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(54) **SPECTRUM SHARING IN A WIRELESS COMMUNICATION NETWORK**

(75) Inventors: **Joseph R Cleveland**, Murphy, TX (US); **Farooq Khan**, Allen, TX (US); **Eran Pisek**, Plano, TX (US); **William J. Semper**, Richardson, TX (US)

Correspondence Address:
DOCKET CLERK
P.O. DRAWER 800889
DALLAS, TX 75380

(73) Assignee: **SAMSUNG ELECTRONICS CO., LTD.**, Suwon-city (KR)

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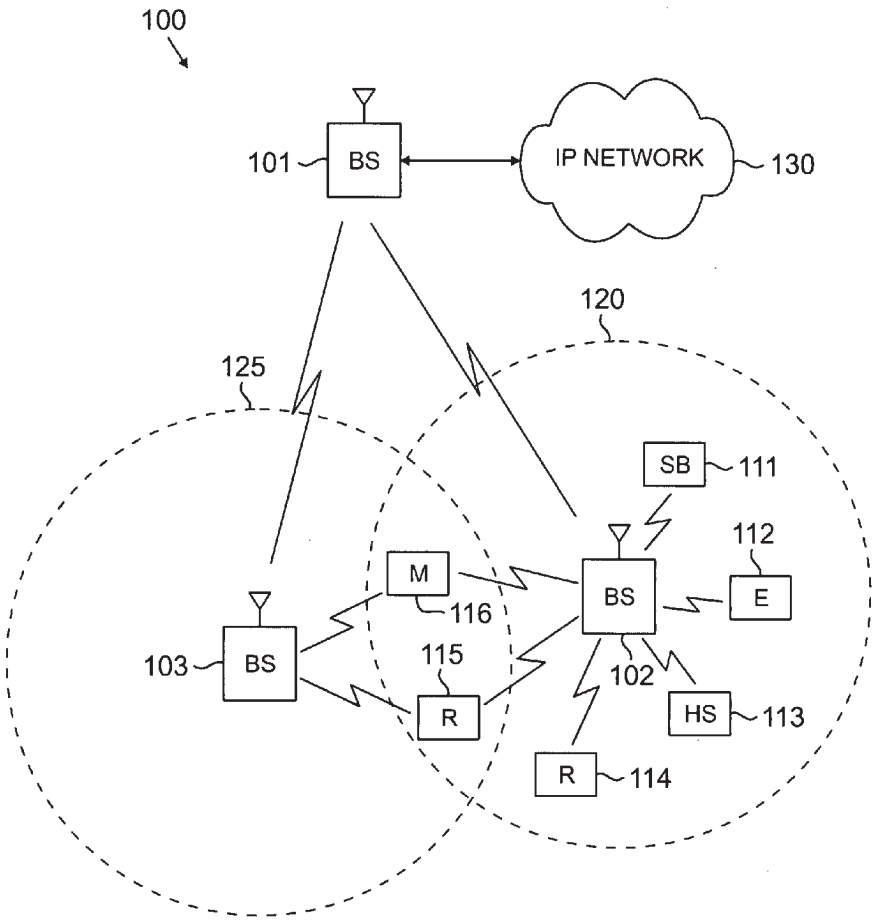
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(57) **ABSTRACT**

A system and method for synchronous spectrum sharing for use in a wireless communication system based on orthogonal frequency-division multiplexing (OFDM) or orthogonal frequency division multiple access (OFDMA) signaling is disclosed. The system includes a frame detector configured to detect a frame of a broadcast waveform and extract sub-carrier information from a subframe or Secondary User Map (SU MAP). SU MAP includes information on usable sub-carrier and pilot sub-carriers for secondary users. The system allows transmitting data from the secondary user node in unused sub-carriers thereby making efficient use of unused or idle spectrum. Accordingly, secondary users of wireless communication systems can dynamically form ad-hoc mesh network communications in fixed or mobile scenarios.



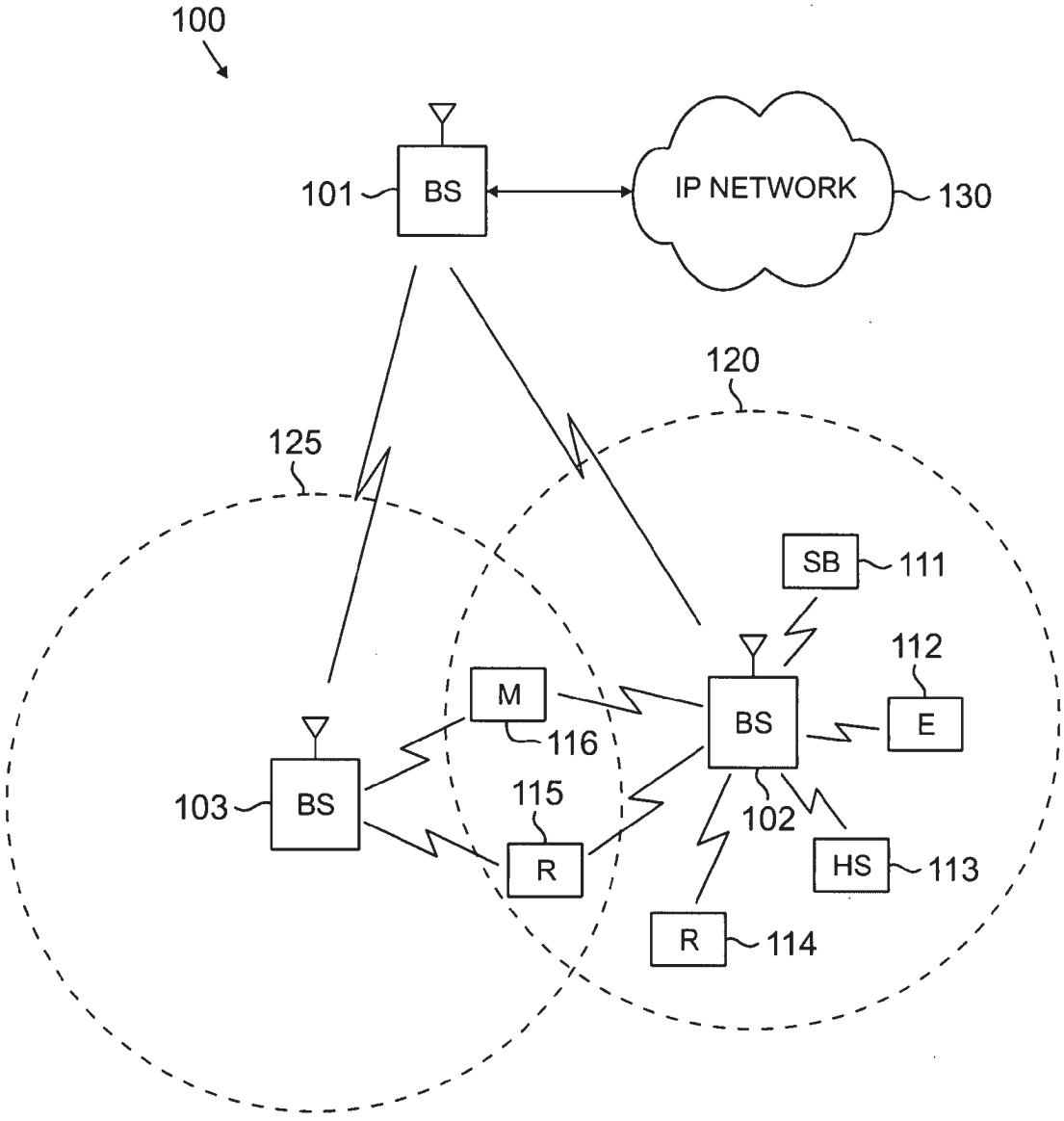

100
101
BS
IP NETWORK
130
120
125
SB
111
112
M
116
BS
E
103
BS
115
R
102
HS
113
R
114

FIG. 1

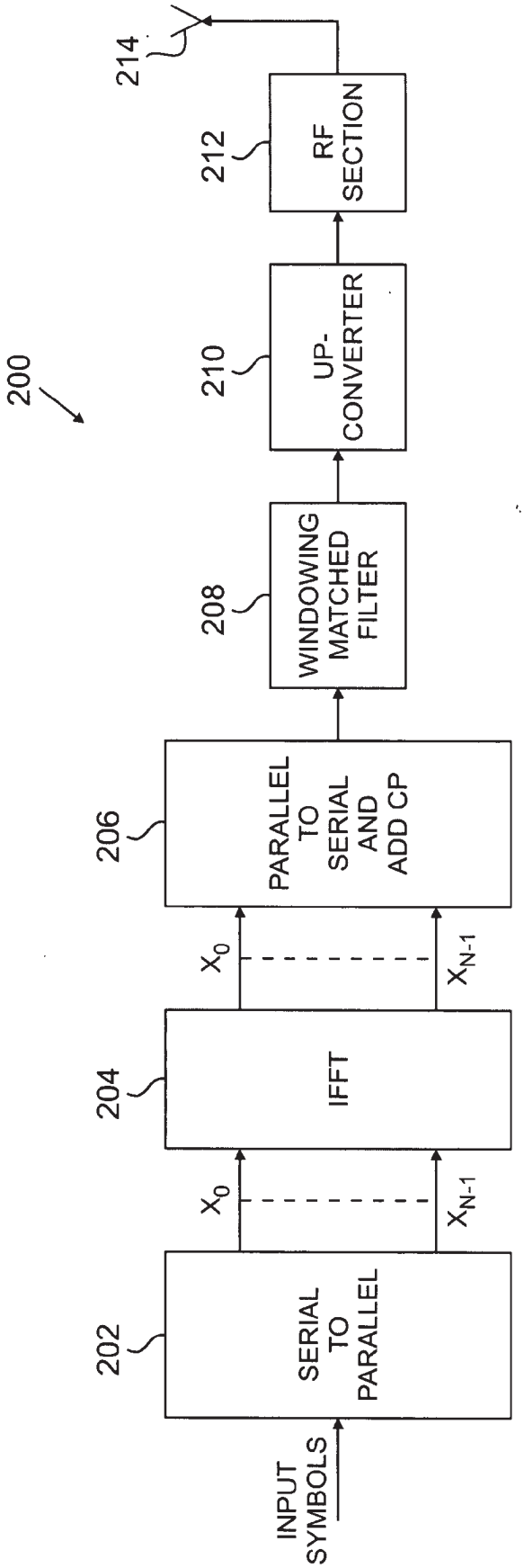

200
INPUT SYMBOLS
202
SERIAL TO PARALLEL
X_0
X_{N-1}
204
IFFT
X_0
X_{N-1}
206
PARALLEL TO SERIAL AND ADD CP
208
WINDOWING MATCHED FILTER
210
UP-CONVERTER
212
RF SECTION
214

FIG. 2

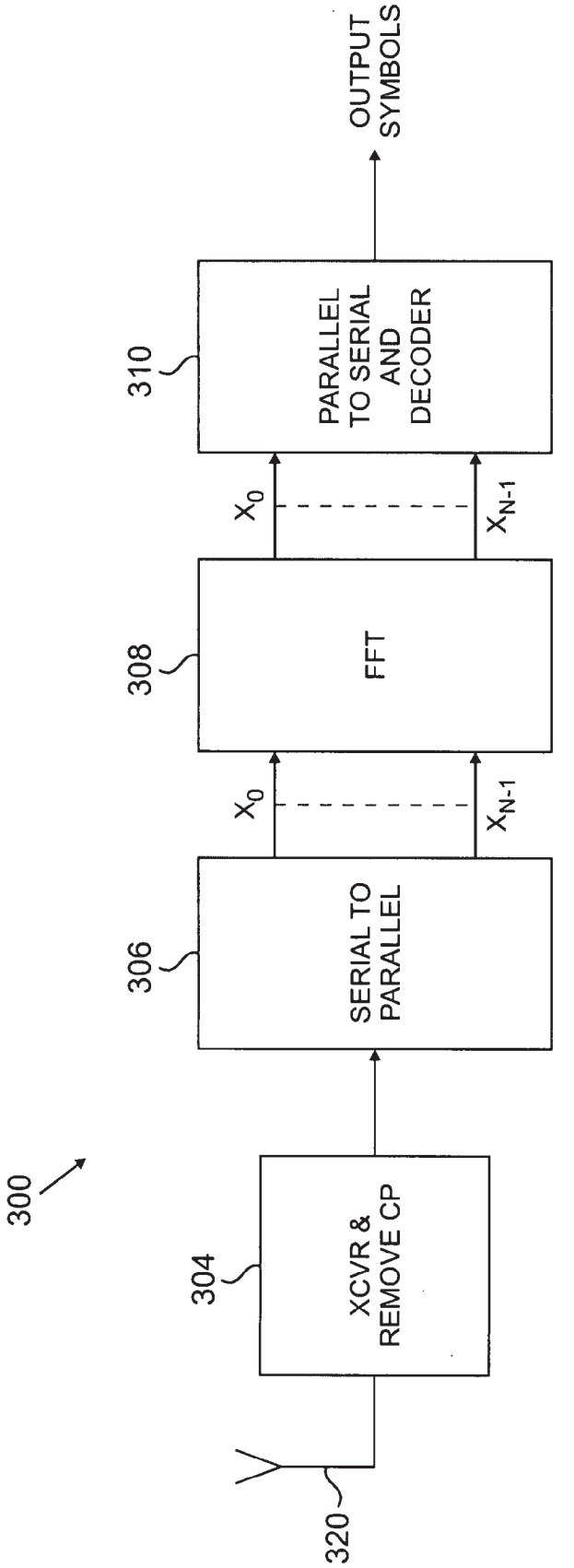

300
320
304
XCVR & REMOVE CP
306
SERIAL TO PARALLEL
X_0
X_{N-1}
308
FFT
X_0
X_{N-1}
310
PARALLEL TO SERIAL AND DECODER
OUTPUT SYMBOLS

FIG. 3

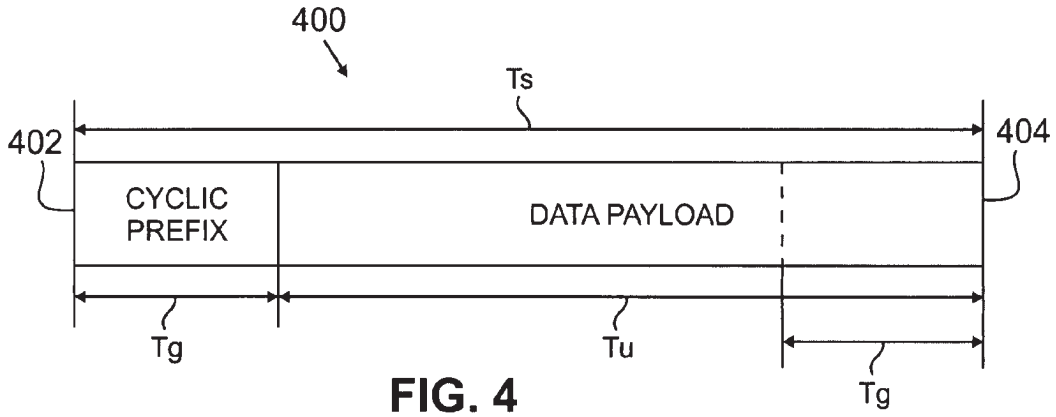


FIG. 4

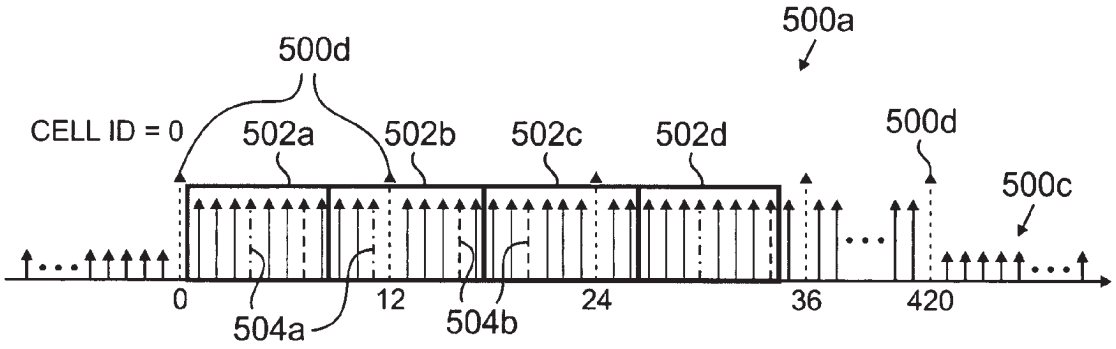


FIG. 5A

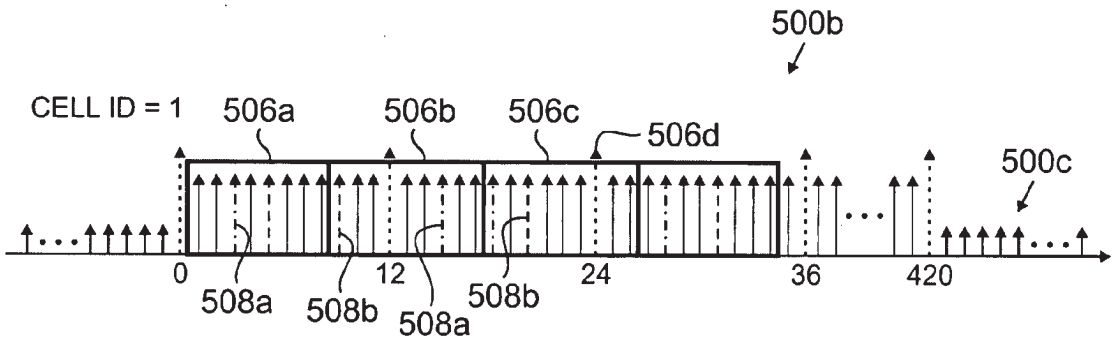


FIG. 5B

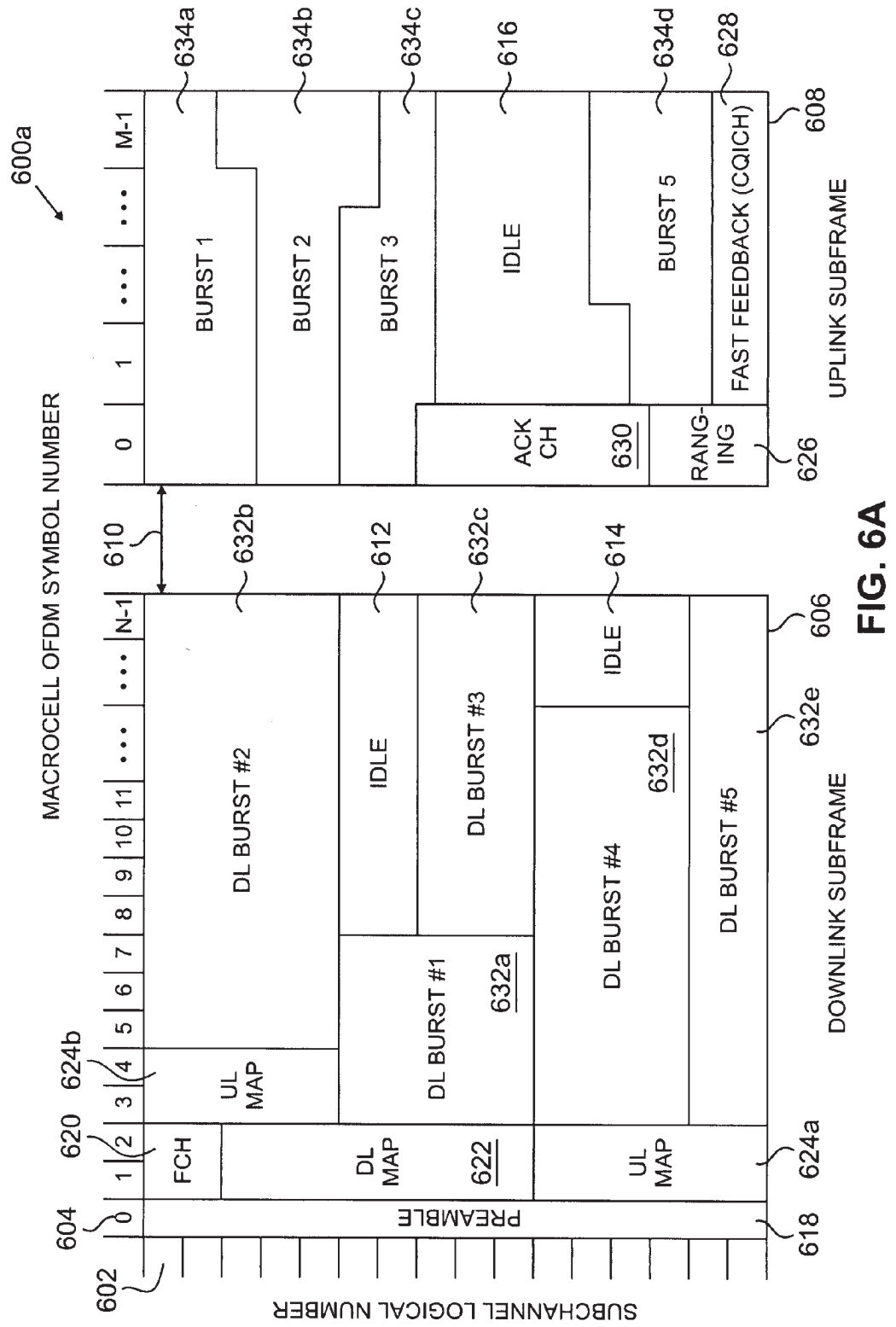

600a
MACROCELL OFDM SYMBOL NUMBER
SUBCHANNEL LOGICAL NUMBER
602
604
620
624b
624a
610
606
608
618
626
628
630
632a
632b
632c
632d
632e
612
614
634a
634b
634c
634d
616
PREAMBLE
FCH
DL MAP
UL MAP
DL BURST #1
DL BURST #2
DL BURST #3
DL BURST #4
DL BURST #5
IDLE
BURST 1
BURST 2
BURST 3
BURST 5
ACK CH
RANG-ING
FAST FEEDBACK (CQICH)
DOWNLINK SUBFRAME
UPLINK SUBFRAME

FIG. 6A

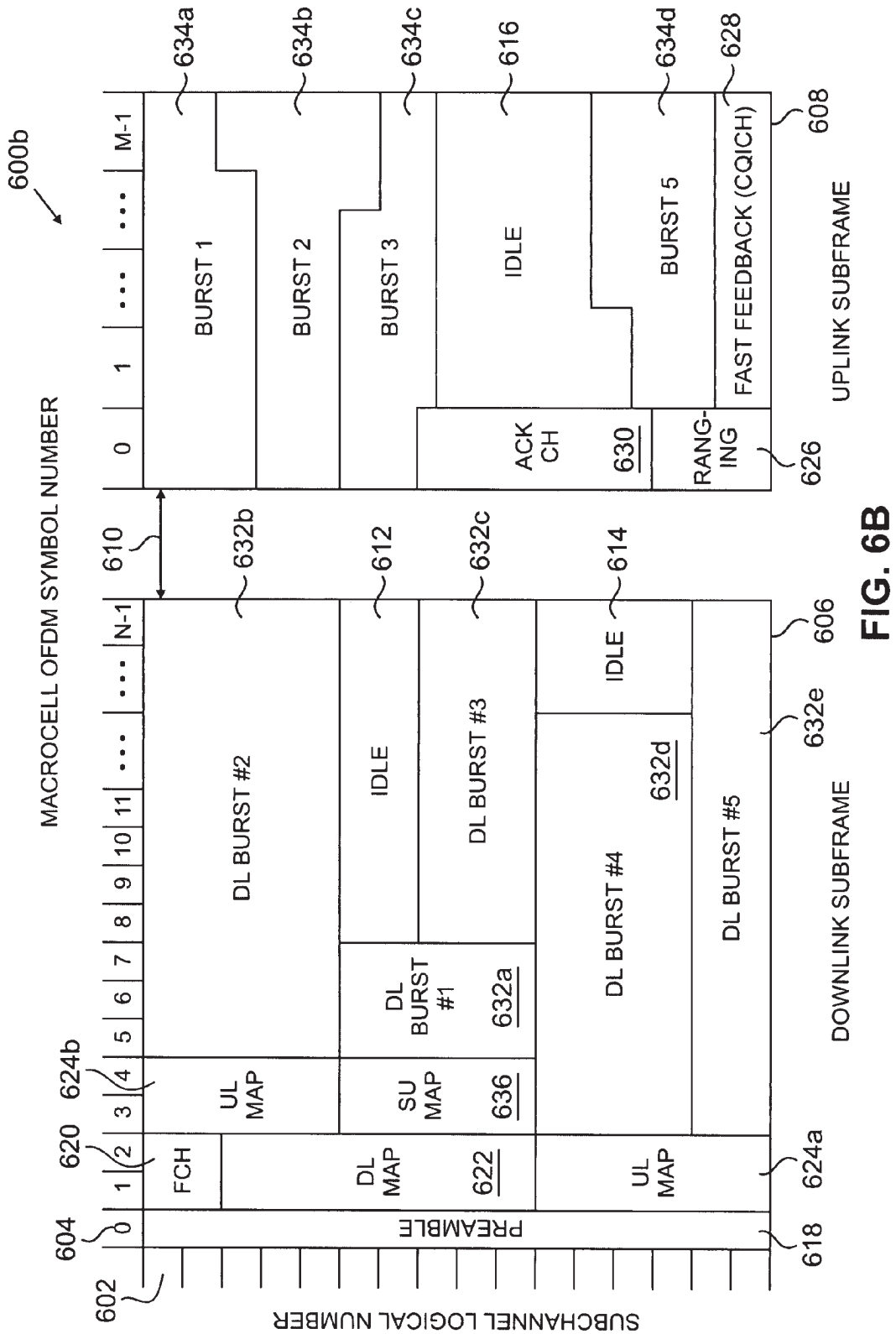

600b
MACROCELL OFDM SYMBOL NUMBER
SUBCHANNEL LOGICAL NUMBER
602
604
620
624b
624a
610
606
608
626
618
632a
632b
632c
632d
632e
634a
634b
634c
634d
636
622
630
612
614
616
628
PREAMBLE
FCH
DL MAP
UL MAP
SU MAP
DL BURST #1
DL BURST #2
DL BURST #3
DL BURST #4
DL BURST #5
IDLE
ACK CH
RANG-ING
BURST 1
BURST 2
BURST 3
BURST 5
FAST FEEDBACK (CQICH)
DOWNLINK SUBFRAME
UPLINK SUBFRAME

FIG. 6B

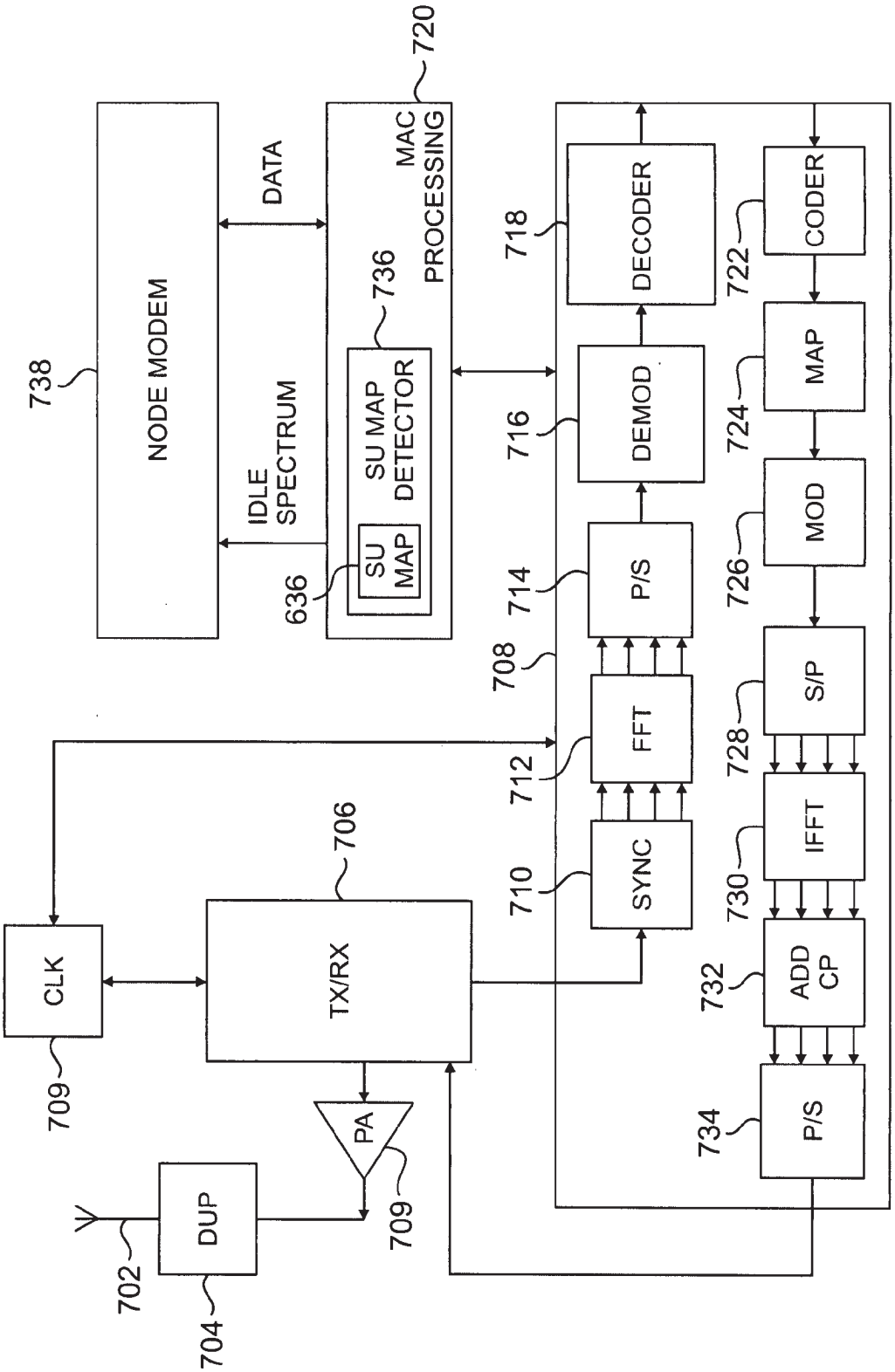

738
NODE MODEM
DATA
IDLE
SPECTRUM
720
MAC
PROCESSING
736
SU MAP
DETECTOR
636
SU
MAP
718
DECODER
716
DEMOD
714
P/S
708
FFT
712
SYNC
710
706
TX/RX
CLK
709
PA
709
DUP
702
704
722
CODER
724
MAP
726
MOD
728
S/P
730
IFFT
732
ADD
CP
734
P/S

FIG. 7

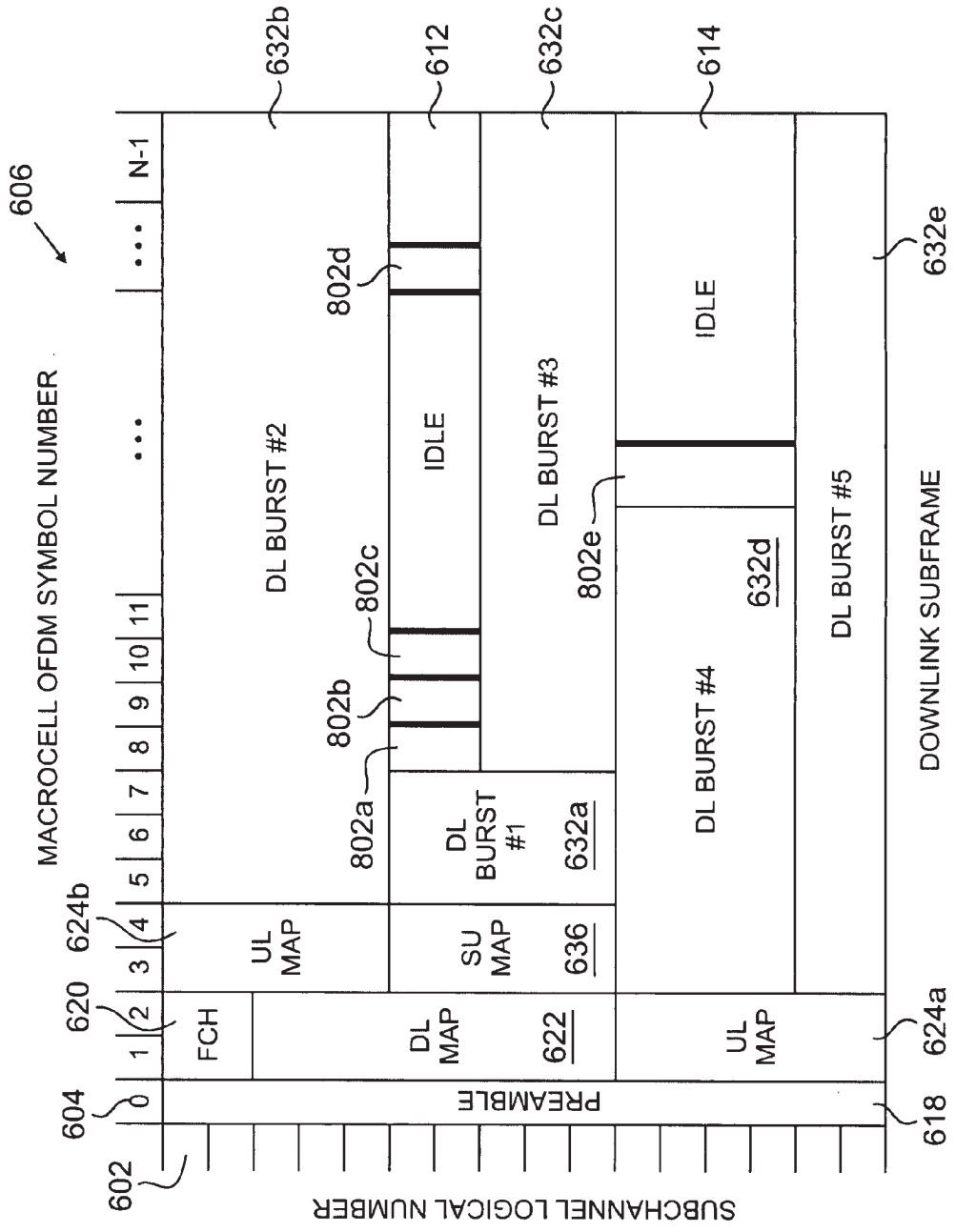

606
MACROCELL OFDM SYMBOL NUMBER
0
1
2
3
4
5
6
7
8
9
10
11
...
N-1
SUBCHANNEL LOGICAL NUMBER
602
604
620
624b
632b
612
632c
614
632e
618
624a
PREAMBLE
FCH
DL MAP
622
UL MAP
SU MAP
636
DL BURST #1
632a
DL BURST #2
DL BURST #3
DL BURST #4
DL BURST #5
IDLE
802a
802b
802c
802d
802e
632d
DOWNLINK SUBFRAME

FIG. 8A

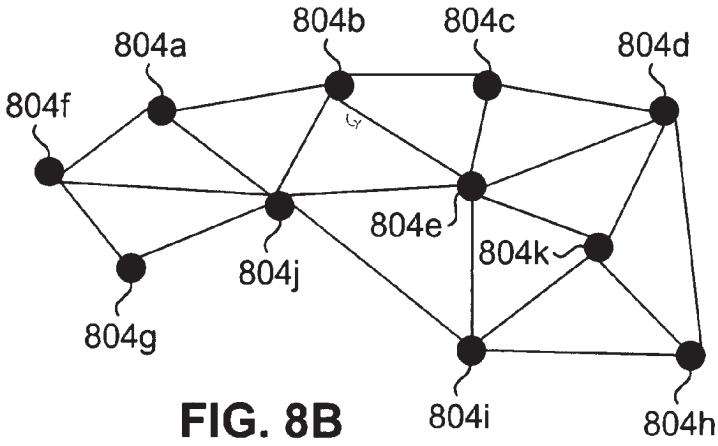

804a
804b
804c
804d
804f
804e
804k
804j
804g
804i
804h

FIG. 8B

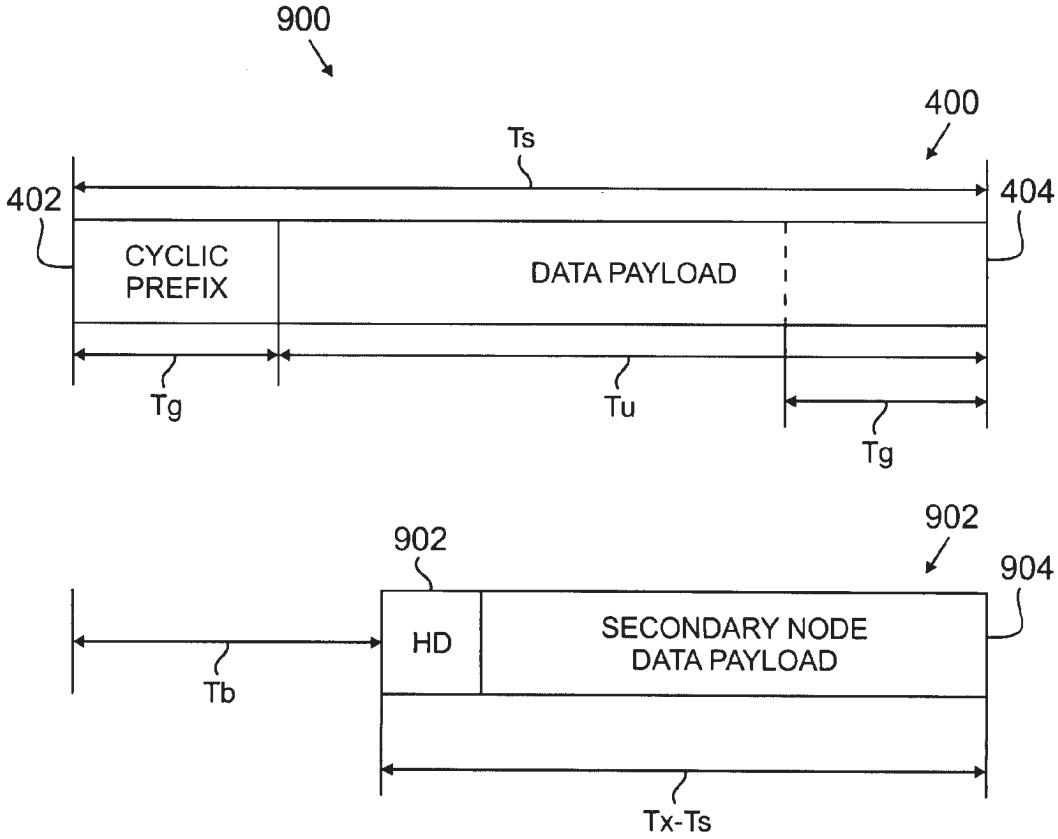

900
400
Ts
402
404
CYCLIC PREFIX
DATA PAYLOAD
Tg
Tu
Tg
902
902
904
HD
SECONDARY NODE DATA PAYLOAD
Tb
Tx-Ts

FIG. 9

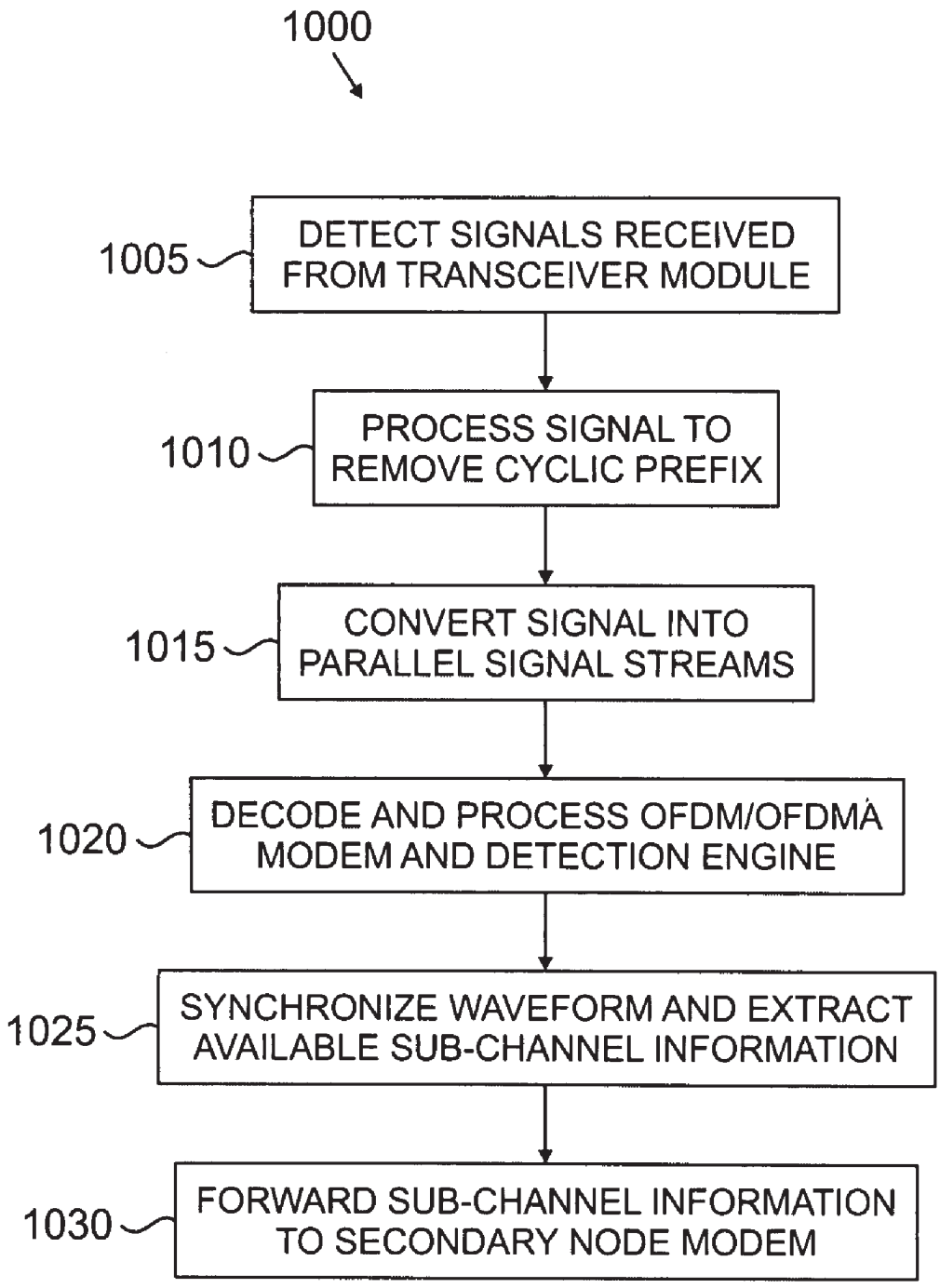

1000
1005
DETECT SIGNALS RECEIVED FROM TRANSCEIVER MODULE
1010
PROCESS SIGNAL TO REMOVE CYCLIC PREFIX
1015
CONVERT SIGNAL INTO PARALLEL SIGNAL STREAMS
1020
DECODE AND PROCESS OFDM/OFDMA MODEM AND DETECTION ENGINE
1025
SYNCHRONIZE WAVEFORM AND EXTRACT AVAILABLE SUB-CHANNEL INFORMATION
1030
FORWARD SUB-CHANNEL INFORMATION TO SECONDARY NODE MODEM

FIG. 10

SPECTRUM SHARING IN A WIRELESS COMMUNICATION NETWORK

CROSS-REFERENCE TO RELATED APPLICATION(S) AND CLAIM OF PRIORITY

[0001] The present application is related to U.S. Provisional Patent No. 60/858,644, filed Nov. 13, 2006, entitled "Method And Procedure For Spectrum Sharing In A WiMAX Network". U.S. Provisional Patent No. 60/858,644 is assigned to the assignee of the present application and is hereby incorporated by reference into the present application as if fully set forth herein. The present application hereby claims priority under 35 U.S.C. §119(e) to U.S. Provisional Patent No. 60/858,644.

TECHNICAL FIELD OF THE INVENTION

[0002] The present disclosure relates generally to communication networks and, in particular, to systems for spectrum sharing in wireless communication systems.

BACKGROUND OF THE INVENTION

[0003] Conventional fixed spectrum allocation schemes lead to significant spectrum under-utilization. For instance, experiments have indicated that as much as 62% of the spectrum below the 3 GHz band is idle even in the most crowded areas (e.g., near downtown Washington D.C. where both government and commercial spectrum usage is intensive). Such under-utilization and increasing demand for the radio spectrum suggest that a more effective spectrum allocation and utilization policy is necessary.

[0004] Currently, secondary users may use the licensed spectrum only when such use does not interfere with a primary user's communication. Such requirements imply that the use of the spectrum varies with time (i.e., dynamically changes), and is dependent on the load imposed by the primary users. Several conventional systems use multiple channels in wireless networks. However, such systems fail in dynamic spectrum access networks. For example, conventional systems assume that the set of available channels is static (i.e., the channels available for use are fixed at the time of network initiation). In multiple access wireless networks, however, such as Worldwide Interoperability for Microwave Access (WiMAX) with orthogonal frequency division multiple access (OFDMA) signaling, specified in IEEE-802.16e (2004) and IEEE-802.16 (2005), the set of available channels dynamically changes. Dynamic spectrum access networks operate in a multi-hop fashion and typically within an IEEE-802.16 or WiMAX network. Thus, conventional spectrum sharing systems and methods fail to address inter-operation with, for example, WiMAX waveforms.

[0005] There is therefore a need for spectrum sharing systems for use in dynamic spectrum sharing networks such as, for example, WiMAX networks.

SUMMARY OF THE INVENTION

[0006] The present disclosure provides systems and methods for spectrum sharing in wireless communication systems.

[0007] In one embodiment, the present disclosure provides a spectrum sharing system for use in a wireless communication system. The wireless communication system includes a primary user node and a secondary user node. The system includes a frame detector configured to detect a frame of a broadcast waveform and to extract subframe information identifying usable sub-carriers for the frame to the secondary user node. The secondary user node transmits data in a first one of usable sub-carriers identified in the subframe information.

[0008] In another embodiment, the present disclosure provides a method of spectrum sharing for use in a wireless communication network having a primary user node and a secondary user node. The method includes detecting a frame of a broadcast waveform and extracting subframe information identifying usable sub-carriers for the frame to the secondary user node. The method also includes transmitting data from the secondary user node in a first sub-carrier identified in the subframe information.

[0009] In still another embodiment, the present disclosure provides an apparatus for forming an ad hoc mesh network, for use in a wireless communication system. The apparatus includes a secondary user node having a node modem. The apparatus also includes a frame detector configured to detect a frame of a broadcast waveform and extract subframe information for the frame to the secondary user node. The secondary user node transmits data in a first unused sub-carrier identified in the subframe information.

[0010] Before undertaking the DETAILED DESCRIPTION OF THE INVENTION below, it may be advantageous to set forth definitions of certain words and phrases used throughout this patent document: the terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation; the term "or," is inclusive, meaning and/or; the phrases "associated with" and "associated therewith," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, or the like; and the term "controller" means any device, system or part thereof that controls at least one operation, such a device may be implemented in hardware, firmware or software, or some combination of at least two of the same. It should be noted that the functionality associated with any particular controller may be centralized or distributed, whether locally or remotely. Definitions for certain words and phrases are provided throughout this patent document, those of ordinary skill in the art should understand that in many, if not most instances, such definitions apply to prior, as well as future uses of such defined words and phrases.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a more complete understanding of the present disclosure and its advantages, reference is now made to the following description taken in conjunction with the accompanying drawings, in which like reference numerals represent like parts:

[0012] FIG. **1** is an exemplary wireless network suitable for spectrum sharing according to one embodiment of the present disclosure;

[0013] FIG. **2** is an exemplary block diagram of an orthogonal frequency-division multiplexing (OFDM) transmitter according to one embodiment of the present disclosure;

[0014] FIG. **3** is an exemplary block diagram of an OFDM receiver according to one embodiment of the present disclosure;

[0015] FIG. **4** depicts an exemplary OFDM symbol data payload inserted with a cyclic prefix (CP) for a given OFDM symbol period according to one embodiment of the present disclosure;

[0016] FIGS. **5**A and **5**B depict exemplary distributed sub-carrier allocations according to one embodiment of the present disclosure;

[0017] FIG. **6**A is an exemplary OFDMA frame structure for a time division duplex (TDD) implementation according to one embodiment of the present disclosure;

[0018] FIG. **6**B is an exemplary OFDMA frame structure for a TDD implementation with the addition of a secondary user MAP (SU MAP) subframe according to one embodiment of the present disclosure;

[0019] FIG. **7** is a simplified block diagram illustrating an exemplary system for the ad-hoc use of an OFDM/OFDMA spectrum by a secondary spectrum user according to one embodiment of the present disclosure;

[0020] FIG. **8**A is an exemplary OFDMA frame structure illustrating secondary node packet bursts occurring in unused OFDM symbol slots according to one embodiment of the present disclosure;

[0021] FIG. **8**B is an exemplary cluster of secondary nodes according to one embodiment of the present disclosure which may provide the secondary node packet bursts depicted in FIG. **8**A;

[0022] FIG. **9** depicts an exemplary OFDM symbol data payload relative to a secondary node data payload for a given OFDM symbol period according to one embodiment of the present disclosure; and

[0023] FIG. **10** is a somewhat simplified flow diagram illustrating an exemplary method of spectrum sharing in a wireless communication network according to one embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0024] FIGS. **1** through **10**, discussed below, and the various embodiments used to describe the principles of the present disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of the present disclosure may be implemented in any suitably arranged wireless communication system.

[0025] FIG. **1** illustrates an exemplary wireless network **100** suitable for synchronous spectrum sharing according to one embodiment of the present disclosure. In the illustrated embodiment, wireless network **100** includes base station (BS) **101**, base station (BS) **102**, and base station (BS) **103**. Base station **101** communicates with base station **102** and base station **103**. Base station **101** also communicates with Internet protocol (IP) network **130**, such as the Internet, a proprietary IP network, or other data network.

[0026] Base station **102** provides wireless broadband access to network **130**, via base station **101**, to a first plurality of subscriber stations within coverage area **120** of base station **102**. The first plurality of subscriber stations includes subscriber station (SS) **111**, subscriber station (SS) **112**, subscriber station (SS) **113**, subscriber station (SS) **114**, subscriber station (SS) **115** and subscriber station (SS) **116**. In an exemplary embodiment, SS **111** may be located in a small business (SB), SS **112** may be located in an enterprise (E), SS **113** may be located in a WiFi hotspot (HS), SS **114** may be located in a first residence, SS **115** may be located in a second residence, and SS **116** may be a mobile (M) device.

[0027] Base station **103** provides wireless broadband access to network **130**, via base station **101**, to a second plurality of subscriber stations within coverage area **125** of base station **103**. The second plurality of subscriber stations includes subscriber station **115** and subscriber station **116**. In alternate embodiments, base stations **102** and **103** may be connected directly to the Internet by means of a wired broadband connection, such as an optical fiber, DSL, cable or T1/E1 line, rather than indirectly through base station **101**.

[0028] In other embodiments, base station **101** may be in communication with either fewer or more base stations. Furthermore, while only six subscriber stations are shown in FIG. **1**, it is understood that wireless network **100** may provide wireless broadband access to more than six subscriber stations. It is noted that subscriber station **115** and subscriber station **116** are on the edge of both coverage area **120** and coverage area **125**. Subscriber station **115** and subscriber station **116** each communicate with both base station **102** and base station **103** and may be said to be operating in handoff mode, as known to those of skill in the art.

[0029] In an exemplary embodiment, base stations **101-103** may communicate with each other and with subscriber stations **111-116** using an IEEE-802.16 wireless metropolitan area network standard, such as, for example, an IEEE-802.16e standard. In another embodiment, however, a different wireless protocol may be employed, such as, for example, a HIPERMAN wireless metropolitan area network standard. Base station **101** may communicate through direct line-of-sight or non-line-of-sight with base station **102** and base station **103**, depending on the technology used for the wireless backhaul. Base station **102** and base station **103** may each communicate through non-line-of-sight with subscriber stations **111-116** using OFDM and/or OFDMA techniques.

[0030] Base station **102** may provide a T1 level service to subscriber station **112** associated with the enterprise and a fractional T1 level service to subscriber station **111** associated with the small business. Base station **102** may provide wireless backhaul for subscriber station **113** associated with the WiFi hotspot, which may be located in an airport, café, hotel, or college campus. Base station **102** may provide digital subscriber line (DSL) level service to subscriber stations **114**, **115** and **116**.

[0031] Subscriber stations **111-116** may use the broadband access to network **130** to access voice, data, video, video teleconferencing, and/or other broadband services. In an exemplary embodiment, one or more of subscriber stations **111-116** may be associated with an access point (AP) of a WiFi WLAN. Subscriber station **116** may be any of a number of mobile devices, including a wireless-enabled laptop computer, personal data assistant, notebook, handheld device, or other wireless-enabled device. Subscriber stations **114** and **115** may be, for example, a wireless-enabled personal computer, a laptop computer, a gateway, or another device.

[0032] Dotted lines show the approximate extents of coverage areas **120** and **125**, which are shown as approximately circular for the purposes of illustration and explanation only. It should be clearly understood that the coverage areas

associated with base stations, for example, coverage areas **120** and **125**, may have other shapes, including irregular shapes, depending upon the configuration of the base stations and variations in the radio environment associated with natural and man-made obstructions.

[0033] Also, the coverage areas associated with base stations are not constant over time and may be dynamic (expanding or contracting or changing shape) based on changing transmission power levels of the base station and/or the subscriber stations, weather conditions, and other factors. In an embodiment, the radius of the coverage areas of the base stations, for example, coverage areas **120** and **125** of base stations **102** and **103**, may extend in the range from less than 2 kilometers to about fifty kilometers from the base stations.

[0034] As is well known in the art, a base station, such as base station **101**, **102**, or **103**, may employ directional antennas to support a plurality of sectors within the coverage area. In FIG. **1**, base stations **102** and **103** are depicted approximately in the center of coverage areas **120** and **125**, respectively. In other embodiments, the use of directional antennas may locate the base station near the edge of the coverage area, for example, at the point of a cone-shaped or pear-shaped coverage area.

[0035] The connection to network **130** from base station **101** may comprise a broadband connection, for example, a fiber optic line, to servers located in a central office or another operating company point-of-presence. The servers may provide communication to an Internet gateway for internet protocol-based communications and to a public switched telephone network gateway for voice-based communications. In the case of voice-based communications in the form of voice-over-IP (VoIP), the traffic may be forwarded directly to the Internet gateway instead of the PSTN gateway. The servers, Internet gateway, and public switched telephone network gateway are not shown in FIG. **1**. In another embodiment, the connection to network **130** may be provided by different network nodes and equipment.

[0036] FIG. **2** is exemplary block diagram of a typical OFDM/OFDMA transmitter **200** according to one embodiment of the present disclosure. Transmitter **200** constructs, for example, an OFDM/OFDMA composite signal by first passing the serial output of a formatted, encoded, interleaved data signal through serial-to-parallel converter **202**. Serial-to-parallel converter **202** separates each data signal into parallel data streams (e.g., $X_0 \ldots X_{N-1}$). A mapping function (MAP) within serial-to-parallel converter **202** maps each parallel data stream into I and Q modulation symbols, which are then applied to inverse fast Fourier transform (IFFT) block **204**. The subcarrier separation is preferably an inverse of the OFDM symbol duration. IFFT block **204** computes the IFFT of each data stream and passes the output to parallel-to-serial and cyclic prefix (CP) block **206**.

[0037] Parallel-to-serial and CP block **206** combines each parallel data stream into a data signal and introduces CP to aid in eliminating inter-symbol interference (ISI) and inter-block interference as later described in detail herein. For operation in time division duplex (TDD) mode, parallel-to-serial and CP block **206** inserts a guard interval (GI) into the signal. The output of parallel-to-serial and CP block **206** is passed to windowing matched filter **208** and then to up-converter block **210**. The output of up-converter block **210** is then passed to RF section block **212** and transmitted via antenna **214**. Accordingly, in the example shown in FIG. **2**, user data signals may be represented by a set of 2N sub-carriers. In addition, pilot plus control signaling may be represented by a set of M separate sub-carriers. In one embodiment, N may be a power of 2 (e.g., $N=2^J$) and M may be a different power of 2 (e.g., $M=2^K$, where $K<J$)

[0038] FIG. **3** is an exemplary block diagram of a typical OFDM/OFDMA receiver **300** according to one embodiment of the present disclosure. Receiver **300** detects the transmitted symbols and essentially reverses the process implemented by transmitter **200** described above. For example, the signal transmitted by antenna **214** is received by antenna **302**. The signal is passed to transceiver and CP remove block **304**. Transceiver and CP remove block **304** removes the CP from the signal and passes the signal to serial-to-parallel block **306**. Serial-to-parallel block **306** separates the data signal into parallel data streams (e.g., $X_0 \ldots X_{N-1}$). A MAP within serial-to-parallel converter **201** maps each parallel data stream into I and Q modulation symbols, which are then passed to fast Fourier transform (FFT) block **308**. The output of FFT block **308** is then passed to parallel-to-serial and decoder block **310** and then output as desired.

[0039] FIG. **4** illustrates OFDM symbol **400** in which CP **402** is inserted into data payload **404** according to one embodiment of the present disclosure where the total symbol period (T_s) is greater than the sum of the guard times (T_g) and the useful symbol period (T_u). OFDM waveforms provide increased symbol duration (i.e., T_s and T_u) and thus improve the robustness of OFDM to delay spread. Accordingly, with the introduction of CP **402**, ISI can be eliminated as long as the duration of CP **402** is longer than the channel delay spread. CP **402** is typically a repetition of the last samples of data portion of the block that is appended to the beginning of data payload **404** as shown in FIG. **4**. CP **402** prevents inter-block interference and makes the channel appear circular. CP **402** therefore permits low-complexity frequency domain equalization. While CP **402** somewhat reduces bandwidth efficiency, the impact of CP **402** is similar to the "roll-off factor" in raised-cosine filtered single-carrier systems. Notably, OFDM has a very sharp, almost "brick-wall" spectrum. Thus, a large fraction of the allocated channel bandwidth may be utilized for data transmission and for moderating the loss in efficiency due to CP **402**.

[0040] Similar attributes exist for OFDMA. The OFDMA symbol structure consists of three types of sub-carriers: (1) Data sub-carriers for data transmission; (2) Pilot sub-carriers for estimation and synchronization purposes; and (3) Null sub-carriers for no transmission (typically used for guard bands and DC carriers). The active sub-carriers (i.e., data and pilot sub-carriers) are generally grouped into subsets of sub-carriers called sub-channels.

[0041] FIGS. **5**A and **5**B depict exemplary distributed sub-carrier allocations **500***a* and **500***b* (collectively referred to herein as distributed sub-carrier allocation **500**) associated with a Fourier fast transform (FFT) bin number **500***c* according to one embodiment of the present disclosure. FIGS. **5**A and **5**B depict distributed sub-carrier allocations **500** in, for example, Cell ID **0** and Cell ID **1**, respectively, and are referred to herein for illustration purposes only.

[0042] FIGS. **5**A and **5**B illustrate a sub-carrier allocation comprised of three types: (a) Data sub-carriers **504** and **508** for data transmission; (b) Pilot sub-carriers **500***d* for estimation and synchronization purposes; and (c) Null sub-carriers **500***c* used for guard bands and DC carriers. In one

implementation, a fixed number of pilot sub-carriers **500***d* are evenly distributed among the active sub-carriers that comprise (a) and (b). As later described herein in more detail, a permutation process draws a sub-carrier pseudo-randomly from permutation groups **502** to form a sub-channel. This allocation of sub-carriers to sub-channels in a pseudorandom fashion is done so that there is a high probability that the sub-carriers for a given sub-channel in a certain cell are different than sub-carriers for that same sub-channel in another cell (for example the sub-carriers in sub-channel **1** in cell **1** will be different than the sub-carriers in sub-channel **1** in cell **2**). This pseudorandom permutation provides an interference averaging effect further reducing the adverse effects of cell to cell interference.

[0043] FIG. **5**A shows four groups of sub-carriers, groups **506***a*, **506***b*, **506***c* and **506***d* (collectively referred to herein as groups **506**). Each of the sub-carriers depicted in groups **506** are associated with a specific sub-channel, sub-channels **508***a* and **508***b* (collectively referred to herein as sub-channels **508**). Although only two sub-channels **508** are shown in FIG. **5**B, it should be understood that any suitable number of sub-channels **508** may be apparent. Each of sub-channels **508** generally includes forty-eight (48) data sub-carriers.

[0044] Similarly, FIG. **5**B illustrates four groups of sub-carriers, groups **506***a*, **506***b*, **506***c* and **506***d* (collectively referred to herein as permutation groups **506**). Each of the sub-carriers depicted in groups **506** are associated with a specific sub-channel, sub-channels **508***a* and **508***b* (collectively referred to herein as sub-channels **508**). Although only two sub-channels **508** are shown in FIG. **5**B, it should be understood that any suitable number of sub-channels **508** may be apparent. Each of sub-channels **508** generally includes forty-eight (48) data sub-carriers.

[0045] The WIMAX OFDMA physical layer (PHY) generally supports sub-channelization in both the up-link (UL) and the down-link (DL). In certain standards such as, for example, IEEE-802.16-2004 and IEEE-802.16-2005, the minimum frequency-time resource unit of sub-channelization is one slot. One slot is typically equal to forty-eight (48) data tones or sub-carriers. The two types of sub-carrier permutations for sub-channelization are the diversity permutation and the contiguous permutation. The diversity permutation draws sub-carriers pseudo-randomly to form a sub-channel and provides frequency diversity and inter-cell interference averaging.

[0046] The diversity permutations include downlink (DL) FUSC (Fully Used Sub-Carrier), DL PUSC (Partially Used Sub-Carrier) and uplink (UL) PUSC and additional optional permutations. With DL PUSC, for each pair of OFDM symbols, the available or usable sub-carriers are grouped into clusters containing fourteen (14) contiguous sub-carriers per symbol, with pilot and data allocations in each cluster in the even and odd symbols.

[0047] A re-arranging scheme is used to form groups of clusters such that each one of the groups (e.g., groups **502** and **506**) is made up of clusters that are distributed throughout the sub-carrier space (e.g., distributed sub-carrier allocation **500**). A sub-channel (e.g., sub-channels **504** and **508**) in a group (e.g., groups **502** and **506**) contains two (2) clusters and is comprised of forty-eight (48) data sub-carriers and eight (8) pilot sub-carriers.

[0048] Analogous to the cluster structure for DL, a tile structure is defined for the UL PUSC. The available sub-carrier space (e.g., distributed sub-carrier allocation **500**) is split into tiles and six (6) tiles, chosen from across the entire spectrum by means of a re-arranging/permutation scheme, are grouped together to form a slot. The slot is comprised of forty-eight (48) data sub-carriers and twenty-four (24) pilot sub-carriers in three (3) OFDM symbols.

[0049] The IEEE-802.16-2005 Wireless MAN OFDMA mode is based on the concept of scalable OFDMA (S-OFDMA). S-OFDMA supports a wide range of bandwidths to flexibly address the need for various spectrum allocation and usage model requirements. The scalability of the OFDMA system is accomplished by adjusting the FFT size while fixing the sub-carrier frequency spacing at 10.94 kHz. Since the resource unit sub-carrier bandwidth and symbol duration is fixed, the impact to higher layers is minimal when scaling the bandwidth. An exemplary set of embodiments for S-OFDMA parameters is listed in TABLE 1 below.

TABLE 1

SCALABLE OFDMA PARAMETERS OF WIMAX

Parameters	Values			
System Channel Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (F_p in MHz)	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	512	1024	2048
Number of Sub-Channels	2	8	16	32
Sub-Carrier Frequency Spacing	10.94 kHz			
Useful Symbol Time ($T_b = 1/f$)	91.4 microseconds			
Guard Time ($T_g = T_b/8$)	11.4 microseconds			
OFDMA Symbol Duration ($T_s = T_b + T_g$)	102.9 microseconds			
Number of OFDMA Symbols (5 ms Frame)	48			

[0050] FIG. **6**A illustrates WiMAX OFDM/OFDMA broadcast frame **600***a* for TDD implementation according to one embodiment of the present disclosure. Broadcast frame **600***a* illustrates the relationship between a given sub-channel logical number **602** and a macrocell OFDM/OFDMA time slot or symbol number **604**. Broadcast frame **600***a* is further divided into and supports sub-channelization in DL subframe **606** and UL subframe **608**. DL sub-frame **606** and UL subframe **608** are separated by transmit/receive transition gaps (TTG) and receive/transmit transition gaps (RTG) (collectively referred to herein as transition gap **610**). Transition gap **610** prevents DL and UL transmission collisions.

[0051] DL subframe **606** and UL subframe **608** include several unused or idle spectrum such as, for example, idle blocks **612**, **614** and **616**. Although a specified number of idle blocks is illustrated in DL subframe **606** and UL subframe **608**, it should be understood that any number of idle blocks in fact be available in accordance with the present disclosure.

[0052] Control information for broadcast frame **600***a* is used to ensure optimal system operation. For example, control information may include preamble **618**, frame control head (FCH) **620**, DL-MAP **622**, UL-MAPs **624***a* and **624***b* (collectively referred to herein as UL-MAP **624**), UL ranging sub-channel **626**, UL channel quality indicator channel (CQICH) **628** and UL acknowledge sub-channel (ACK) **630**. Preamble **618** is used for synchronization is the first symbol number **604** of broadcast frame **600***a*. FCH **620** follows preamble **618** and provides frame configuration information such as MAP message length, coding scheme and usable sub-channels.

[0053] DL-MAP **622** and UL-MAP **624** provide sub-channel allocation and other control information for DL subframe **606** and UL subframe **608**, respectively. UL ranging sub-channel **626** is allocated for mobile stations (MS) to perform closed-loop time, frequency, and power adjustment as well as bandwidth requests. UL CQICH **628** is allocated for the MS to feedback channel state information, while UL ACK **630** is allocated for the MS to feedback DL (hybrid automatic request) HARQ acknowledgement.

[0054] Finally, DL subframe **606** is shown with several DL data bursts **632***a*, **632***b*, **632***c*, **632***d* and **632***e* (collectively referred to as DL data bursts **632**). It should be understood that any suitable number of DL data bursts **632** may be included in DL subframe **606**. Similarly, UL subframe **608** is shown with several UL data bursts **634***a*, **634***b*, **634***c* and **634***d*) (collectively referred to herein as UL data bursts **634**). It should be understood that any suitable number of UL data bursts **634** may be included in UL subframe **606**.

[0055] In one embodiment, the present disclosure provides a system for secondary users to dynamically access available channels (e.g., in "white space") to broadcast IEEE-802.16 or WiMAX signals. The system provides such access to secondary users on a non-interfering or leasing basis. The term "secondary user" generally refers to a spectrum user who is not an owner of the spectrum but who operates in the spectrum based on agreements/etiquettes imposed by the primary users or regulatory entities.

[0056] The available spectrum and/or sub-carriers for use by the secondary users are time varying and location-dependent because of the traffic load and distribution of the primary users. Thus, in one embodiment, the present disclosure may use a formatted message in the downlink OFDMA frame that identifies spectrum available for use by the secondary users. In another embodiment, the present disclosure provides that the secondary users opportunistically form ad-hoc mesh network communications in fixed or mobile scenarios.

[0057] FIG. **6**B depicts an exemplary WiMAX OFDMA frame structure **600***b* according to one embodiment of the present disclosure. Frame structure **600***b* is similar to frame structure **600***a* described above. Frame structure **600***b* includes subframe or Secondary User Map (SU MAP) **636**. SU MAP **636** identifies those sub-carriers that are usable by secondary users. TABLE 2 is an example frame format for SU MAP **636** according to embodiment of the present disclosure.

TABLE 2

EXAMPLE OF SU MAP FRAME FORMAT

Syntax	Size	Notes
SU_MAP( ) {		
N_SLOTS	8 bits	The number of idle slots available in the frame.
For (n=0;n<N_SLOTS;n++){		
PERM_Indicator	1 bit	Indicates whether or not open slot 'n', as defined by the parameters below, is available in all future frames.
UL-DL Indicator	1 bit	Indicates whether open slot 'n' is in the Up Link Frame ('0') or the Down Link Frame ('1').
OFDMA Symbol Offset	8 bits	The offset of the OFDMA symbol in which slot n starts, measured in OFDMA symbols from the beginning of frame in which open slot 'n' is included (either UL or DL, depending on the UL-DL Indicator).
Subchannel Offset	6 bits	The lowest index OFDMA subchannel in open slot n, starting from subchannel '0'
No. OFDMA Symbols	7 bits	The number of OFDMA symbols that make up open slot 'n'.
No. Channels	6 bits	The number of subchannels, with subsequent indexes, that make up slot 'n'

[0058] In one embodiment, SU MAP **636** identifies the groupings of sub-carriers into one or more SU sub-channels. The format of the SU sub-channel identifies the SU pilot sub-carriers used for channel estimation by the secondary user terminals. While FIG. **6**B illustrates the location of the SU MAP **636** as adjacent to DL MAP **622** and UL MAP **624***b*, the location of SU MAP **636** within OFDMA frame structure **600***b* may be in any suitable location. Moreover, SU MAP **636** may be occupied by any suitable number of sub-channels and symbol periods. Preferably, the size of SU MAP **636** is known by the secondary user or users in one embodiment of the present disclosure.

[0059] FIG. **7** is a somewhat simplified block diagram illustrating system **700** for ad-hoc use of OFDM/OFDMA spectrum by a secondary user according to one embodiment of the present disclosure. System **700** includes an antenna **702** to receive and transmit signals. Antenna **702** is operably connected to a suitable duplexer **704**.

[0060] When antenna **702** receives a signal, duplexer **704** passes the signal to transceiver **706**. Transceiver **706** may be any suitable transceiver such as, for example, a radio frequency integrated circuit (RFIC) transceiver. Transceiver **706** removes the CP from the signal and passes the signal to

processing block **708**. Processing block **708** and transceiver **706** may be synchronized using clock/synchronizer module **709**.

[0061] While in processing block **708**, synchronizer **710** synchronizes and then separates the data signal into parallel data streams such as, for example, $X_0 \ldots X_{N-1}$. A MAP within synchronizer **710** maps each parallel data stream into I and Q modulation symbols, which are then passed to fast Fourier transform (FFT) block **712**. The output of FFT block **712** is then passed to parallel-to-serial block **714**. The output of parallel-to-serial block **714** is passed to demodulator **716** where the signal is demodulated and subsequently passed on to decoder block **718**. The output of the decoder block is then passed to MAC processing block **720**. It should be understood that processing block **708** may be any suitable signal processing circuit.

[0062] Similarly, before antenna **702** can transmit a signal from MAC processing block **720**, the OFDM/OFDMA composite signal generally passes through processing block **708**. The composite signal is coded in coding block **722** and mapped using mapping block **724**. The output of mapping block **724** is modulated in modulation block **726** and then passed through serial-to-parallel converter **728**. Accordingly, the OFDM/OFDMA composite signal is a formatted, encoded and interleaved data signal. Serial-to-parallel converter **728** separates each data signal into parallel data streams (e.g., $X_0 \ldots X_{N-1}$). A mapping function (MAP) within serial-to-parallel converter **728** maps each parallel data stream into I and Q modulation symbols, which are then applied to inverse fast Fourier transform (IFFT) block **730**. The subcarrier separation is preferably an inverse of the symbol rate.

[0063] IFFT block **730** computes the IFFT of each data stream and passes the output to cyclic prefix (CP) block **732**. CP block **732** introduces CP to aid in eliminating inter-symbol interference (ISI) and inter-block interference as described in detail herein. The parallel-to-serial block **734** combines each parallel data stream into a data signal and sums the multiple sub-carriers to the transmission frequency. For operation in time division duplex (TDD) mode, CP block **732** inserts a guard interval (GI) into the signal. The output of parallel-to-serial **736** is passed to windowing matched filter (not shown) and then to transceiver **706**. The signal is passed to power amplifier **740**, duplexer **704** before being transmitted by antenna **702**.

[0064] Still referring to FIG. **7**, suppose a secondary user or users detect a broadcast OFDMA waveform. The secondary user first synchronizes the waveform using, for example, synchronizer **710**, to an OFDMA frame, such as OFDMA frame **600***b*. The secondary user accordingly extracts information from SU MAP **636** stored in, for example, SU MAP detector **736**. The extracted information, which may include, for example, information on available spectrum and SU sub-channels, is sent to MAC processing block **720**. MAC processing block **720** forwards the available spectrum and SU sub-channel information to the node controller or node modem **738**. Node modem **738** may also include additional routing protocols. Node modem **738** may be any suitable node controller or modem including, for example, MANET node controllers.

[0065] At this point, if a secondary user has data to transmit, the secondary user transmits the data to a neighboring secondary node or nodes in the idle spectrum space as later described herein in conjunction with FIGS. **8**A and **8**B. For example, the SUM MAP detector **736** sends idle block information to node modem **738** in response to the secondary user's transmitting need. In one scenario, the secondary user or users may transmit a signal identical or substantially identical to the OFDMA signal used by the primary users. In another scenario, the secondary user uses a signal that does not exceed the spectrum allowed by idle sub-carriers. Transmission by the ad-hoc node within the UL idle spectrum may similarly be conducted. If a secondary user does not have data to transmit, the secondary user listens for data symbols transmitted by neighboring secondary nodes on idle sub-carriers during the idle symbol periods.

[0066] FIG. **8**A is an expanded view of DL subframe **606** of broadcast frame **600***b* shown with secondary node data bursts **802***a*, **802***b*, **802***c*, **802***d* and **802***e* (collectively referred to herein as secondary node data bursts **802**) according to one embodiment of the present disclosure. Secondary node data bursts **802** are located in unused symbol numbers **604**. For example, secondary node data burst **802***a* occurs in idle block **612** and specifically within the "8th" symbol number **604**.

[0067] Similarly, secondary node data burst **802***b* occurs in idle block **612** and specifically within the "9th" symbol number **604**. Likewise, secondary node data burst **802***c* occurs in idle block **612** and specifically within the "10th" symbol number **604**. Secondary node data burst **802***d* occurs in idle block **612** between the "11th" symbol number **604** and the "N−1" symbol number **604**. As still another example, secondary node data burst **802***e* occurs in idle block **614** within some symbol number **604** between the "11th" symbol number **604** and the "N−1" symbol number **604**.

[0068] FIG. **8**B illustrates an example cluster of secondary nodes **804***a*-**804***k* (collectively referred to herein as secondary nodes **804**). As one example, secondary node **804***a* may have transmitted secondary node data burst **802***a* in idle block **612**, while secondary node **804***b* may have transmitted secondary node data burst **802***b* in idle block **612**. At the same time, secondary node **804***c* may have transmitted secondary node data burst **802***c* in idle block **612** and secondary node **804***d* may have transmitted secondary node data burst **802***d* in idle block **612**. Similarly, secondary node **804***e* may have transmitted secondary node data burst **802***e* in idle block **614**. It should be understood that any suitable number and combinations of secondary nodes **804** may transmit data into idle block **612** and **614** at the same time.

[0069] Each one of secondary user nodes **804** uses an OFDM/OFDMA frame detector **402** to synchronize to broadcast frame **600**, and to detect, for example, preamble **618**, DL-MAP **622** and UL-MAP **624**. Although there are a specific number of secondary user nodes **804** and secondary shown in FIG. **8**B, any suitable number of secondary user nodes **804** and secondary node data bursts **802** may be used in accordance with the present disclosure.

[0070] DL-MAP **622** and UL-MAP **624** provide sub-channel allocation and other control information for DL subframe **606** and UL subframe **608**, respectively. Thereby, each one of secondary user nodes **804** can ascertain which set of sub-carriers and symbol number **604** will be idle or unassigned during a given OFDM/OFDMA frame, such as broadcast frame **600**. If one of secondary nodes **804** has no data to transmit, that secondary node **804** listens for data symbols transmitted by neighboring secondary nodes **804** on

idle sub-carriers during the idle symbol periods (e.g., idle blocks **612**, **614** and **616**). On the other hand, if one of secondary nodes **804** has data to transmit, that secondary node **804** transmits data transmitted to neighboring secondary nodes **804** on idle sub-carriers during the idle symbol periods for the down-link as illustrated by FIG. **8**A. Transmission by the ad-hoc or secondary node **804** within up-link idle spectrum is similarly accomplished.

[0071] In one embodiment of the present disclosure, the secondary node **804** starts transmission after the passage of a guard time (T_9), such as in the ALOHA scheme. In another embodiment of the present disclosure, the transmitting node determines if another secondary node **804** is already transmitting in unassigned sub-carriers in symbol number **604** by conventional carrier sense multiple access (CSMA) techniques.

[0072] As shown in FIGS. **8**A and **8**B, two secondary nodes **804** may transmit simultaneously in the same symbol number **604** in different sub-carriers. If unassigned sub-carriers are found to be in use by other secondary nodes **804**, other secondary nodes **804** waits for the next idle block (e.g., idle block **612**, **614** or **616**) and repeats the access process.

[0073] In one embodiment according to the present disclosure, the battery life for battery-powered secondary nodes **804** may be extended. For example, secondary nodes **804** can power-down the transmitter circuitry when there is no data to transmit. Furthermore, secondary nodes **804** can power-down the receiver circuitry and other non-essential circuits during symbol number **604** when there are no idle sub-carriers. Secondary node **804** powers up at the appropriate time to receive the OFDM frame, DL-MAP and UL-MAP.

[0074] FIG. **9** illustrates the relative relationship **900** between the symbol periods of OFDM symbol **400** (which as described earlier in conjunction with the description accompanying FIG. **4**) and the symbol period or length (T_x) **902** of secondary node data burst **802**. Symbol period **902** is preferably kept less than or equal to in time duration of OFDM symbol period (T_s). The header (HD) and secondary node data burst or payload **904** may use a variable length symbol format. However, a shorter symbol period (T_x) implies a greater subcarrier spacing if the secondary node modulation is based on OFDM as well. Thus, as seen in FIG. **9**, the symbol period (T_x) for symbol **902** is generally about "T_b" less than the same for OFDM symbol **400**.

[0075] FIG. **10** is a somewhat simplified flow diagram of method **100** for spectrum sharing in WiMAX networks according to one embodiment of the present disclosure. In step **1005**, an OFDM/OFDMA frame detector detects signals received from a transceiver module, such as transceiver **706**.

[0076] In step **1010**, the signal is passed to a synchronizer, such as synchronizer module **710**, where the CP is removed and the signal is synchronized with an OFDM/OFDMA frame such as, for example, frame structure **600***b* according to one embodiment of the present disclosure. The signal is also separated into parallel data streams (e.g., $X_0 \ldots X_{N-1}$). A MAP within synchronizer **710** maps each data stream into I and Q modulation symbols.

[0077] In step **1015**, the signal is then passed to an FFT block, such as FFT block **712**. In step **1020**, the data streams are passed to parallel-to-serial converter, such as parallel-to-serial block **714**. The signal is demodulated in a demodulator, such as demodulator **716**, and then output to a decoder, such as decoder block **718**.

[0078] In step **1025**, a processing module, such as MAC processing block **720**, and an SU MAP detector, such as SU MAP detector **736**, detects the decoded signal and extracts the SU sub-channel information for that frame from an SU MAP, such as SU MAP **636**. In step **1030**, MAC processing block **720** then outputs the signal and SU sub-channel information to a node modem, such as node modem **738**.

[0079] Accordingly, method **1000** provides secondary users with dynamic access to channel availability through the use of an SU MAP detector **736** and SU MAP **636** in broadcast wireless waveforms such as, for example, in IEEE-802.16 or WiMAX, in a non-interfering or leasing basis.

[0080] In describing method **1000** and system **700**, "secondary users" generally refers to spectrum users who are not owners of the spectrum but who operate in the spectrum based on agreements/etiquettes imposed by the primary users or regulatory entities. For example, using method **1000**, secondary users of system **700** dynamically form ad-hoc mesh network communications in fixed or mobile scenarios. In other words, secondary users refer to spectrum users who are not owners of the spectrum but who operate in the spectrum based on agreements/etiquettes imposed by the primary users or regulatory entities. For example, secondary users of method **1000** may dynamically form ad-hoc mesh network communications in fixed or mobile scenarios.

[0081] Although the present disclosure has been described with an exemplary embodiment, various changes and modifications may be suggested to one skilled in the art. For example, the present disclosure primarily describes spectrum sharing in a WiMAX communication network, it should be understood, however, that embodiments of the present disclosure may be used in any suitable wireless communication system.

[0082] It is intended that the present disclosure encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A spectrum sharing system for use in a wireless communication system having a primary user node and a secondary user node, the system comprising:

a frame detector configured to detect a frame of a broadcast waveform and to extract subframe information identifying usable sub-carriers for the frame to the secondary user node,

wherein the secondary user node transmits data in a first one of usable sub-carriers identified in the subframe information.

2. The system set forth in claim **1**, wherein the subframe information is stored in a secondary user map (SU MAP).

3. The system set forth in claim **1**, wherein the frame detector is one of: an OFDM frame detector and an OFDMA frame detector.

4. The system set forth in claim **1**, wherein the broadcast waveform is one of: an OFDM waveform and an OFDMA waveform.

5. The system set forth in claim **1**, wherein the secondary user node comprises a node modem.

6. The system set forth in claim **5**, wherein the node modem is a MANET node modem.

7. The system set forth in claim **5**, wherein the node modem and the frame detector are synchronized.

8. The system set forth in claim **1**, wherein the secondary user node extracts usable pilot sub-carriers for the frame.

9. The system set forth in claim **1**, wherein a second secondary user node transmits data in a second usable sub-carrier identified in the subframe information.

10. The system set forth in claim **1**, wherein the wireless communication system is a WiMAX communication system.

11. For use in a wireless communication network having a primary user node and a secondary user node, a method of spectrum sharing, the method comprising:

detecting a frame of a broadcast waveform;

extracting subframe information identifying usable sub-carriers for the frame to the secondary user node; and

transmitting data from the secondary user node in a first sub-carrier identified in the subframe information.

12. The method set forth in claim **11**, wherein the subframe information is stored in a secondary user map (SU MAP).

13. The method set forth in claim **11**, wherein the detecting the frame is accomplished by one of: an OFDM frame detector and an OFDMA frame detector.

14. The method set forth in claim **11**, wherein the broadcast waveform is one of: an OFDM waveform and an OFDMA waveform.

15. The method set forth in claim **11**, wherein the secondary user node comprises a node modem.

16. The method set forth in claim **14**, wherein the node modem is a MANET node modem.

17. The method set forth in claim **14** further comprising:

synchronizing the node modem and the frame detector.

18. The method set forth in claim **11** further comprising:

extracting usable pilot sub-carriers for the frame.

19. The method set forth in claim **11** further comprising:

transmitting data from a second secondary user node into a second sub-carrier identified in the subframe information.

20. The method set forth in claim **11** further comprising:

dynamically forming an ad hoc mesh network with the secondary user node.

21. The method set forth in claim **11**, wherein the wireless communication network is a WiMAX communication network.

22. For use in a wireless communication system, an apparatus for forming an ad hoc mesh network, the apparatus comprising:

a secondary user node having a node modem; and

a frame detector configured to detect a frame of a broadcast waveform and extract subframe information for the frame to the secondary user node,

wherein the secondary user node transmits data in a first unused sub-carrier identified in the subframe information.

23. The apparatus set forth in claim **22**, wherein the subframe information is stored in a secondary user map (SU MAP).

24. The apparatus set forth in claim **22**, wherein the node modem and the frame detector are synchronized.

25. The apparatus set forth in claim **22**, wherein the secondary user node extracts usable pilot sub-carriers for the frame.

26. The apparatus set forth in claim **22**, wherein wireless communication system is a WiMAX communication system.

* * * * *