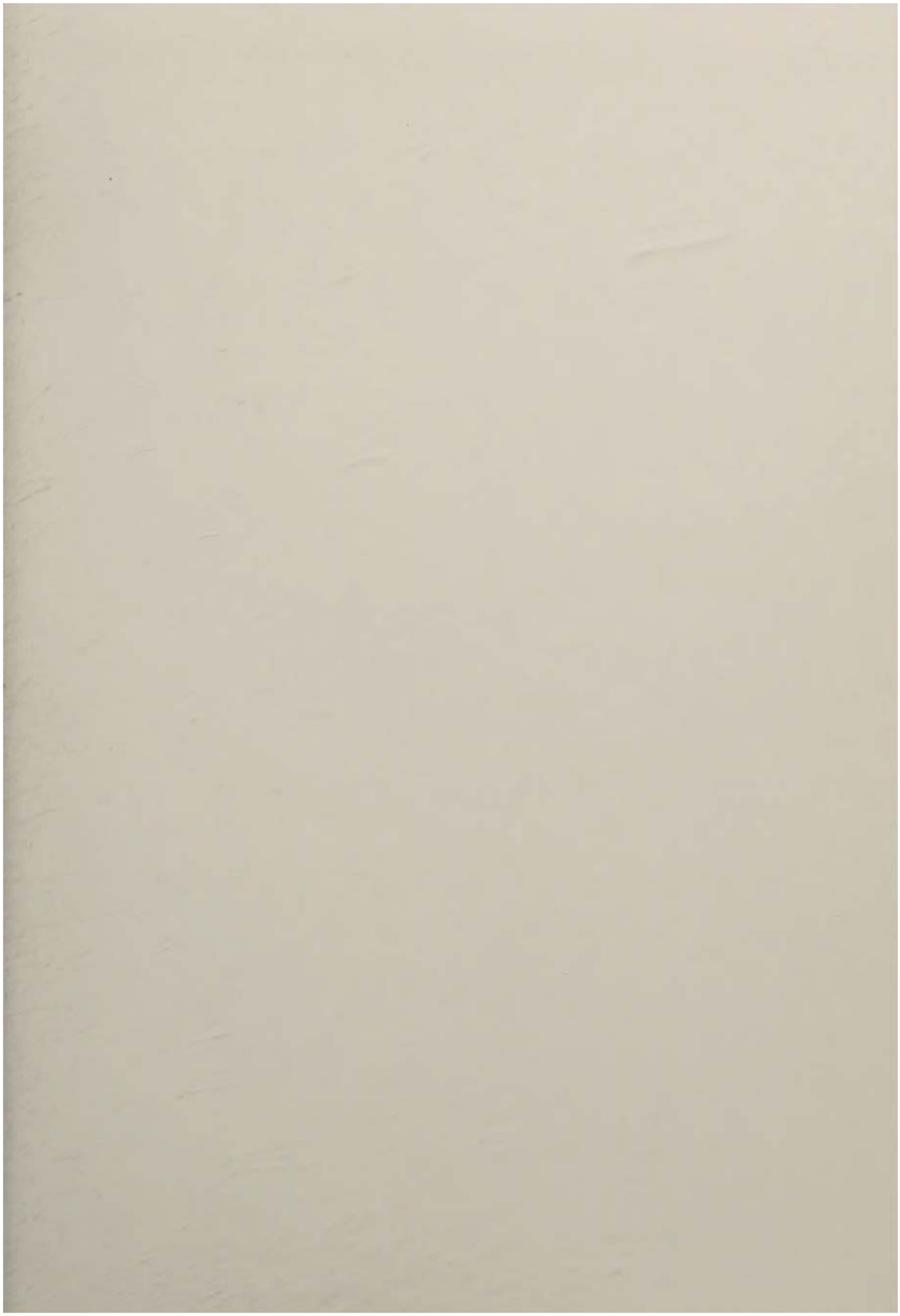
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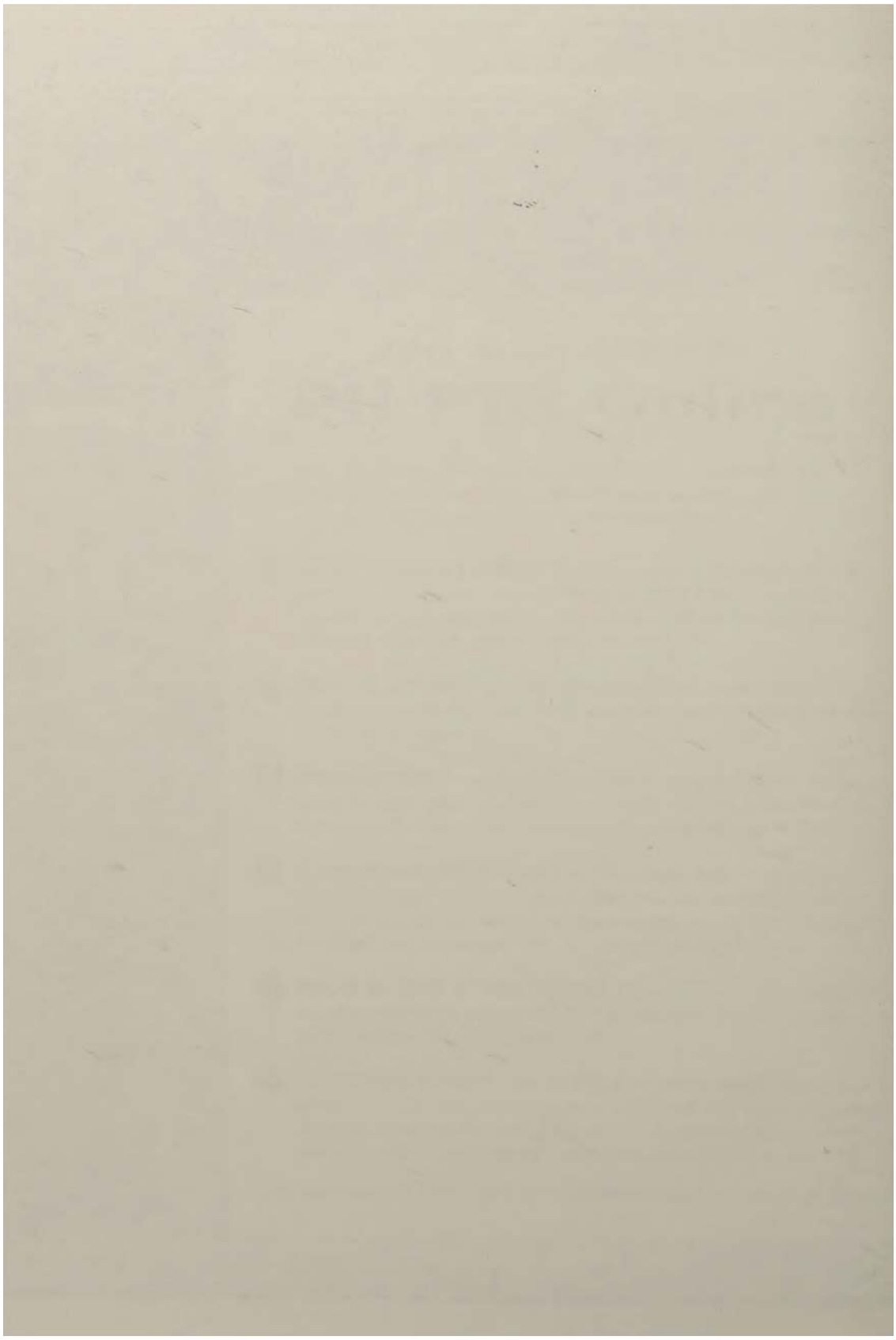
Xdrive, 8
Xilinx, 105

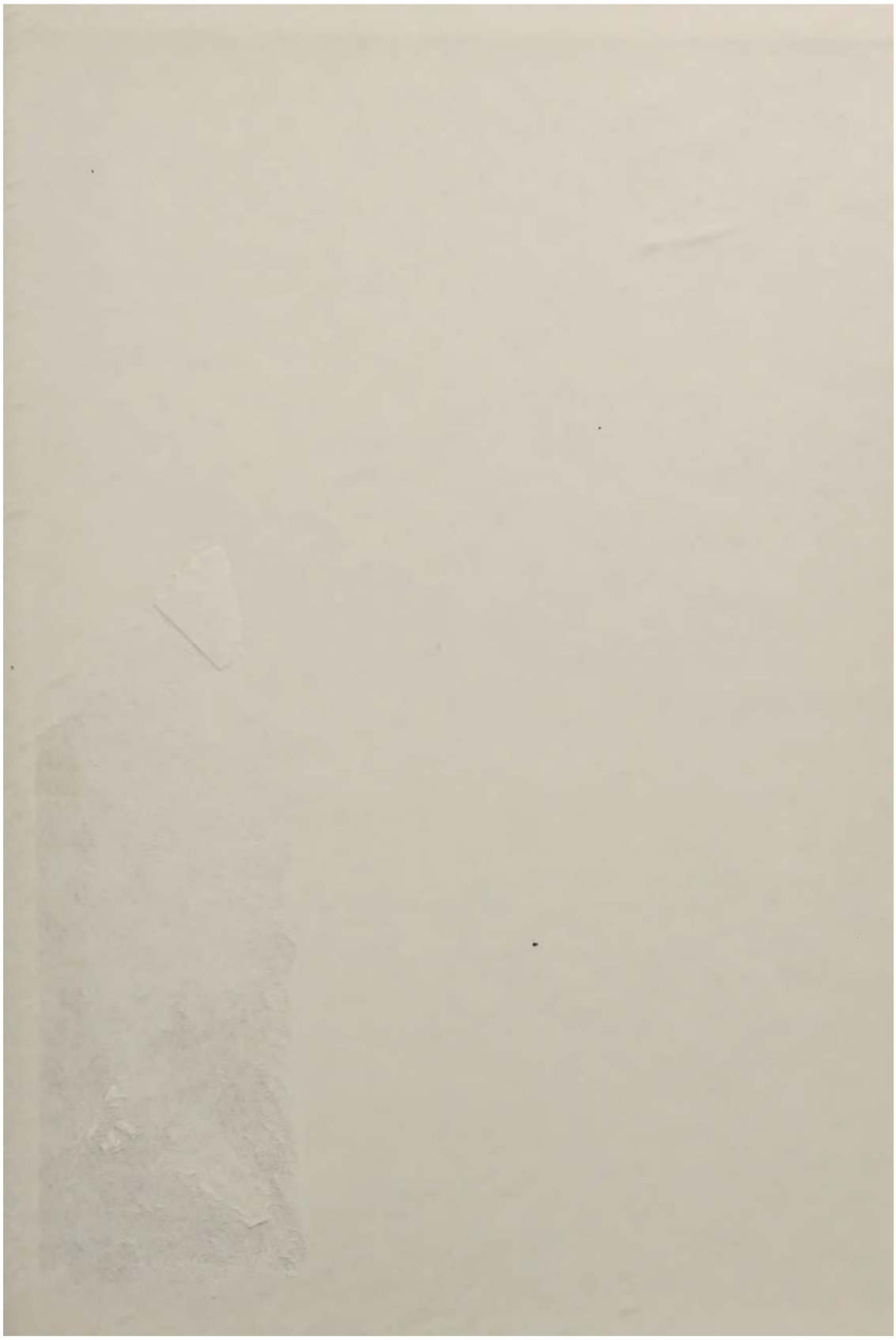
Y

Yahoo! Briefcase, 8
Yahoo! Photos, 8


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