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CARRIER SENSE ADAPTIVE TRANSMISSION (CSAT) SCHEME

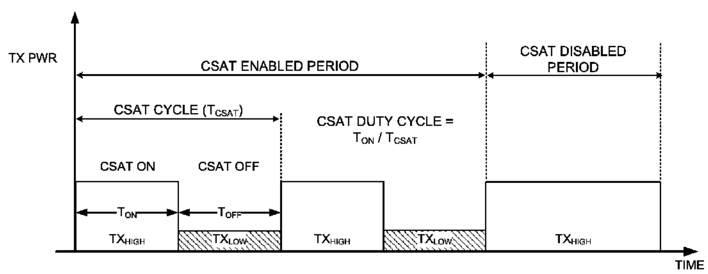

FIG. 6

(57) Abstract: Systems and methods for Standalone (SA) Carrier Sense Adaptive Transmission (CSAT) in unlicensed spectrum are disclosed.

WO 2016/074185 A1

STANDALONE CARRIER SENSE ADAPTIVE TRANSMISSION (CSAT) IN UNLICENSED SPECTRUM

INTRODUCTION

[0001] Aspects of this disclosure relate generally to telecommunications, and more particularly to co-existence between wireless Radio Access Technologies (RATs) and the like.

[0002] Wireless communication systems are widely deployed to provide various types of communication content, such as voice, data, multimedia, and so on. Typical wireless communication systems are multiple-access systems capable of supporting communication with multiple users by sharing available system resources (e.g., bandwidth, transmit power, etc.). Examples of such multiple-access systems include Code Division Multiple Access (CDMA) systems, Time Division Multiple Access (TDMA) systems, Frequency Division Multiple Access (FDMA) systems, Orthogonal Frequency Division Multiple Access (OFDMA) systems, and others. These systems are often deployed in conformity with specifications such as Long Term Evolution (LTE) provided by the Third Generation Partnership Project (3GPP), Ultra Mobile Broadband (UMB) and Evolution Data Optimized (EV-DO) provided by the Third Generation Partnership Project 2 (3GPP2), 802.11 provided the Institute of Electrical and Electronics Engineers (IEEE), etc.

[0003] In cellular networks, “macro cell” base stations provide connectivity and coverage to a large number of users over a certain geographical area. A macro network deployment is carefully planned, designed, and implemented to offer good coverage over the geographical region. Even such careful planning, however, cannot fully accommodate channel characteristics such as fading, multipath, shadowing, etc., especially in indoor environments. Indoor users therefore often face coverage issues (e.g., call outages and quality degradation) resulting in poor user experience.

[0004] To improve indoor or other specific geographic coverage, such as for residential homes and office buildings, additional “small cell,” typically low-power base stations have recently begun to be deployed to supplement conventional macro networks. Small cell base stations may also provide incremental capacity growth, richer user experience, and so on.

[0005] Recently, small cell LTE operations, for example, have been extended into the unlicensed frequency spectrum such as the Unlicensed National Information

Infrastructure (U-NII) band used by Wireless Local Area Network (WLAN) technologies. This extension of small cell LTE operation is designed to increase spectral efficiency and hence capacity of the LTE system. However, it may also encroach on the operations of other RATs that typically utilize the same unlicensed bands, most notably IEEE 802.11x WLAN technologies generally referred to as "Wi-Fi."

SUMMARY

[0006] Systems and methods for Standalone (SA) Carrier Sense Adaptive Transmission (CSAT) in unlicensed spectrum are disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The accompanying drawings are presented to aid in the description of various aspects of the disclosure and are provided solely for illustration of the aspects and not limitation thereof.

[0008] FIG. 1 illustrates an example mixed-deployment wireless communication system including macro cell base stations and small cell base stations.

[0009] FIG. 2 is a block diagram illustrating an example frame structure for Time-Division Long-Term Evolution (TD-LTE) communications.

[0010] FIG. 3 illustrates different subframe configurations for the TD-LTE frame structure of FIG. 2 according to the LTE standard.

[0011] FIG. 4 illustrates an example small cell base station with co-located radio components (e.g., LTE and Wi-Fi) configured for unlicensed spectrum operation.

[0012] FIG. 5 is a signaling flow diagram illustrating an example message exchange between co-located radios.

[0013] FIG. 6 illustrates in more detail certain aspects of a Carrier Sense Adaptive Transmission (CSAT) communication scheme for cycling cellular operation in accordance with a long-term Time Division Multiplexed (TDM) communication pattern.

[0014] FIG. 7 illustrates an example CSAT communication scheme for a PCell utilizing Almost Blank Radio Frames (ABRFs) to coordinate control signaling.

[0015] FIG. 8 illustrates an example Master Information Block (MIB) adapted to convey CSAT parameter information.

[0016] FIG. 9 illustrates an example Downlink Control Information (DCI) message adapted to convey CSAT parameter information.

[0017] FIG. 10 is a signaling flow diagram illustrating system acquisition in a CSAT communication scheme.

[0018] FIG. 11 is a timing diagram illustrating an example paging structure adapted for use in a CSAT communication scheme.

[0019] FIG. 12 is a signaling flow diagram illustrating an example random access procedure that may be adapted for use with a CSAT communication scheme.

[0020] FIG. 13 is a timing diagram illustrating an example adaptation of the random access procedure of FIG. 12 for operation with a CSAT communication scheme.

[0021] FIG. 14 is a timing diagram illustrating an adaptation of UpLink (UL) Hybrid Automatic Repeat Request (HARQ) for operation with a CSAT communication scheme.

[0022] FIG. 15 illustrates an example Discontinuous Reception (DRX) communication mode, which may be used to communicate with certain user devices for applications that do not require continuous reception.

[0023] FIG. 16 is a timing diagram illustrating an example DRX structure adapted for use in a CSAT communication scheme.

[0024] FIG. 17 is another timing diagram illustrating an example DRX structure adapted for use in a CSAT communication scheme.

[0025] FIG. 18 illustrates an example CSAT communication scheme for a Primary Cell (PCell) utilizing a DownLink (DL)-lite configuration to opportunistically reduce co-channel interference.

[0026] FIG. 19 is a signaling flow diagram illustrating an example PCell swap procedure for switching the PCell of a connected mode user device between the user device's existing component carriers.

[0027] FIG. 20 is a signaling flow diagram illustrating an example PCell add procedure for switching the PCell of a connected mode user device from one of the user device's existing component carriers to a new component carrier.

[0028] FIG. 21 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0029] FIG. 22 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0030] FIG. 23 is a flow diagram illustrating an example method of system acquisition in an unlicensed band of radio frequencies.

[0031] FIG. 24 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0032] FIG. 25 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0033] FIG. 26 is a flow diagram illustrating an example method of system monitoring in an unlicensed band of radio frequencies.

[0034] FIG. 27 is a flow diagram illustrating an example method of mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0035] FIG. 28 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0036] FIG. 29 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0037] FIG. 30 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[0038] FIG. 31 is a simplified block diagram of several sample aspects of components that may be employed in communication nodes and configured to support communication as taught herein.

[0039] FIGS. 32-41 are other simplified block diagrams of several sample aspects of apparatuses configured to support communication as taught herein.

[0040] FIG.42 illustrates an example communication system environment in which the teachings and structures herein may be incorporated.

DETAILED DESCRIPTION

[0041] The present disclosure relates generally to Standalone (SA) Carrier Sense Adaptive Transmission (CSAT). For SA operation, various techniques are described in detail below to facilitate aspects such as control signaling, user device synchronization, channel selection, paging, random access, interference management, retransmission, discontinuous reception, cell transition, and so on, in accordance with a CSAT communication scheme

[0042] More specific aspects of the disclosure are provided in the following description and related drawings directed to various examples provided for illustration purposes. Alternate aspects may be devised without departing from the scope of the disclosure. Additionally, well-known aspects of the disclosure may not be described in detail or may be omitted so as not to obscure more relevant details.

[0043] Those of skill in the art will appreciate that the information and signals described below may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description below may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof, depending in part on the particular application, in part on the desired design, in part on the corresponding technology, etc.

[0044] Further, many aspects are described in terms of sequences of actions to be performed by, for example, elements of a computing device. It will be recognized that various actions described herein can be performed by specific circuits (e.g., Application Specific Integrated Circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both. In addition, for each of the aspects described herein, the corresponding form of any such aspect may be implemented as, for example, “logic configured to” perform the described action.

[0045] FIG. 1 illustrates an example mixed-deployment wireless communication system, in which small cell base stations are deployed in conjunction with and to supplement the coverage of macro cell base stations. As used herein, small cells generally refer to a class of low-powered base stations that may include or be otherwise referred to as femto cells, pico cells, micro cells, etc. As noted in the background above, they may be deployed to provide improved signaling, incremental capacity growth, richer user experience, and so on.

[0046] The illustrated wireless communication system 100 is a multiple-access system that is divided into a plurality of cells 102 and configured to support communication for a number of users. Communication coverage in each of the cells 102 is provided by a corresponding base station 110, which interacts with one or more user devices 120viaDownLink (DL) and/or UpLink (UL) connections. In general, the DL corresponds to communication from a base station to a user device, while the UL corresponds to communication from a user device to a base station.

[0047] As will be described in more detail below, these different entities may be variously configured in accordance with the teachings herein to provide or otherwise support the SA CSAT discussed briefly above. For example, one or more of the small cell base stations 110 may include a CSAT management module 112, while one or more of the user devices 120 may include a CSAT management module 122.

[0048] As used herein, the terms “user device” and “base station” are not intended to be specific or otherwise limited to any particular Radio Access Technology (RAT), unless otherwise noted. In general, such user devices may be any wireless communication device (e.g., a mobile phone, router, personal computer, server, etc.) used by a user to communicate over a communications network, and may be alternatively referred to in different RAT environments as an Access Terminal (AT), a Mobile Station (MS), a Subscriber Station (STA), a User Equipment (UE), etc. Similarly, a base station may operate according to one of several RATs in communication with user devices depending on the network in which it is deployed, and may be alternatively referred to as an Access Point (AP), a Network Node, a NodeB, an evolved NodeB (eNB), etc. In addition, in some systems a base station may provide purely edge node signaling functions while in other systems it may provide additional control and/or network management functions.

[0049] Returning to FIG. 1, the different base stations 110 include an example macro cell base station 110A and two example small cell base stations 110B, 110C. The macro cell base station 110A is configured to provide communication coverage within a macro cell coverage area 102A, which may cover a few blocks within a neighborhood or several square miles in a rural environment. Meanwhile, the small cell base stations110B, 110Care configured to provide communication coverage within respective small cell coverage areas 102B, 102C, with varying degrees of overlap existing among the different coverage areas. In some systems, each cell may be further divided into one or more sectors (not shown).

[0050] Turning to the illustrated connections in more detail, the user device 120Amay transmit and receive messages via a wireless link with the macro cell base station 110A, the message including information related to various types of communication (e.g., voice, data, multimedia services, associated control signaling, etc.). The user device 120B may similarly communicate with the small cell base station 110B via another wireless link, and the user device 120C may similarly communicate with the small cell base station 110C via another wireless link. In addition, in some scenarios, the user device 120C, for example, may also communicate with the macro cell base station 110A via a separate wireless link in addition to the wireless link it maintains with the small cell base station 110C.

[0051] As is further illustrated in FIG. 1, the macro cell base station 110A may communicate with a corresponding wide area or external network130, via a wired link or via a wireless link, while the small cell base stations 110B, 110C may also similarly communicate with the network130, via their own wired or wireless links. For example, the small cell base stations 110B, 110C may communicate with the network130 by way of an Internet Protocol (IP) connection, such as via a Digital Subscriber Line (DSL, e.g., including Asymmetric DSL (ADSL), High Data Rate DSL (HDSL), Very High Speed DSL (VDSL), etc.), a TV cable carrying IP traffic, a Broadband over Power Line (BPL) connection, an Optical Fiber (OF) cable, a satellite link, or some other link.

[0052] The network130 may comprise any type of electronically connected group of computers and/or devices, including, for example, Internet, Intranet, Local Area Networks (LANs), or Wide Area Networks (WANs). In addition, the connectivity to the network may be, for example, by remote modem, Ethernet (IEEE 802.3), Token Ring (IEEE 802.5), Fiber Distributed Datalink Interface (FDDI) Asynchronous Transfer Mode (ATM), Wireless Ethernet (IEEE 802.11), Bluetooth (IEEE 802.15.1), or some other connection. As used herein, the network130 includes network variations such as the public Internet, a private network within the Internet, a secure network within the Internet, a private network, a public network, a value-added network, an intranet, and the like. In certain systems, the network130 may also comprise a Virtual Private Network (VPN).

[0053] Accordingly, it will be appreciated that the macro cell base station 110A and/or either or both of the small cell base stations 110B, 110C may be connected to the network130 using any of a multitude of devices or methods. These connections may be referred to as the "backbone" or the "backhaul" of the network, and may in some implementations be used to manage and coordinate communications between the macro cell base station 110A, the small cell base station 110B, and/or the small cell base station 110C. In this way, as a user device moves through such a mixed communication network environment that provides both macro cell and small cell coverage, the user device may be served in certain locations by macro cell base stations, at other locations by small cell base stations, and, in some scenarios, by both macro cell and small cell base stations.

[0054] For their wireless air interfaces, each base station 110 may operate according to one of several RATs depending on the network in which it is deployed. These networks may include, for example, Code Division Multiple Access (CDMA) networks, Time Division Multiple Access (TDMA) networks, Frequency Division Multiple Access (FDMA) networks, Orthogonal FDMA (OFDMA) networks, Single-Carrier FDMA (SC-FDMA) networks, and so on. The terms "network" and "system" are often used interchangeably. A CDMA network may implement a RAT such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband-CDMA (W-CDMA) and Low Chip Rate (LCR). cdma2000 covers IS-2000, IS-95 and IS-856 standards. A TDMA network may implement a RAT such as Global System for Mobile Communications (GSM). An OFDMA network may implement a RAT such as Evolved UTRA (E-UTRA), IEEE 802.11, IEEE 802.16, IEEE 802.20, Flash-OFDM®, etc. UTRA, E-UTRA, and GSM are part of Universal Mobile Telecommunication System (UMTS). Long Term Evolution (LTE) is a release of UMTS that uses E-UTRA. UTRA, E-UTRA, GSM, UMTS, and LTE are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). cdma2000 is described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). These documents are publicly available.

[0055] For illustration purposes, an example LTE frame structure is described below with reference to FIGS. 2 – 3. In general, although the basic system timing is similar, two different frame structures are defined for LTE for different duplexing modes. Frequency Division Duplexing (FDD) uses a Type 1 frame structure (FS1) and Time Division Duplexing uses a Type 2 frame structure (FS2). The TDD FS2 frame structure is described below for illustration purposes, but it will be appreciated that the techniques herein are generally applicable to either FS1 or FS2 implementations.

[0056] FIG. 2 is a block diagram illustrating an example frame structure for Time-Division Long-Term Evolution (TD-LTE) communications. In LTE, the base stations 110 of FIG. 1 are generally referred to as eNBs and the user devices 120 are generally referred to as UEs. The transmission timeline may be partitioned into units of radio frames (RFs). Each radio frame may have a predetermined duration (e.g., 10 milliseconds (ms)) and may be partitioned into 10 subframes with indices of 0 through 9, the first 5 subframes constituting a first half frame (Half Frame 0) and the second 5 subframes constituting a second half frame (Half Frame 1). Each subframe may correspond to a downlink subframe (D), an uplink subframe (U), or a special subframe (S). Each downlink and uplink subframe may be divided into two slots. Each special subframe may be divided into a downlink pilot time slot (DwPTS), a guard period (GP), and an uplink pilot time slot (UpPTS). Depending on the configuration, the duration of DwPTS, UpPTS, and GP may vary.

[0057] Each radio frame may thus include 20 slots with indices of 0 through 19. Each slot may include L symbol periods, e.g., 7 symbol periods for a normal cyclic prefix (as shown in FIG. 2) or 6 symbol periods for an extended cyclic prefix. The 2L symbol periods in each subframe may be assigned indices of 0 through 2L-1. The available time frequency resources may be partitioned into resource blocks (RBs). Each resource block may cover N subcarriers (e.g., 12 subcarriers) in one slot.

[0058] FIG.3 illustrates different subframe configurations for the TD-LTE frame structure of FIG. 2 according to the LTE standard. Here, the designations “D,”“U,” and “S” indicate that the subframe is configured as a respective one of the downlink, uplink, and special subframes described above. As shown, several DL/UL configurations with a5 ms switch-point periodicity (i.e., two special subframes per radio framespaced5 ms apart) and a 10 ms switch-point periodicity (i.e., one special subframe per radio frame) may be chosen for the TD-LTE frame. Configurations 0, 1, and 2 have two identical5 ms half frames within a 10 ms TDD-LTE frame. The particular configuration employed may be broadcast by the eNB using a SIB-1 (System Information Block Type 1) message.

[0059] Returning to FIG. 2, an LTE eNB may send a Primary Synchronization Signal (PSS) and a Secondary Synchronization Signal (SSS) for each cell in the eNB. The SSS may be sent in the last symbol period of the second slot in each of subframes 0 and 5 of each radio frame. The PSS may be sent in the third symbol period in each of subframes 1 and 6 (during the DwPTS slot) of each radio frame. The synchronization signals may be used by UEs for cell detection and acquisition. The eNB may send a Physical Broadcast Channel (PBCH) in symbol periods 0 to 3 in slot 1 of subframe 0. The PBCH may carry certain system information.

[0060] Reference signals are transmitted during the first and fifth symbol periods of each downlink slot when the normal cyclic prefix is used and during the first and fourth symbol periods when the extended cyclic prefix is used. For example, the eNB may send a Cell-specific Reference Signal (CRS) for each cell in the eNB on all component carriers. The CRS may be sent in symbols 0 and 4 of each downlink slot in case of the normal cyclic prefix, and in symbols 0 and 3 of each downlink slot in case of the extended cyclic prefix. The CRS may be used by UEs for coherent demodulation of physical channels, timing and frequency tracking, Radio Link Monitoring (RLM), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ) measurements, etc.

[0061] The eNB may send a Physical Control Format Indicator Channel (PCFICH) in the first symbol period of each downlink subframe, as seen in FIG. 2. The PCFICH may convey the number of symbol periods (M) used for control channels, where M may be equal to 1, 2, or 3 and may change from subframe to subframe. M may also be equal to 4 for a small system bandwidth, e.g., with less than 10 resource blocks. In the example shown in FIG. 2, M=3. The eNB may send a Physical HARQ Indicator Channel (PHICH) and a Physical Downlink Control Channel (PDCCH) in the first M symbol periods of each downlink subframe. The PDCCH and PHICH are also included in the first three symbol periods in the example shown in FIG. 2. The PHICH may carry information to support Hybrid Automatic Repeat Request (HARQ). The PDCCH may carry information on resource allocation for UEs and control information for downlink channels. The eNB may send a Physical Downlink Shared Channel (PDSCH) in the remaining symbol periods of each downlink subframe. The PDSCH may carry data for UEs scheduled for data transmission on the downlink. The various signals and channels in LTE are described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

[0062] The eNB may send the PSS, SSS, and PBCH in the center 1.08 MHz of the system bandwidth used by the eNB. The eNB may send the PCFICH and PHICH across the entire system bandwidth in each symbol period in which these channels are sent.

The eNB may send the PDCCH to groups of UEs in certain portions of the system bandwidth. The eNB may send the PDSCH to specific UEs in specific portions of the system bandwidth. The eNB may send the PSS, SSS, PBCH, PCFICH, and PHICH in a broadcast manner to all UEs, may send the PDCCH in a unicast manner to specific UEs, and may also send the PDSCH in a unicast manner to specific UEs.

[0063] A number of resource elements may be available in each symbol period. Each resource element may cover one subcarrier in one symbol period and may be used to send one modulation symbol, which may be a real or complex value. Resource elements not used for a reference signal in each symbol period may be arranged into Resource Element Groups (REGs). Each REG may include four resource elements in one symbol period. The PCFICH may occupy four REGs, which may be spaced approximately equally across frequency, in symbol period 0. The PHICH may occupy three REGs, which may be spread across frequency, in one or more configurable symbol periods. For example, the three REGs for the PHICH may all belong in symbol period 0 or may be spread in symbol periods 0, 1, and 2. The PDCCH may occupy 9, 18, 32, or 64 REGs, which may be selected from the available REGs, in the first M symbol periods. Only certain combinations of REGs may be allowed for the PDCCH.

[0064] A UE may know the specific REGs used for the PHICH and the PCFICH. The UE may search different combinations of REGs for the PDCCH. The number of combinations to search is typically less than the number of allowed combinations for the PDCCH. An eNB may send the PDCCH to the UE in any of the combinations that the UE will search.

[0065] Returning to FIG. 1, cellular systems such as LTE are typically confined to one or more licensed frequency bands that have been reserved for such communications (e.g., by a government entity such as the Federal Communications Commission (FCC) in the United States). However, certain communication systems, in particular those employing small cell base stations as in the design of FIG. 1, have extended cellular operations into unlicensed frequency bands such as the Unlicensed National Information Infrastructure (U-NII) band used by Wireless Local Area Network (WLAN) technologies. For illustration purposes, the description below may refer in some respects to an LTE system operating on an unlicensed band by way of example when appropriate, although it will be appreciated that such descriptions are not intended to exclude other cellular communication technologies. LTE on an unlicensed band may also be referred to herein as LTE/LTE-Advanced in unlicensed spectrum, or simply LTE in the surrounding context. With reference to FIGS. 2 – 3 above, the PSS, SSS, CRS, PBCH, PUCCH, and PUSCH in LTE on an unlicensed band are otherwise the same or substantially the same as in the LTE standard described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

[0066] The unlicensed spectrum may be employed by cellular systems in different ways. For example, in some systems, the unlicensed spectrum may be employed in a standalone configuration, with all carriers operating exclusively in an unlicensed portion of the wireless spectrum (e.g., LTE Standalone). In other systems, the unlicensed spectrum may be employed in a manner that is supplemental to licensed band operation by utilizing one or more unlicensed carriers operating in the unlicensed portion of the wireless spectrum in conjunction with an anchor licensed carrier operating in the licensed portion of the wireless spectrum (e.g., LTE Supplemental DownLink (SDL)). In either case, carrier aggregation may be employed to manage the different component carriers, with one carrier serving as the Primary Cell (PCell) for the corresponding user (e.g., an anchor licensed carrier in LTE SDL or a designated one of the unlicensed carriers in LTE Standalone) and the remaining carriers serving as respective Secondary Cells (SCells).

[0067] The extension of small cell operation into unlicensed frequency bands such as the U-NII (5 GHz) band may therefore be implemented in a variety of ways and increase the capacity of cellular systems such as LTE. As discussed briefly in the background above, however, it may also encroach on the operations of other "native" RATs that typically utilize the same unlicensed band, most notably IEEE 802.11x WLAN technologies generally referred to as "Wi-Fi."

[0068] In some small cell base station designs, the small cell base station may include such a native RAT radio co-located with its cellular radio. According to various aspects described herein, the small cell base station may leverage the co-located radio to facilitate co-existence between the different RATs when operating on a shared unlicensed band. For example, the co-located radio may be used to conduct different measurements on the unlicensed band and dynamically determine the extent to which the unlicensed band is being utilized by devices operating in accordance with the native RAT. The cellular radio's use of the shared unlicensed band may then be specially adapted to balance the desire for efficient cellular operation against the need for stable co-existence.

[0069] FIG. 4 illustrates an example small cell base station with co-located radio components configured for unlicensed spectrum operation. The small cell base station 400 may correspond, for example, to one of the small cell base stations110B, 110C illustrated in FIG. 1. In this example, the small cell base station 400 is configured to provide a WLAN air interface (e.g., in accordance with an IEEE 802.11x protocol) in addition to a cellular air interface (e.g., in accordance with an LTE protocol). For illustration purposes, the small cell base station 400is shown as including an 802.11x radio component / module (e.g., transceiver) 402 co-located with an LTE radio component / module (e.g., transceiver) 404.

[0070] As used herein, the term co-located (e.g., radios, base stations, transceivers, etc.) may include in accordance with various aspects, one or more of, for example: components that are in the same housing; components that are hosted by the same processor; components that are within a defined distance of one another; and/or components that are connected via an interface (e.g., an Ethernet switch) where the interface meets the latency requirements of any required inter-component communication (e.g., messaging). In some designs, the advantages discussed herein may be achieved by adding a radio component of the native unlicensed band RAT of interest to a given cellular small cell base station without that base station necessarily providing corresponding communication access via the native unlicensed band RAT (e.g., adding a Wi-Fi chip or similar circuitry to an LTE small cell base station). If desired, a low functionality Wi-Fi circuit may be employed to reduce costs (e.g., a Wi-Fi receiver simply providing low-level sniffing).

[0071] Returning to FIG. 4, the Wi-Fi radio 402 and the LTE radio 404 may perform monitoring of one or more channels (e.g., on a corresponding carrier frequency) to perform various corresponding operating channel or environment measurements (e.g., CQI, RSSI,RSRP, or other RLM measurements) using corresponding Network / Neighbor Listen (NL) modules 406 and 408, respectively, or any other suitable component(s).

[0072] The small cell base station 400 may communicate with one or more user devices via the Wi-Fi radio 402 and the LTE radio 404, illustrated as an STA 450 and a UE 460, respectively. Similar to the Wi-Fi radio 402 and the LTE radio 404, the

STA450 includes a corresponding NL module 452 and the UE 460 includes a corresponding NL module 462 for performing various operating channel or environment measurements, either independently or under the direction of the Wi-Fi radio 402 and the LTE radio 404, respectively. In this regard, the measurements may be retained at the STA 450 and/or the UE 460, or reported to the Wi-Fi radio 402 and the LTE radio 404, respectively, with or without any pre-processing being performed by the STA 450orthe UE 460.

[0073] While FIG. 4shows a single STA 450 and a single UE 460 for illustration purposes, it will be appreciated that the small cell base station 400 can communicate with multiple STAs and/or UEs. Additionally, while FIG. 4 illustrates one type of user device communicating with the small cell base station 400 via the Wi-Fi radio 402 (i.e., the STA 450) and another type of user device communicating with the small cell base station 400 via the LTE radio 404 (i.e., the UE 460), it will be appreciated that a single user device (e.g., a smartphone) may be capable of communicating with the small cell base station 400 via both the Wi-Fi radio 402 and the LTE radio 404, either simultaneously or at different times.

[0074] As is further illustrated in FIG. 4, the small cell base station 400 may also include a network interface 410, which may include various components for interfacing with corresponding network entities (e.g., Self-Organizing Network (SON) nodes), such as a component for interfacing with a Wi-Fi SON 412 and/or a component for interfacing with an LTE SON 414. The small cell base station 400 may also include a host 420, which may include one or more general purpose controllers or processors 422 and memory 424 configured to store related data and/or instructions. The host 420 may perform processing in accordance with the appropriate RAT(s) used for communication (e.g., via a Wi-Fi protocol stack 426 and/or an LTE protocol stack 428), as well as other functions for the small cell base station 400.In particular, the host 420 may further include a RAT interface 430(e.g., a bus or the like) that enables the radios 402 and 404 to communicate with one another via various message exchanges.

[0075] FIG. 5 is a signaling flow diagram illustrating an example message exchange between co-located radios. In this example, one RAT (e.g., LTE) requests a measurement from another RAT (e.g., Wi-Fi) and opportunistically ceases transmission for the measurement. FIG. 5 will be explained below with continued reference to FIG. 4.

[0076] Initially, the LTE SON 414 notifies the LTE stack428 via a message 520 that a measurement gap is upcoming on the shared unlicensed band. The LTE SON414 then sends a command522 to cause the LTE radio (RF)404 to temporarily turn off transmission on the unlicensed band, in response to which the LTE radio404disables the appropriate RF components for a period of time (e.g., so as to not interfere with any measurements during this time).

[0077] The LTE SON 414 also sends a message 524 to the co-located Wi-Fi SON 412 requesting that a measurement be taken on the unlicensed band. In response, the Wi-Fi SON 412 sends a corresponding request 526 via the Wi-Fi stack 426 to the Wi-Fi radio402, or some other suitable Wi-Fi radio component (e.g., a low cost, reduced functionality Wi-Fi receiver).

[0078] After the Wi-Fi radio402 conducts measurements for Wi-Fi related signaling on the unlicensed band, a report 528 including the results of the measurements is sent to the LTE SON 414 via the Wi-Fi stack 426 and the Wi-Fi SON 412. In some instances, the measurement report may include not only measurements performed by the Wi-Fi radio 402 itself, but also measurements collected by the Wi-Fi radio 402 from the STA 450. The LTE SON 414 may then send a command 530 to cause the LTE radio 404 to turn back on transmission on the unlicensed band (e.g., at the end of the defined period of time).

[0079] The information included in the measurement report (e.g., information indicative of how Wi-Fi devices are utilizing the unlicensed band) may be compiled along with various LTE measurements and measurement reports. Based on information about the current operating conditions on the shared unlicensed band (e.g., as collected by one or a combination of the Wi-Fi radio 402, the LTE radio 404, the STA 450, and/or the UE 460), the small cell base station 400 may specially adapt different aspects of its cellular operations in order to manage co-existence between the different RATs. Returning to FIG. 5, the LTE SON414, for example, may then send a message532 that informs the LTE stack 428how LTE communication is to be modified.

[0080] There are several aspects of cellular operation that may be adapted in order to manage co-existence between the different RATs. For example, the small cell base station 400 may select certain carriers as preferable when operating in the unlicensed band, may opportunistically enable or disable operation on those carriers, may selectively adjust the transmission power of those carriers, if necessary (e.g., periodically or intermittently in accordance with a transmission pattern), and/or take other steps to balance the desire for efficient cellular operation against the need for stable co-existence.

[0081] One particular adaptation technique is referred to herein as Carrier Sense Adaptive Transmission (CSAT), where the transmission power on a given carrier (PCell and/or SCell) may be dynamically adapted by cycling between periods of high transmission power (referred to as a full or partial "ON" state) and low transmission power (referred to as a full or partial "OFF" state).During CSAT operation, transmission may be cycled in accordance with a (long-term) Time Division Multiplexed (TDM) communication pattern. In the ON state, the corresponding PCell and/or SCell may operate at relatively high power (e.g., full powered ON state, as a special case). In the OFF state, the corresponding PCell and/or SCell may operate at a reduced, relatively low power (e.g., fully depowered OFF state, as a special case).

[0082] FIG. 6 illustrates in more detail certain aspects of a CSAT communication scheme for cycling cellular operation in accordance with a long-term TDM communication pattern.

[0083] When enabled, the corresponding PCell and/or SCell operation is cycled between CSAT ON periods and CSAT OFF periods within a given CSAT cycle (T_{CSAT}). During an associated ON period of time, T_{ON}, PCell and/or SCell transmission on the unlicensed band may proceed at a normal, relatively high transmission power. During an associated OFF period of time, T_{OFF}, however, PCell and/or SCell transmission on the unlicensed band is reduced or even fully disabled to yield the medium to a competing RAT (as well as to perform various measurements via a co-located radio of the competing RAT).

[0084] Each of the associated CSAT parameters, including, for example, the CSAT cycle duration (T_{CSAT}), the CSAT pattern duty cycle (i.e., T_{ON} / T_{CSAT}), and the relative transmission powers during ON / OFF periods, may be adapted based on the current signaling conditions to optimize CSAT operation. As an example, if the utilization of a given channel by Wi-Fi devices is high, an LTE radio may adjust one or more of the CSAT parameters such that usage of the channel by the LTE radio is reduced. For example, the LTE radio may reduce its transmit duty cycle or transmit power on the channel. Conversely, if utilization of a given channel by Wi-Fi devices is low, an LTE radio may adjust one or more of the CSAT parameters such that usage of the channel by the LTE radio is increased. For example, the LTE radio may increase its transmit duty cycle or transmit power on the channel.

[0085] A CSAT scheme as provided herein may offer several advantages for mixed RAT co-existence, particularly in unlicensed spectrum. For example, by adapting communication based on signals associated with a first RAT (e.g., Wi-Fi), a second RAT (e.g., LTE) may react to co-channel utilization by devices that use the first RAT while refraining from reacting to extraneous interference by other devices (e.g., non-Wi-Fi devices) or adjacent channels. As another example, a CSAT scheme enables a device that uses one RAT to control how much protection is to be afforded to co-channel communications by devices that use another RAT by adjusting the particular parameters employed. In addition, such a scheme may be implemented in whole or at least in part without changes to the underlying RAT communication protocol. In an LTE system, for example, CSAT may be generally implemented without changing the LTE PHY or MAC layer protocols, but by simply changing the LTE software.

[0086] To improve overall system efficiency, certain CSAT cycling parameters may be synchronized, in whole or in part, across different small cells, at least within a given operator. For example, various communication pattern aspects and related measurement periods may be synchronized with system-specific timing patterns of the host RAT, such as LTE's System Frame Number (SFN) numerology. The use of a system-specific timing pattern framework may provide more natural and efficient coordination among small cell base stations than system-independent techniques. In addition, while CSAT cycle durations (T_{CSAT}) and CSAT pattern duty cycles (i.e., T_{ON} / T_{CSAT}), for example, may vary from cell to cell, the operator may set a minimum CSAT ON period ($T_{ON,min}$) and/or a minimum CSAT OFF period ($T_{OFF,min}$)to provide measurement gaps, designate specific opportunities for measurement periods with respect to particular locations in a given SFN, and so on.

[0087] For PCell operation, various techniques are described in detail below to facilitate aspects such as control signaling, user device synchronization, channel selection, paging, random access, interference management, retransmission, discontinuous reception, cell transition, and so on, in accordance with a CSAT communication scheme. As with the discussion of FIGS. 2 – 3, the description below is made generally with reference to the TDD FS2 frame structure for illustration purposes, but it will be appreciated that the techniques herein are generally applicable to either FDD FS1 or TDD FS2 implementations.

[0088] FIG. 7 illustrates an example CSAT communication scheme for a PCell utilizing Almost Blank Radio Frames (ABRFs) to coordinate control signaling. As in FIG. 6, during CSAT ON periods of communication, transmission on a shared operating spectrum such as an unlicensed band is generally enabled. During CSAT OFF periods, transmission on the shared operating spectrum is generally disabled to allow other-system operations and to conduct medium utilization measurements.

[0089] In this example, the CSAT timing structure is deployed in conjunction with an LTE SFN numerology. As discussed above in more detail with reference to FIGS. 2 – 3, an LTE system frame is generally divided into 1024 numbered Radio Frames (RFs), which together constitute an SFN cycle (e.g., lasting 10.24s for 10ms RFs). CSAT timing parameters such as the CSAT cycle duration (T_{CSAT}) and the nominal CSAT duty cycle (T_{ON} / T_{CSAT}) may be aligned and adapted to fit within the framework of each SFN cycle. For example, each CSAT cycle may cover a particular number of RFs (e.g., four RFs, RF_T to RF_{T+3}, in FIG. 7) and be divided into CSAT ON and CSAT OFF periods covering respective subsets of those RFs based on the associated duty cycle (e.g., two RFs, RF_T to RF_{T+1}, for the CSAT ON period and two RFs, RF_{T+2} to RF_{T+3}, for the CSAT OFF period in FIG. 7,thereby implementing a 50% duty cycle).As another example, CSAT cycles may be aligned with SFN cycle boundaries such that each SFN cycle starts with a CSAT ON period (e.g., a CSAT ON transition may be scheduled to occur at the first RF boundary). As another example, various measurement opportunities may be enforced at particular times within a given SFN cycle (e.g., in terms of specific RF locations).

[0090] As is further illustrated in FIG. 7, each CSAT OFF period may include one or more ABRFs configured to convey select control signaling during the CSAT OFF period in order to facilitate continued system operation. The control signaling may include information relevant to system acquisition, timing synchronization, CSAT parameter settings, interference measurements (e.g., Radio Resource Measurements (RRM) / Radio Link Measurements (RLM)), tracking loops, gain control (e.g., Automatic Gain Control (AGC)), etc. ABRFs may be sent over one or more than one of the RFs constituting the CSAT OFF period (e.g., in accordance with a periodicity N representing the number RFs over which the ABRF repeats).

[0091] In the illustrated example, the ABRF utilized for the CSAT OFF period in FIG. 7 is configured for an LTE system and includes transmission of the first LTE subframe (SF0) and the third OFDM symbol (symbol 2) of the second LTE subframe (SF1). The SF0 transmission includes PSS, CRS, and Master Information Block (MIB) signaling. The SF1, symbol 2 transmission includes SSS signaling. Here, the ABRF is transmitted with a periodicity of N=1 in each CSAT OFF RF (i.e., RF_{T+2} and RF_{T+3}).It will be appreciated that different ABRF configurations may be used as desired depending on the RAT employed and the signaling desired. It will be further appreciated, however, that, while not required, limiting ABRF signaling to the first two subframes in an LTE system, for example, allows such a configuration to be used ubiquitously across all LTE TDD configurations, which each utilize a common subframe structure during at least the first two subframes.

[0092] In some designs, the ABRF configuration may be dynamic, even within a given CSAT OFF period. For example, some control signals may require periodic transmission that is less frequent than every RF but potentially more frequent than certain CSAT cycles would otherwise provide. The first LTE System Information Block (SIB-1) signaling, for example, may be adequately transmitted by relatively short CSAT cycles where the transmission gap is 40ms or shorter (e.g., T_{CSAT} = 2 or 4 RFs) but not adequately transmitted by other, relatively long CSAT cycles (e.g., T_{CSAT} = 8 or 16 RFs). Accordingly, the subframe carrying such a signal (e.g., SF5 for SIB-1) or a punctured version thereof (retaining only the desired symbol periods) may be included in the ABRF configuration only when necessary in accordance with the required periodicity.

[0093] To coordinate user device operation with PCell CSAT cycling, corresponding CSAT parameters may be transmitted (e.g., broadcasted) to the user devices on one or more channels. Different parameters may be signaled in different ways. For example, in an LTE system, the CSAT cycle duration (T_{CSAT}) may be signaled via MIB signaling (e.g., using one or more reserved bits). As another example, the CSAT ON duration (T_{ON}) as an indication of the CSAT duty cycle (T_{ON} / T_{CSAT}) may be signaled via PDCCH signaling (e.g., using a Downlink Control Information (DCI) message). User device awareness of the CSAT pattern may increase battery efficiency (e.g., by allowing the user device to reduce monitoring during CSAT OFF periods) as well as reduce receiver complexity (e.g., by allowing the user device to freeze different tracking loops during CSAT OFF periods).

[0094] FIG. 8illustrates an example MIB adapted to convey CSAT parameter information. In general, a MIB is transmitted on the PBCH and includes a limited number of the most essential and most frequently transmitted parameters used to acquire other information from the cell. As shown, the MIB800may carry, in particular, downlink channel bandwidth information 802 (e.g., in term of RBs), PHICH configuration information 804 (e.g., PHICH duration and PHICH resource), an SFN index or other identifier 806 for the RF in which the MIB 800 is transmitted, and a group of unused bits 808 reserved for future use.

[0095] One or more of the reserved bits 808 may be used to convey CSAT parameter information. In the illustrated example, information concerning the CSAT cycle duration (T_{CSAT}) 810 is included in the reserved bits 808. Where the CSAT communication scheme is substantially aligned with the corresponding SFN structure, identifying the CSAT cycle duration (T_{CSAT}) 810 may be sufficient to convey the CSAT cycle boundaries. For example, when CSAT cycles are aligned with RF boundaries and each SFN cycle starts with a CSAT ON period (i.e., SFN mod CSAT_Cycle = 0), an index parameter representing one of a set of predetermined CSAT cycle durations (e.g., T_{CSAT} = {2 RFs, 4 RFs, 8 RFs, 16 RFs}) may be used for the CSAT cycle duration (T_{CSAT}) 810. A set of two predetermined CSAT cycle durations requires only one bit (out of the ten reserve bits for an LTE MIB), a set of four predetermined CSAT cycle durations requires only two bits, etc.

[0096] In general, an LTE MIB uses a fixed schedule with a periodicity of 40ms and repetitions made every10ms. More specifically, the first transmission of the MIB is scheduled in SF0 of every fourth RF (i.e., RFs for which SFN mod 4 = 0), and repetitions are scheduled in SF0 of all other RFs. Further, as discussed above with reference to FIG. 7, MIB signaling may be included in one or more ABRFs. Thus, a user device will be able to read MIB information even during CSAT OFF periods.

[0097] FIG. 9 illustrates an example DCI message adapted to convey CSAT parameter information. In general, a DCI message is transmitted on the PDCCH and is used to indicate a resource assignment for one Radio Network Temporary Identifier (RNTI). A user device may attempt to decode DCI messages that are received in the PDCCH in either UE-specific or common PDCCH search spaces.

[0098] In the illustrated example, the DCI message 900 includes CSAT ON duration (T_{ON}) information for N cells ($Cell_1$ 902, $Cell_2$ 904, $Cell_3$ 906, … $Cell_N$ 908). Where the

CSAT cycle duration (T_{CSAT}) is signaled separately (e.g., via MIB signaling as described above with reference to FIG. 8) and the CSAT ON duration (T_{ON}) is aligned with RF boundaries, an index parameter representing one of a set of predetermined CSAT ON duration (T_{ON}) values as a fraction of the CSAT cycle duration (T_{CSAT}) may be used (e.g., T_{ON} = {1/16, 1/8, 1/4, 3/8, ½, 5/8, ¾, 1}). A set of four predetermined CSAT ON duration values requires only two bits, a set of eight predetermined CSAT ON duration values requires only three bits, etc.

[0099] The DCI message 900 may be sent on one or more different DCI "formats" used in LTE in PDCCH. As an example, DCI format 1C (DCI-1C), which is defined for compact scheduling of a PDSCH codeword, may be repurposed to convey a CSAT ON duration (T_{ON}) index. In LTE, up to five serving cells are permitted and a DCI-1C message contains 15 bits. Thus, different CSAT ON duration (T_{ON}) information for each of the permitted number of serving cells may be included in a DCI-1C message with an allocation of three bits, allowing for a set of eight predetermined CSAT ON duration values to be conveyed in this manner. It will be appreciated, however, that other numbers of cells and bits may be used as desired (e.g., a fewer number of cells, a larger set of values, a common set of values for different cells, etc.).Based on a guaranteed CSAT ON period of at least the first RF in each CSAT cycle, most user devices will be able to quickly read the DCI-1C message and identify the CSAT pattern.

[00100] It will be appreciated that in some systems, DCI-1C messages may be utilized for other purposes as well and that accommodations may be made for co-existence of both techniques. For example, DCI-1C messages may also be used to signal dynamic TDD configuration information. Enhancements to LTE TDD for DL-UL Interference Management and Traffic Adaptation (eIMTA) specify an adaptive change to the LTE-TDD configuration based on current traffic conditions. Typically, the eIMTA_RNTI is signaled in DCI-1C in each of SF0, SF1, SF4, and SF5. Multiplexing and reusing one of these (e.g., SF5) for the CSAT ON duration (T_{ON}) allows both sets of information to be conveyed.

[00101] Turning to system detection, it may be more efficient to perform system acquisition on each of the native RAT channels (e.g., each of the twenty channels defined by Wi-Fi) rather than to run a traditional frequency scan in the unlicensed band. Context awareness can be used to trigger/prohibit scanning and acquisition based on location, time, user mobility state, etc.

[00102] FIG. 10 is a signaling flow diagram illustrating system acquisition in a CSAT communication scheme. In this example, a small cell base station 1004 is providing service via a PCell operating in accordance with a CSAT communication scheme (e.g., of the type described above with reference to FIG. 7) and a user device 1002 is performing system acquisition.

[00103] As shown, the user device 1002 initially receives and processes system synchronization information (e.g., PSS/SSS signaling) (signal 1012). With reference to FIG. 7, the PSS/SSS signaling, for example, may be present in only the first Half Frame (HF) of a given ABRF (e.g., in SF0-SF1) rather than in both HFs (e.g., in SF0-SF1 and SF5-SF6) of a normal RF. Soft combining may be used to reconstruct the PSS/SSS signaling over multiple ABRFs as necessary. From this, the user device 1002 acquires the Physical Cell Identifier (PCI), time slot, and frame synchronization of the base station 1004, which enables the user device 1002 to locate and decode other information.

[00104] In particular, the user device 1002 is able to decode the MIB broadcasted by the base station 1004 (signal 1014).As discussed above, the MIB may be used to provide information regarding CSAT cycle timing (e.g., the CSAT cycle duration (T_{CSAT})), among other information (e.g., SFN). Accordingly, based on the decoded MIB, the user device 1002 may locate the start of the next CSAT cycle (e.g., the RF where SFN mod $T_{CSAT} = 0$), and hence, the next guaranteed CSAT ON period (block 1016).

[00105] At the next guaranteed CSAT ON period (block 1018), the user device 1002 may decode SIB-1,which is guaranteed to be available, and, based on the information in SIB-1, decode SIB-2, and so on (signal 1020). Decoding of SIB-1 and SIB-2 allows the user device 1002 to begin accessing the system (e.g., via RACH) (signal 1022).

[00106] FIG. 11 is a timing diagram illustrating an example paging structure adapted for use in a CSAT communication scheme. In this example, the CSAT cycle duration is set to 8 RFs (i.e., $T_{CSAT} = 8$) and the paging cycle is set to 64 RFs for illustration purposes.

[00107] A Paging Frame (PF) is an RF that may contain one or multiple Paging Occasion (PO) subframes for sending a paging message used for paging and system information change notification. In LTE, for example, the location of a PF for a given user device (LTE UE) is defined by certain paging parameters according to the following equation:

SFN mod T=(T/N)*(UE_ID mod N) (Eq. 1)

[00108] Here, T=min(UE specific Discontinuous Reception (DRX) value, DefaultPagingCycle) and represents the minimum DRX cycle as between the UE-specific DRX cycle and the default, cell-specific DRX cycle. Meanwhile, N=min(T, nB) and represents the number of paging frames in a paging cycle of the UE, where nB={2T, T, T/2, T/4, T/8, T/16, T/32}. Finally, UE_ID=International Mobile Subscriber Identity (IMSI) mod 1024 and is used as a pseudorandom spacing value. The DefaultPagingCycle and nB parameters are broadcast in system information (SIB-2).

[00109] In order to ensure that paging is scheduled during a CSAT ON period, one or more of the paging parameters may be specially configured based on the CSAT cycling parameters to align all PFs with the first RF of a CSAT cycle, which is guaranteed to be a CSAT ON period. For example, the nB parameter may be set to (T / T_{CSAT}) to match the PF periodicity with the CSAT cycle. In the illustrated example, where the CSAT cycle duration is set to 8 RFs (i.e., T_{CSAT} = 8) in FIG. 11, nB may be set to nB = T/8, and hence, N = min(T, T/8) = T/8. Accordingly, the location of a given PF will be at SFN mod T=8 * (UE_ID mod T/8) = a multiple of 8, which aligns with the beginning of CSAT cycles where the cell is guaranteed to be ON even if it is unloaded.

[00110] FIG. 12 is a signaling flow diagram illustrating an example random access procedure that may be adapted for use with a CSAT communication scheme. In this example, a small cell base station 1204 is providing service via a PCell operating in accordance with a CSAT communication scheme (e.g., of the type described above with reference to FIG. 7) and a user device 1202 is performing a contention-based random access procedure to gain access to cell resources.

[00111] Contention-based random access is generally a four step procedure. Initially, the user device transmits a random access preamble (Msg1 1212), the format and PRACH time domain resource allocation of which may be indicated by a PRACH-ConfigurationIndex parameter. In conjunction with transmitting Msg1, the user device sets a Random Access Response (RAR) timer (e.g., in accordance with a ra-ResponseWindowSize parameter)(block 1222) and waits for an RAR message (Msg2 1214)on the PDCCH. Upon receiving Msg2 before the RAR timer expires, the user device cancels the RAR timer (block 1224). Otherwise, the user device retransmits Msg1 1212.

[00112] In Msg2, the user device receives the timing alignment value, resources (uplink grant),and temporary identifier (C-RNTI) to be utilized in transmitting an RRC request (Msg3 1216). In conjunction with transmitting Msg3, the user device sets a Contention Resolution (CR) timer (e.g., in accordance with a mac-ContentionResolutionTimer parameter) (block 1226).

[00113] After transmission of Msg3, the user device monitors the PDCCH for a CR message containing its temporary identifier (Msg4 1218) until expiration of the CR timer. In conjunction with successfully decoding Msg4, the user device cancels the CR timer (block 1228).

[00114] In order to ensure that random access is coordinated with the CSAT pattern employed, one or more of the random access parameters may be specially configured based on the CSAT cycling parameters to constrain PRACH (time) resources and base station responses to only fall within CSAT ON periods. For example, the base station may configure PRACH resources to only fall in the first half of odd frames (e.g., via the prach-ConfigurationIndex satisfying T0 = 2 (odd frames only) and T1 = 0 (located in the first HF)), configure the RAR window to cover SF0 of the first CSAT ON period in the following RF (e.g., via the ra-ResponseWindowSize), configure the contention resolution window to cover multiple CSAT ON periods (e.g., via the mac-ContentionResolutionTimer), and so on.

[00115] FIG. 13 is a timing diagram illustrating an example adaptation of the random access procedure of FIG. 12foroperation with a CSAT communication scheme. In this example, the CSAT cycle duration is set to 2 RFs (i.e., $T_{CSAT} = 2$), the duty cycle is set to ½ (i.e., $T_{ON} = 1$), and the TDD configuration is set to ‘1’ for illustration purposes. Further, the prach-ConfigurationIndex = 1 (i.e., corresponding to a (0, 2, 0, 1) configuration that specifies odd radio frames, the first HF, and the second UL subframe), the RAR window parameter ra-ResponseWindowSize = 10ms, and the Msg3 contention window parameter mac-ContentionResolutionTimer = 32ms.

[00116] As shown, the timing diagram of FIG. 13 covers a full CSAT cycle corresponding to RF_N (a CSAT ON period) through RF_{N+1}(a CSAT OFF period) as well as the preceding RF_{N-1}(a CSAT OFF period) and the succeeding RF_{N+2} (a CSAT ON period). In order to ensure that the RAR Msg2 is delivered in RF_N (a CSAT ON period), the user device sends its preamble Msg1 in the preceding RF_{N-1}(a CSAT OFF period), during the second UL subframe as specified by the prach-ConfigurationIndex. Because

the RAR window parameter ra-ResponseWindowSize is set to a relatively long value (10ms being an illustrative example), the RAR Msg2 delivered in SF0 of RF_N (a CSAT ON period) is guaranteed to be within the RAR window.

[00117] As discussed in more detail above with reference to FIG. 12, upon receiving the RAR Msg2, the user device may send the RRC Msg3 (e.g., later in RF_N) and set its CR timer. Because the CR timer parameter mac-ContentionResolutionTimer is set to a relatively long value (32ms being an illustrative example), the user device may wait for another CSAT ON period at RF_{N+2} to receive the CR Msg4 without the CR timer expiring due to the delay introduced by RF_{N+1} (a CSAT OFF period).

[00118] In some designs, the base station may opportunistically extend the CSAT ON period to finish the RACH procedure (e.g., adapting over all duty cycles and taking into account any increase in T_{ON}).

[00119] Returning to FIG. 7 and the discussion above concerning various user device signaling measurements (e.g., RRM / RLM), these measurements may be coordinated with CSAT operation to ensure that they are not corrupted by performance during CSAT OFF periods when the requisite signaling (e.g., LTE PSS/SSS and/or CRS) may be disabled. Corruption of such measurements may impact not only channel selection, but also other measurement-based procedures, including user device-assisted radio resource and power managing, PCI collision detection, other U-SON algorithms, mobility, tracking loop procedures, etc., thereby detrimentally affecting proper operation of the system.

[00120] To facilitate coordination, user devices may utilize the CSAT parameters broadcast by their respective serving cells (e.g., via MIB and PDCCH signaling as discussed in more detail above). For example, for measurements on its serving cell, a user device may utilize its knowledge of the CSAT cycle (T_{CSAT}) and ON duration (T_{ON}) to run all measurement loops only during CSAT ON periods and during one or more designated subframes (e.g., SF0) in ABRFs of the CSAT OFF periods. For intra-frequency neighbor cells or inter-frequency measurements, although the ON duration (T_{ON}) may not be known per se, a user device may utilize its knowledge of the synchronized CSAT cycle (T_{CSAT}) to perform measurements during minimum guaranteed transmission periods (e.g., the first RF of each CSAT cycle and/or SF0).

[00121] Returning again to FIG. 7, for relatively short CSAT cycles, it may not be feasible to assume that a given HARQ procedure will be able to be completed within a single CSAT ON period. Although DL HARQ is asynchronous and can be continued over multiple CSAT cycles, UL HARQ is synchronous and may run into an intervening CSAT OFF period.

[00122] FIG. 14 is a timing diagram illustrating an adaptation of UL HARQ for operation with a CSAT communication scheme. As in FIG. 6, during CSAT ON periods of communication, transmission on a shared operating spectrum such as an unlicensed band is generally enabled. During CSAT OFF periods, transmission on the shared operating spectrum is generally disabled to allow other-system operations and to conduct medium utilization measurements.

[00123] In this example, UL HARQ is modified to be effectively asynchronous, similar to DL HARQ where the base station provides instructions to the user device regarding which HARQ process to use during each subframe for which resources are allocated. Asynchronous HARQ increases flexibility because re-transmissions do not have to be scheduled during every subframe.

[00124] As shown, however, to implement an asynchronous HARQ scheme while minimizing the changes required, user devices may be configured to refrain from retransmission opportunities that may be scheduled during CSAT OFF periods and continue in the next retransmission opportunity during the next CSAT ON period. Both the user device and the base station will understand and expect this retransmission pattern.

[00125] In other designs, the user device may flush the UL buffer upon reaching a CSAT OFF period, but the base station may resend the packet as a new grant and constrain HARQ parameters to decode in 1-2 transmissions and target low PER. This may be an alternative and simpler solution, but may also impact UL capacity.

[00126] As a further enhancement, user device synchronization with CSAT and its corresponding TDM communication pattern may be coordinated with other communication system operations, such as (connected mode) Discontinuous Reception (DRX, or cDRX).

[00127] FIG. 15 illustrates an example DRX communication mode, which may be used to communicate with certain user devices (illustrated at LTE UEs) for applications that do not require continuous reception. As shown, during certain predetermined or negotiated times, the user device's receiver (RX) is turned ON (e.g., in a connected state), while at other times, it is turned OFF (referred to as a DRX gap) and the user device enters a low power state. During the ON duration of a given DRX cycle, the user device's receiver may monitor a corresponding control channel or the like (illustrated as an LTE PDCCH) to identify DL data. The base station serving the user device may control the DRX operation and schedule communications accordingly.

[00128] To avoid crowding on select resources, user devices may be divided into groups and different groups may monitor the PDCCH at different times. A drxStartOffset parameter may be used to specify different offset subframes for different groups where their respective ON durations are designated to start.

[00129] In general, DRX allows a user device to conserve battery power by monitoring control channels only at configurable or predetermined intervals rather than continuously. It may therefore be advantageous to specially configure one or more DRX parameters (e.g., drxStartOffset) to substantially synchronize DRX operation with CSAT operation (e.g., at least to guarantee that each DRX ON duration overlaps with $T_{ON,min}$).

[00130] FIG. 16 is a timing diagram illustrating an example DRX structure adapted for use in a CSAT communication scheme. In this example, the CSAT cycle duration is set to 2 RFs (i.e., T_{CSAT} = 20ms), the duty cycle is set to ½ (i.e., T_{ON} = 10ms), the minimum CSAT ON period is set to 1 RF (i.e., $T_{ON,min}$ = 10ms), and the TDD configuration is set to ‘1’ for illustration purposes. Further, the DRX cycle is set to twice the CSAT cycle (2 * T_{CSAT}) and the DRX ON duration (onDuration) is set to 6psf (10ms), where psf (PDCCH-Subframe) refers to a subframe with PDCCH. For FDD operation, this represents any subframe, whereas for TDD operation, it represents only DL subframes and subframes including DwPTS. (Thus, 6psf in TDD config1, for example, corresponds to 10ms.)

[00131] As shown, the user devices are divided into two groups, Group 1 and Group 2. In this example, the Group 1 and Group 2 DRX ON durations are staggered across alternating CSAT cycles by setting Group 1 drxStartOffset = 0 and Group 2 drxStartOffset = T_{CSAT}. The DRX ON duration for each user device is aligned with $T_{ON,min}$ as a guaranteed CSAT ON period.

[00132] FIG. 17 is another timing diagram illustrating an example DRX structure adapted for use in a CSAT communication scheme. In this example, the CSAT cycle duration is set to 16 RFs (i.e., T_{CSAT} = 160ms), the duty cycle is set to ½ (i.e., T_{ON} = 80ms), the minimum CSAT ON period is set to 4 RFs (i.e., $T_{ON,min}$ = 40ms), and the

TDD configuration is again set to '1' for illustration purposes. Further, the DRX cycle is set to the CSAT cycle (T_{CSAT}) and the DRX ON duration (onDuration) is set to 12psf (20ms).

[00133] As shown, the user devices are again divided into two groups, Group 1 and Group 2. In this example, the Group 1 and Group 2 DRX ON durations are staggered within a common CSAT cycle by setting Group 1 drxStartOffset = 0 and Group 2 drxStartOffset = $T_{ON,min}$ / 2. The DRX ON duration for each user device is again aligned with $T_{ON,min}$ as a guaranteed CSAT ON period.

[00134] As a further enhancement, in some situations a base station may opportunistically switch a PCell to a DL "lite" configuration during one or more CSAT ON periods to further reduce unnecessary medium utilization and co-channel interference to native RATs. For example, if there is little or no traffic on a given PCell, the base station may switch the PCell to a low duty cycle CSAT pattern coupled with a TDD config0 structure having minimal DL subframes.

[00135] FIG. 18 illustrates an example CSAT communication scheme for a PCell utilizing a DL-lite configuration to opportunistically reduce co-channel interference. As in FIG. 7, during CSAT ON periods of communication, transmission on a shared operating spectrum such as an unlicensed band is generally enabled. During CSAT OFF periods, transmission on the shared operating spectrum is generally disabled to allow other-system operations and to conduct medium utilization measurements, but may contain one or more ABRFs to facilitate continued control signaling as appropriate.

[00136] In this example, the CSAT duty cycle (T_{ON} / T_{CSAT}) is reduced to the minimum allowable setting (i.e., $T_{ON} = T_{ON,min}$), which here is 1 RF (T_{ON} = 10ms) out of 4 RFs (T_{CSAT} = 40ms). In addition, the TDD configuration is set to a minimal DL subframe structure, which here is TDD config0, having only two out of ten subframes configured for DL operation (i.e., SF0 and SF5). Thus, for the illustrated CSAT cycle, this DL lite configuration utilizes a relatively small (e.g., 20% effective) transmission duty cycle, which still provides opportunities for neighbor cell measurements but reduces co-channel interference to other RATs such as Wi-Fi. Further, when the operating scenario changes (e.g., traffic increases), the base station may switch out of the DL lite configuration to a higher duty cycle and/or higher DL usage structure.

[00137] A base station may from time to time desire to switch the PCell for one or more user devices. This may be for load balancing purposes, improved channel selection purposes, etc., which are all the more important for standalone implementations on an unlicensed band where co-existence is more dynamic. Different approaches may be used for different types of PCell switches (e.g., PCell swap vs. PCell add), for different RRC modes (e.g., connected mode vs. idle mode user devices), and so on. Intra-base station handover from one cell to another cell provided by the same base station may be referred to as “self-handover” or “blind handover.”

[00138] FIG. 19is a signaling flow diagram illustrating an example PCell swap procedure for switching the PCell of a connected mode user device between the user device’s existing component carriers. In this example, a small cell base station 1904 is providing service to a user deice 1902 via two cells, a first (source) cell 1908 and a second (target) cell 1906.

[00139] Initially, the source cell 1908 serves as the PCell of the user device 1902 and the target cell 1906 services as an SCell for the user device 1902.However, because of load balancing and/or channel selection determinations, the base station 1904 may desire the user device 1902 to reconfigure its SCell as its PCell and vice versa.

[00140] As shown, the PCell switch from the source cell 1908 to the (existing) target cell 1906 may be achieved with minimal signaling and transparency to the core network. In particular, the base station 1904 may send to the user device 1902 via the source cell 1908 a handover command 1912 instructing the user device to reconfigure its PCell / SCell designations, and in response, the user device 1902 may send to the base station 1904 via the target cell 1906 a handover confirm message 1914. No notification to a Mobility Management Entity (MME) or the like and no packet forwarding are necessary.

[00141] FIG. 20 is a signaling flow diagram illustrating an example PCell add procedure for switching the PCell of a connected mode user device from one of the user device’s existing component carriers to a new component carrier. In this example, a small cell base station 2004 is again providing service to a user deice 2002 via two cells, a first (source) cell 2008 and a second (bridge) cell 2006. The base station 2004 is also capable of providing service on a third (target) cell 2010.

[00142] Initially, the source cell 2008 serves as the PCell of the user device 2002 and the bridge cell 2006 services as an SCell for the user device 2002. However, because of load balancing and/or channel selection determinations, the base station 2004 may desire the user device 2002 to switch its PCell to the target cell 2010.

[00143] As shown, the PCell switch from the source cell 2008 to the (new) target cell 2010 may again be achieved with transparency to the core network. No notification to an MME or the like and no packet forwarding are necessary. However, because the user device 2002 has a limited number of radio chains (two in this example), the base station 2004 may utilize its SCellas an intermediary “bridge” PCell (bridge cell 2006) while it adds the (new) target cell 2010.

[00144] In particular, as in the PCell swap procedure of FIG. 19, the base station 2004 may initially send to the user device 2002 via the source cell 2008 a handover command 2012 instructing the user device to reconfigure its PCell / SCell designations, and in response, the user device 2002 may send to the base station 2004 via the bridge cell 2006 a handover confirm message 2014. Meanwhile, the source cell 2008 may be vacated and the target cell 2010 may be added (block 2016). Once available, the base station 2004 may send to the user device 2002 via the bridge cell 2006 a handover command 2018 instructing the user device to configure the target cell 2010 as its PCell, and in response, the user device 2002 may send to the base station 2004 via the target cell 2010 a handover confirm message 2020.

[00145] In the examples of FIGS. 19 and 20, the user device for which the PCell is being reconfigured is a connected mode user device. For idle mode user devices, there is no active connection and the base station may not know with certainty whether such a user device is actually within its particular coverage area. Accordingly, rather than explicitly commanding idle mode user devices to perform a PCell swap or add, the base station may instead change cell reselection priority(e.g., via SIB-5 signaling to set priority and cell-specific offset) in order to bias the reselection procedure in favor of certain other component carriers. In addition, the base station may bar the current component carrier (e.g., via SIB-1 signaling by setting cellBarred = barred and intraFreqReselection = notallowed) to expedite the search process and prioritize other existing component carriers. In LTE, for example, a barred cell cannot be accessed for cell selection / reselection purposes for 300 seconds. Informing idle mode users about a PCell change may help such user devices to monitor correct paging channels, etc.

[00146] FIG.21 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2100 may be performed, for example, by a base station (e.g., the small cell base station110B illustrated in FIG. 1).

[00147] As shown, the method 2100 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2110). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2120). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00148] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the resource in accordance with a TDM communication pattern (block 2130). The cycling may be variously based on the identified utilization of the resource.

[00149] As discussed in more detail above, the base station may then transmit a one or more ABRFs during at least one depowered period of the TDM communication pattern (block 2140). In accordance with the techniques herein, each ABRF may comprise one or more control signals and omit one or more other signals. The one or more control signals may comprise, for example, at least one of: a PSS, a CRS, a MIB signal, an SSS, or a combination thereof. In some designs, the ABRF may be configured dynamically in accordance with one or more control signal periodicity requirements, the TDM communication pattern, or a combination thereof.

[00150] FIG. 22 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2200 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00151] As shown, the method 2200 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2210). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2220). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00152] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the resource in accordance with a TDM communication pattern (block 2230). The cycling may be variously based on the identified utilization of the resource.

[00153] As discussed in more detail above, the base station may then transmit one or more parameters of the TDM communication pattern to one or more user devices (block 2240).

[00154] The transmitting may comprise conveying a cycle duration of the TDM communication pattern via a MIB signal. For example, the cycle duration may be encoded in one or more reserved bits of the MIB signal.

[00155] The transmitting may also comprise conveying a duty cycle of the TDM communication pattern via a DCI message. For example, the duty cycle may be encoded in one or more bits of a format 1C DCI message.

[00156] FIG. 23 is a flow diagram illustrating an example method of system acquisition in an unlicensed band of radio frequencies. The method 2300 may be performed, for example, by a user device (e.g., the user device 120C illustrated in FIG. 1).

[00157] As shown, the method 2300 may include the user device receiving system synchronization information from a base station (block 2310) and decoding a MIB signal of the base station based on the system synchronization information (block 2320). Based on the decoded MIB signal, the user device may determine cycle timing information relating to a cycling of operation by the base station on a PCell between powered and depowered periods of transmission in accordance with a TDM communication pattern (block 2330), and monitor SIB signaling in accordance with a receive window that is set based on the cycle timing information (block 2340).

[00158] FIG. 24 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2400 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00159] As shown, the method 2400 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2410). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2420). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00160] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the

resource in accordance with a TDM communication pattern (block 2430). The cycling may be variously based on the identified utilization of the resource.

[00161] As discussed in more detail above, the base station may then set one or more paging parameters to align user device paging with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern (block 2440), and transmit a paging message to a user device in accordance with the one or more paging parameters (block 2450).

[00162] FIG. 25 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2500 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00163] As shown, the method 2500 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2510). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2520). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00164] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the resource in accordance with a TDM communication pattern (block 2530). The cycling may be variously based on the identified utilization of the resource.

[00165] As discussed in more detail above, the base station may then set one or more random access parameters to align random access resources with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern (block 2540), and transmit the one or more random access parameters to a user device for use in a random access procedure (block 2550).

[00166] In some designs, the method 2500 may further comprise extending at least one powered period of the TDM communication pattern to complete the random access procedure.

[00167] FIG. 26 is a flow diagram illustrating an example method of system monitoring in an unlicensed band of radio frequencies. The method 2600 may be performed, for example, by a user device (e.g., the user device 120C illustrated in FIG. 1).

[00168] As shown, the method 2600 may include the user device determining cycle timing information relating to a cycling of operation by a base station on a PCell between powered and depowered periods of transmission in accordance with a TDM communication pattern (block 2610), and monitoring signaling (e.g., PSS, SSS, and/or CRS) on a first unlicensed frequency corresponding to the PCell (e.g., intra-frequency monitoring) and/or a second unlicensed frequency (e.g., inter-frequency monitoring) during at least one powered period of the TDM communication pattern, during a designated subframe of at least one depowered period of the TDM communication pattern, or a combination thereof (block 2620). The user device may then disable monitoring of the signaling on the first unlicensed frequency and/or the second unlicensed frequency during other subframes of at least one depowered period of the TDM communication pattern (block 2630).

[00169] FIG. 27 is a flow diagram illustrating an example method of mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2700 may be performed, for example, by a user device (e.g., the user device 120C illustrated in FIG. 1).

[00170] As shown, the method 2700 may include the user device determining cycle timing information relating to a cycling of operation by a base station on a PCell between powered and depowered periods of transmission in accordance with a TDM communication pattern (block 2710), and beginning an uplink HARQ retransmission procedure during a first powered period of the TDM communication pattern (block 2720). The user device may subsequently ignore one or more scheduled transmission opportunities associated with the HARQ retransmission procedure during a depowered period of the TDM communication pattern (block 2730), and resume the HARQ retransmission procedure during a second powered period of the TDM communication pattern (block 2740).

[00171] FIG. 28 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2800 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00172] As shown, the method 2800 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2810). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The

base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2820). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00173] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the resource in accordance with a TDM communication pattern (block 2830). The cycling may be variously based on the identified utilization of the resource.

[00174] As discussed in more detail above, the base station may then set one or more DRX parameters to align DRX operation with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern (block 2840), and transmit the one or more DRX parameters to one or more user devices for use in a DRX cycling operation (block 2850). The one or more user devices may comprise, for example, a first group of user devices and a second group of user devices, the first and second groups being transmitted respective DRX parameters to align them with a minimum powered period of the TDM communication pattern and to stagger them within or between cycles of the TDM communication pattern.

[00175] FIG. 29 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 2900 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00176] As shown, the method 2900 may include the base station receiving signals via a resource using a first RAT (e.g., Wi-Fi) (block 2910). The resource may be an unlicensed radio frequency band shared by Wi-Fi and LTE devices, for example. The base station may then identify utilization of the resource associated with the first RAT based on the received signals (block 2920). Utilization of the resource may give an indication of an amount of interference (e.g., co-channel interference).

[00177] In response, the base station may cycle operation of a second RAT (e.g., LTE) on a PCell between powered and depowered periods of transmission over the resource in accordance with a TDM communication pattern (block 2930). The cycling may be variously based on the identified utilization of the resource.

[00178] As discussed in more detail above, the base station may then opportunistically depower transmission on a portion of at least one powered period of the TDM communication pattern based on a loading condition of the second RAT (block 2940). The method 2900 may further comprise, in some designs, opportunistically setting one or more cycling parameters of the TDM communication pattern based on the loading condition of the second RAT.

[00179] FIG.30 is a flow diagram illustrating an example method of communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies. The method 3000 may be performed, for example, by a base station (e.g., the small cell base station 110B illustrated in FIG. 1).

[00180] As shown, the method 3000 may include the base station exchanging control and data signaling on a PCell provided by a base station operating on the shared operating spectrum (block 3010), and exchanging data signaling on an SCell provided by the base station operating on the shared operating spectrum (block 3020). As discussed in more detail above, the base station may then reconfigure the SCell as the PCell and the PCell as the SCell for one or more user devices based on a load balancing condition or a channel selection algorithm (block 3030).

[00181] In some designs, the method 3000 may further comprise switching the reconfigured PCell to a new component carrier. In some designs, the method 3000 may further comprise signaling one or more adjusted cell reselection parameters to an idle mode user to bias cell reselection in favor of a target PCell, and triggering the cell reselection.

[00182] FIG. 31 illustrates several sample components (represented by corresponding blocks) that may be incorporated into an apparatus 3102, an apparatus 3104, and an apparatus 3106 (corresponding to, for example, a user device, a base station, and a network entity, respectively) to support the SA CSAT operations as taught herein. It will be appreciated that these components may be implemented in different types of apparatuses in different implementations (e.g., in an ASIC, in an SoC, etc.).The illustrated components may also be incorporated into other apparatuses in a communication system. For example, other apparatuses in a system may include components similar to those described to provide similar functionality. Also, a given apparatus may contain one or more of the components. For example, an apparatus may include multiple transceiver components that enable the apparatus to operate on multiple carriers and/or communicate via different technologies.

[00183] The apparatus 3102 and the apparatus 3104 each include at least one wireless communication device (represented by the communication devices 3108 and 3114 (and the communication device 3120 if the apparatus 3104 is a relay)) for communicating with other nodes via at least one designated RAT. Each communication device 3108 includes at least one transmitter (represented by the transmitter 3110) for transmitting and encoding signals (e.g., messages, indications, information, and so on) and at least one receiver (represented by the receiver 3112) for receiving and decoding signals (e.g., messages, indications, information, pilots, and so on).Similarly, each communication device 3114 includes at least one transmitter (represented by the transmitter 3116) for transmitting signals (e.g., messages, indications, information, pilots, and so on) and at least one receiver (represented by the receiver 3118) for receiving signals (e.g., messages, indications, information, and so on).If the apparatus 3104 is a relay station, each communication device 3120 may include at least one transmitter (represented by the transmitter 3122) for transmitting signals (e.g., messages, indications, information, pilots, and so on) and at least one receiver (represented by the receiver 3124) for receiving signals (e.g., messages, indications, information, and so on).

[00184] A transmitter and a receiver may comprise an integrated device (e.g., embodied as a transmitter circuit and a receiver circuit of a single communication device) in some implementations, may comprise a separate transmitter device and a separate receiver device in some implementations, or may be embodied in other ways in other implementations. A wireless communication device (e.g., one of multiple wireless communication devices) of the apparatus 3104 may also comprise a Network Listen Module (NLM) or the like for performing various measurements.

[00185] The apparatus 3106 (and the apparatus 3104 if it is not a relay station) includes at least one communication device (represented by the communication device 3126 and, optionally, 3120) for communicating with other nodes. For example, the communication device 3126 may comprise a network interface that is configured to communicate with one or more network entities via a wire-based or wireless backhaul. In some aspects, the communication device 3126 may be implemented as a transceiver configured to support wire-based or wireless signal communication. This communication may involve, for example, sending and receiving: messages, parameters, or other types of information. Accordingly, in the example of FIG. 31, the communication device 3126 is shown as comprising a transmitter 3128 and a receiver 3130.Similarly, if the apparatus 3104 is not a relay station, the communication device 3120 may comprise a network interface that is configured to communicate with one or more network entities via a wire-based or wireless backhaul. As with the communication device 3126, the communication device 3120 is shown as comprising a transmitter 3122 and a receiver 3124.

[00186] The apparatuses 3102, 3104, and 3106 also include other components that may be used in conjunction with the SA CSAT operations as taught herein. The apparatus 3102 includes a processing system 3132 for providing functionality relating to, for example, user device operations to support SA CSAT as taught herein and for providing other processing functionality. The apparatus 3104 includes a processing system 3134 for providing functionality relating to, for example, base station operations to support SA CSAT as taught herein and for providing other processing functionality. The apparatus 3106 includes a processing system 3136 for providing functionality relating to, for example, network operations to support SA CSAT as taught herein and for providing other processing functionality. The apparatuses 3102, 3104, and 3106 include memory components 3138, 3140, and 3142 (e.g., each including a memory device), respectively, for maintaining information (e.g., information indicative of reserved resources, thresholds, parameters, and so on).In addition, the apparatuses 3102, 3104, and 3106 include user interface devices 3144, 3146, and 3148, respectively, for providing indications (e.g., audible and/or visual indications) to a user and/or for receiving user input (e.g., upon user actuation of a sensing device such a keypad, a touch screen, a microphone, and so on).

[00187] For convenience, the apparatuses 3102, 3104, and/or 3106 are shown in FIG. 31 as including various components that may be configured according to the various examples described herein. It will be appreciated, however, that the illustrated blocks may have different functionality in different designs.

[00188] The components of FIG. 31 may be implemented in various ways. In some implementations, the components of FIG. 31 may be implemented in one or more circuits such as, for example, one or more processors and/or one or more ASICs (which may include one or more processors).Here, each circuit may use and/or incorporate at least one memory component for storing information or executable code used by the circuit to provide this functionality. For example, some or all of the functionality represented by blocks 3108, 3132, 3138, and 3144 may be implemented by processor and memory component(s) of the apparatus 3102 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Similarly, some or all of the functionality represented by blocks 3114, 3120, 3134, 3140, and 3146 may be implemented by processor and memory component(s) of the apparatus 3104 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components).Also, some or all of the functionality represented by blocks 3126, 3136, 3142, and 3148 may be implemented by processor and memory component(s) of the apparatus 3106 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components).

[00189] FIG.32 illustrates an example base station apparatus 3200 represented as a series of interrelated functional modules. A module for receiving 3202 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 3204 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 3206 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for transmitting 3208 may correspond at least in some aspects to, for example, communication device as discussed herein.

[00190] FIG. 33 illustrates an example base station apparatus 3300 represented as a series of interrelated functional modules. A module for receiving 3302 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 3304 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 3306 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for transmitting 3308 may correspond at least in some aspects to, for example, a communication device as discussed herein.

[00191] FIG.34 illustrates an example user device apparatus 3400 represented as a series of interrelated functional modules. A module for receiving 3402 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for decoding 3404 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for determining 3406 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for monitoring 3408 may correspond at least in some aspects to, for example, a communication device as discussed herein.

[00192] FIG. 35 illustrates an example base station apparatus 3500 represented as a series of interrelated functional modules. A module for receiving 3502 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 3504 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 3506 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for setting 3508 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for transmitting 3510 may correspond at least in some aspects to, for example, a communication device as discussed herein.

[00193] FIG. 36 illustrates an example base station apparatus 3600 represented as a series of interrelated functional modules. A module for receiving 3602 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 3604 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 3606 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for setting 3608 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for transmitting 3610 may correspond at least in some aspects to, for example, a communication device as discussed herein.

[00194] FIG. 37 illustrates an example user device apparatus 3700 represented as a series of interrelated functional modules. A module for determining 3702 may correspond at least in some aspects to, for example, processing system in conjunction with a communication device as discussed herein. A module for monitoring 3704 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for disabling 3706 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein.

[00195] FIG. 38 illustrates an example user device apparatus 3800 represented as a series of interrelated functional modules. A module for determining 3802 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for beginning 3804 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for ignoring 3806 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for resuming 3808 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein.

[00196] FIG. 39 illustrates an example base station apparatus 3900 represented as a series of interrelated functional modules. A module for receiving 3902 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 3904 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 3906 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for setting 3908 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for transmitting 3910 may correspond at least in some aspects to, for example, a communication device as discussed herein.

[00197] FIG. 40 illustrates an example base station apparatus 4000 represented as a series of interrelated functional modules. A module for receiving 4002 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for identifying 4004 may correspond at least in some aspects to, for example, a processing system as discussed herein. A module for cycling 4006 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein. A module for depowering 4008 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein.

[00198] FIG. 41 illustrates an example user device apparatus 4100 represented as a series of interrelated functional modules. A module for exchanging 4102 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for exchanging 4104 may correspond at least in some aspects to, for example, a communication device as discussed herein. A module for reconfiguring 4106 may correspond at least in some aspects to, for example, a processing system in conjunction with a communication device as discussed herein.

[00199] The functionality of the modules of FIGS.32-41 may be implemented in various ways consistent with the teachings herein. In some designs, the functionality of these modules may be implemented as one or more electrical components. In some designs, the functionality of these blocks may be implemented as a processing system including one or more processor components. In some designs, the functionality of these modules may be implemented using, for example, at least a portion of one or more integrated circuits (e.g., an ASIC). As discussed herein, an integrated circuit may include a processor, software, other related components, or some combination thereof. Thus, the functionality of different modules may be implemented, for example, as different subsets of an integrated circuit, as different subsets of a set of software modules, or a combination thereof. Also, it will be appreciated that a given subset (e.g., of an integrated circuit and/or of a set of software modules) may provide at least a portion of the functionality for more than one module.

[00200] In addition, the components and functions represented by FIGS.32-41, as well as other components and functions described herein, may be implemented using any suitable means. Such means also may be implemented, at least in part, using corresponding structure as taught herein. For example, the components described above in conjunction with the "module for" components of FIGS.32-41 also may correspond to similarly designated "means for" functionality. Thus, in some aspects one or more of such means may be implemented using one or more of processor components, integrated circuits, or other suitable structure as taught herein.

[00201] FIG. 42 illustrates an example communication system environment in which the SA CSAT teachings and structures herein may be incorporated. The wireless communication system 4200, which will be described at least in part as an LTE network for illustration purposes, includes a number of eNBs 4210 and other network entities. Each of the eNBs 4210 provides communication coverage for a particular geographic area, such as macro cell or small cell coverage areas.

[00202] In the illustrated example, the eNBs 4210A, 4210B, and 4210Care macro cell eNBs for the macro cells 4202A, 4202B, and 4202C, respectively. The macro cells 4202A, 4202B, and 4202C may cover a relatively large geographic area (e.g., several kilometers in radius) and may allow unrestricted access by UEs with service subscription. The eNB 4210Xis a particular small cell eNB referred to as a pico cell eNB for the pico cell 4202X. The pico cell 4202X may cover a relatively small geographic area and may allow unrestricted access by UEs with service subscription. The eNBs 4210Y and 4210Zare particular small cells referred to as femto cell eNBs for the femto cells 4202Y and 4202Z, respectively. The femto cells 4202Y and 4202Z may cover a relatively small geographic area (e.g., a home) and may allow unrestricted access by UEs (e.g., when operated in an open access mode) or restricted access by UEs having association with the femto cell (e.g., UEs in a Closed Subscriber Group (CSG), UEs for users in the home, etc.), as discussed in more detail below.

[00203] The wireless network 4200 also includes a relay station 4210R. A relay station is a station that receives a transmission of data and/or other information from an upstream station (e.g., an eNB or a UE) and sends a transmission of the data and/or other information to a downstream station (e.g., a UE or an eNB). A relay station may also be a UE that relays transmissions for other UEs (e.g., a mobile hotspot). In the example shown in FIG. 42, the relay station 4210R communicates with the eNB 4210A and a UE 4220R in order to facilitate communication between the eNB 4210A and the UE 4220R. A relay station may also be referred to as a relay eNB, a relay, etc.

[00204] The wireless network 4200 is a heterogeneous network in that it includes eNBs of different types, including macro eNBs, pico eNBs, femto eNBs, relays, etc. As discussed in more detail above, these different types of eNBs may have different transmit power levels, different coverage areas, and different impacts on interference in the wireless network 4200. For example, macro eNBs may have a relatively high transmit power level whereas pico eNBs, femto eNBs, and relays may have a lower transmit power level (e.g., by a relative margin, such as a 10 dBm difference or more).

[00205] Returning to FIG. 42, the wireless network 4200 may support synchronous or asynchronous operation. For synchronous operation, the eNBs may have similar frame timing, and transmissions from different eNBs may be approximately aligned in time. For asynchronous operation, the eNBs may have different frame timing, and transmissions from different eNBs may not be aligned in time. Unless otherwise noted, the techniques described herein may be used for both synchronous and asynchronous operation.

[00206] A network controller 4230 may couple to a set of eNBs and provide coordination and control for these eNBs. The network controller 4230 may communicate with the eNBs 4210 via a backhaul. The eNBs 4210 may also communicate with one another, e.g., directly or indirectly via a wireless or wireline backhaul.

[00207] As shown, the UEs 4220 may be dispersed throughout the wireless network 4200, and each UE may be stationary or mobile, corresponding to, for example, a cellular phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a laptop computer, a cordless phone, a wireless local loop (WLL) station, or other mobile entities. In FIG. 42, a solid line with double arrows indicates desired transmissions between a UE and a serving eNB, which is an eNB designated to serve the UE on the downlink and/or uplink. A dashed line with double arrows indicates potentially interfering transmissions between a UE and an eNB. For example, UE 4220Y may be in proximity to femto eNBs 4210Y, 4210Z. Uplink transmissions from UE 4220Y may interfere with femto eNBs 4210Y, 4210Z.Uplink transmissions from UE 4220Y may jam femto eNBs 4210Y, 4210Z and degrade the quality of reception of other uplink signals to femto eNBs 4210Y, 4210Z.

[00208] Small cell eNBs such as the pico cell eNB 4210X and femto eNBs 4210Y, 4210Z may be configured to support different types of access modes. For example, in an open access mode, a small cell eNB may allow any UE to obtain any type of service via the small cell. In a restricted (or closed) access mode, a small cell may only allow authorized UEs to obtain service via the small cell. For example, a small cell eNB may only allow UEs (e.g., so called home UEs) belonging to a certain subscriber group (e.g., a CSG) to obtain service via the small cell. In a hybrid access mode, alien UEs (e.g., non-home UEs, non-CSG UEs) may be given limited access to the small cell. For example, a macro UE that does not belong to a small cell's CSG may be allowed to access the small cell only if sufficient resources are available for all home UEs currently being served by the small cell.

[00209] By way of example, femto eNB 4210Y may be an open-access femto eNB with no restricted associations to UEs. The femto eNB 4210Z may be a higher transmission power eNB initially deployed to provide coverage to an area. Femto eNB 4210Z may be deployed to cover a large service area. Meanwhile, femto eNB 4210Y may be a lower transmission power eNB deployed later than femto eNB 4210Z to provide coverage for a hotspot area (e.g., a sports arena or stadium) for loading traffic from either or both eNB 4210C, eNB 4210Z.

[00210] It should be understood that any reference to an element herein using a designation such as “first,” “second,” and so forth does not generally limit the quantity or order of those elements. Rather, these designations may be used herein as a convenient method of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements may be employed there or that the first element must precede the second element in some manner. Also, unless stated otherwise a set of elements may comprise one or more elements. In addition, terminology of the form “at least one of A, B, or C” or “one or more of A, B, or C” or “at least one of the group consisting of A, B, and C” used in the description or the claims means “A or B or C or any combination of these elements.” For example, this terminology may include A, or B, or C, or A and B, or A and C, or A and B and C, or 2A, or 2B, or 2C, and so on.

[00211] In view of the descriptions and explanations above, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[00212] Accordingly, it will be appreciated, for example, that an apparatus or any component of an apparatus may be configured to (or made operable to or adapted to) provide functionality as taught herein. This may be achieved, for example: by manufacturing (e.g., fabricating) the apparatus or component so that it will provide the functionality; by programming the apparatus or component so that it will provide the functionality; or through the use of some other suitable implementation technique. As one example, an integrated circuit may be fabricated to provide the requisite functionality. As another example, an integrated circuit may be fabricated to support the requisite functionality and then configured (e.g., via programming) to provide the requisite functionality. As yet another example, a processor circuit may execute code to provide the requisite functionality.

[00213] Moreover, the methods, sequences, and/or algorithms described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor (e.g., cache memory).

[00214] Accordingly, it will also be appreciated, for example, that certain aspects of the disclosure can include a computer-readable medium embodying a method for communication for mitigating interference between RATs sharing operating spectrum in an unlicensed band of radio frequencies.

[00215] While the foregoing disclosure shows various illustrative aspects, it should be noted that various changes and modifications may be made to the illustrated examples without departing from the scope defined by the appended claims. The present disclosure is not intended to be limited to the specifically illustrated examples alone. For example, unless otherwise noted, the functions, steps, and/or actions of the method claims in accordance with the aspects of the disclosure described herein need not be performed in any particular order. Furthermore, although certain aspects may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

CLAIMS

WHAT IS CLAIMED IS:

1. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource; and

transmitting one or more Almost Blank Radio Frames (ABRFs) during at least one depowered period of the TDM communication pattern, wherein each ABRF comprises one or more control signals and omits one or more other signals.

2. The method of claim 1, wherein the one or more control signals comprise at least one of: a Primary Synchronization Signal (PSS), a Cell-specific Reference Signal (CRS), a Master Information Block (MIB) signal, a Secondary Synchronization Signal (SSS), or a combination thereof.

3. The method of claim 1, wherein the ABRF is configured dynamically in accordance with one or more control signal periodicity requirements, the TDM communication pattern, or a combination thereof.

4. The method of claim 1, wherein:

the resource is an unlicensed radio frequency band;

the first RAT comprises Wi-Fi technology; and

the second RAT comprises Long Term Evolution (LTE) technology.

5. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource; and

transmitting one or more parameters of the TDM communication pattern to one or more user devices.

6. The method of claim 5, wherein the transmitting comprises conveying a cycle duration of the TDM communication pattern via a Master Information Block (MIB) signal.

7. The method of claim 6, wherein the cycle duration is encoded in one or more reserved bits of the MIB signal.

8. The method of claim 5, wherein the transmitting comprises conveying a duty cycle of the TDM communication pattern via a Downlink Control Information (DCI) message.

9. The method of claim 8, wherein the duty cycle is encoded in one or more bits of a format 1C DCI message.

10. A method of system acquisition in an unlicensed band of radio frequencies, the method comprising:

receiving system synchronization information from a base station;

decoding a Master Information Block (MIB) signal of the base station based on the system synchronization information;

determining cycle timing information relating to a cycling of operation by the base station on a Primary Cell (PCell) between powered and depowered periods of transmission in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycle timing information is determined based on the decoded MIB signal; and

monitoring System Information Block (SIB) signaling in accordance with a receive window that is set based on the cycle timing information.

11. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource;

setting one or more paging parameters to align user device paging with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern; and

transmitting a paging message to a user device in accordance with the one or more paging parameters.

12. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource;

setting one or more random access parameters to align random access resources with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern; and

transmitting the one or more random access parameters to a user device for use in a random access procedure.

13. The method of claim 12, further comprising extending at least one powered period of the TDM communication pattern to complete the random access procedure.

14. A method of system monitoring in an unlicensed band of radio frequencies, the method comprising:

determining cycle timing information relating to a cycling of operation by a base station on a Primary Cell (PCell) between powered and depowered periods of transmission in accordance with a Time Division Multiplexing (TDM) communication pattern;

monitoring, by a user device, signaling on a first unlicensed frequency corresponding to the PCell and/or a second unlicensed frequency during at least one powered period of the TDM communication pattern, during a designated subframe of at least one depowered period of the TDM communication pattern, or a combination thereof; and

disabling monitoring by the user device of the signaling on the first unlicensed frequency and/or the second unlicensed frequency during other subframes of at least one depowered period of the TDM communication pattern.

15. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

determining cycle timing information relating to a cycling of operation by a base station on a Primary Cell (PCell) between powered and depowered periods of transmission in accordance with a Time Division Multiplexing (TDM) communication pattern;

beginning an uplink Hybrid Automatic Repeat Request (HARQ) retransmission procedure during a first powered period of the TDM communication pattern;

ignoring one or more scheduled transmission opportunities associated with the HARQ retransmission procedure during a depowered period of the TDM communication pattern; and

resuming the HARQ retransmission procedure during a second powered period of the TDM communication pattern.

16. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource;

setting one or more Discontinuous Reception (DRX) parameters to align DRX operation with at least one powered period of the TDM communication pattern, wherein the setting is based on the TDM communication pattern; and

transmitting the one or more DRX parameters to one or more user devices for use in a DRX cycling operation.

17. The method of claim 16, wherein the one or more user devices comprise a first group of user devices and a second group of user devices, the first and second groups being transmitted respective DRX parameters to align them with a minimum

powered period of the TDM communication pattern and to stagger them within or between cycles of the TDM communication pattern.

18. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

receiving signals via a resource, wherein a first RAT is used to receive the signals;

identifying utilization of the resource associated with the first RAT, wherein the identification is based on the received signals;

cycling operation of a second RAT on a Primary Cell (PCell) between powered and depowered periods of transmission over the resource in accordance with a Time Division Multiplexing (TDM) communication pattern, wherein the cycling is based on the identified utilization of the resource; and

opportunistically depowering transmission on a portion of at least one powered period of the TDM communication pattern based on a loading condition of the second RAT.

19. The method of claim 18, further comprising opportunistically setting one or more cycling parameters of the TDM communication pattern based on the loading condition of the second RAT.

20. A method of communication for mitigating interference between Radio Access Technologies (RATs) sharing operating spectrum in an unlicensed band of radio frequencies, the method comprising:

exchanging control and data signaling on a Primary Cell (PCell) provided by a base station operating on the shared operating spectrum;

exchanging data signaling on a Secondary Cell (SCell) provided by the base station operating on the shared operating spectrum; and

reconfiguring the SCell as the PCell and the PCell as the SCell for one or more user devices based on a load balancing condition or a channel selection algorithm.

21. The method of claim 20, further comprising switching the reconfigured PCell to a new component carrier.

22. The method of claim 20, further comprising:

signaling one or more adjusted cell reselection parameters to an idle mode user to bias cell reselection in favor of a target PCell; and

triggering the cell reselection.

23. An apparatus comprising at least one processor and memory coupled to the at least one processor, the at least one processor and memory being configured to perform a method in accordance with any of claims 1 to 22.

24. An apparatus comprising means for performing a method in accordance with any of claims 1 to 22.

25. A computer-readable medium comprising at least one instruction for causing a computer or processor to perform a method in accordance with any of claims 1 to 22.

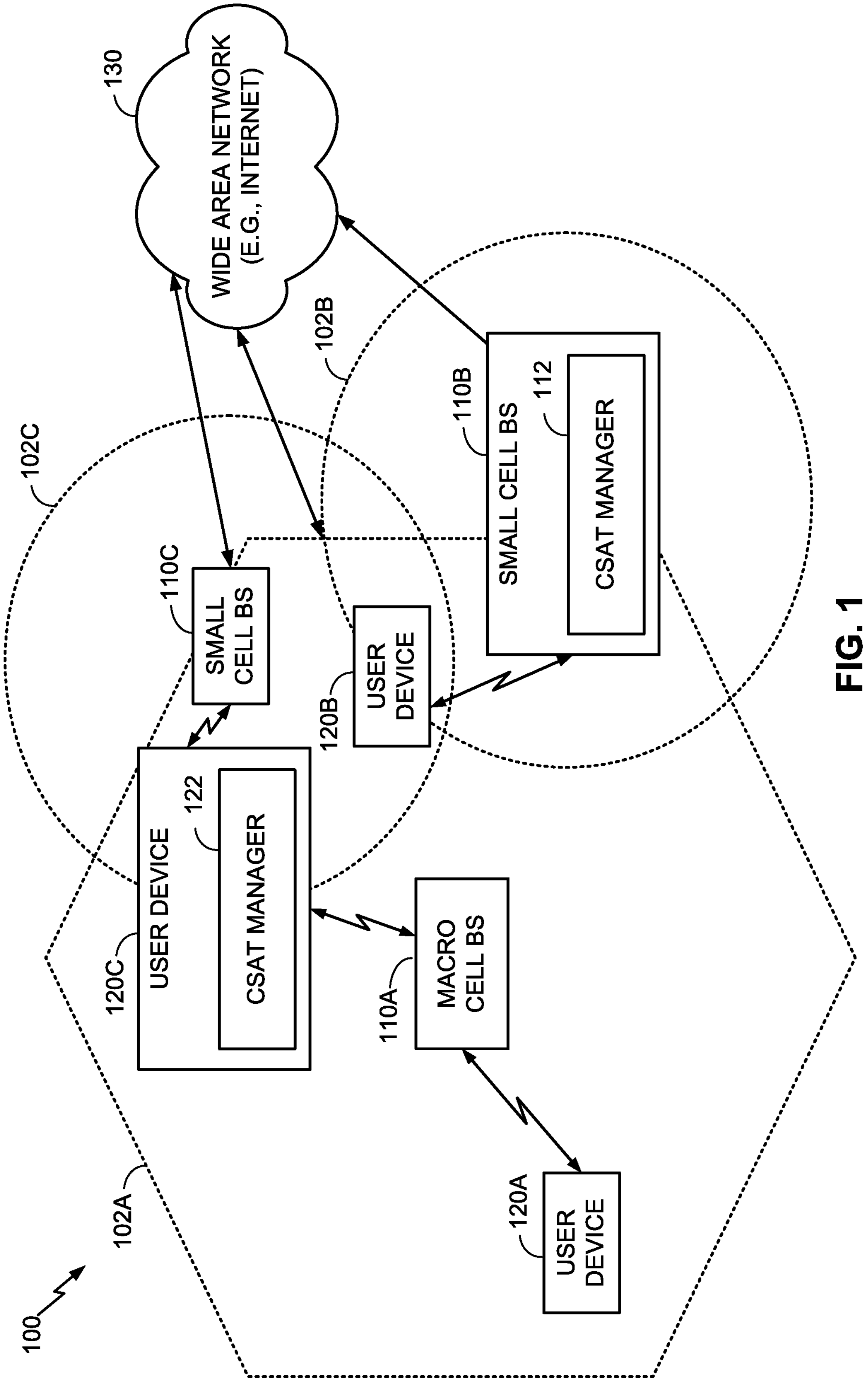
100
102A
102B
102C
110A
MACRO CELL BS
110B
SMALL CELL BS
110C
SMALL CELL BS
112
CSAT MANAGER
120A
USER DEVICE
120B
USER DEVICE
120C
USER DEVICE
122
CSAT MANAGER
130
WIDE AREA NETWORK
(E.G., INTERNET)

FIG. 1

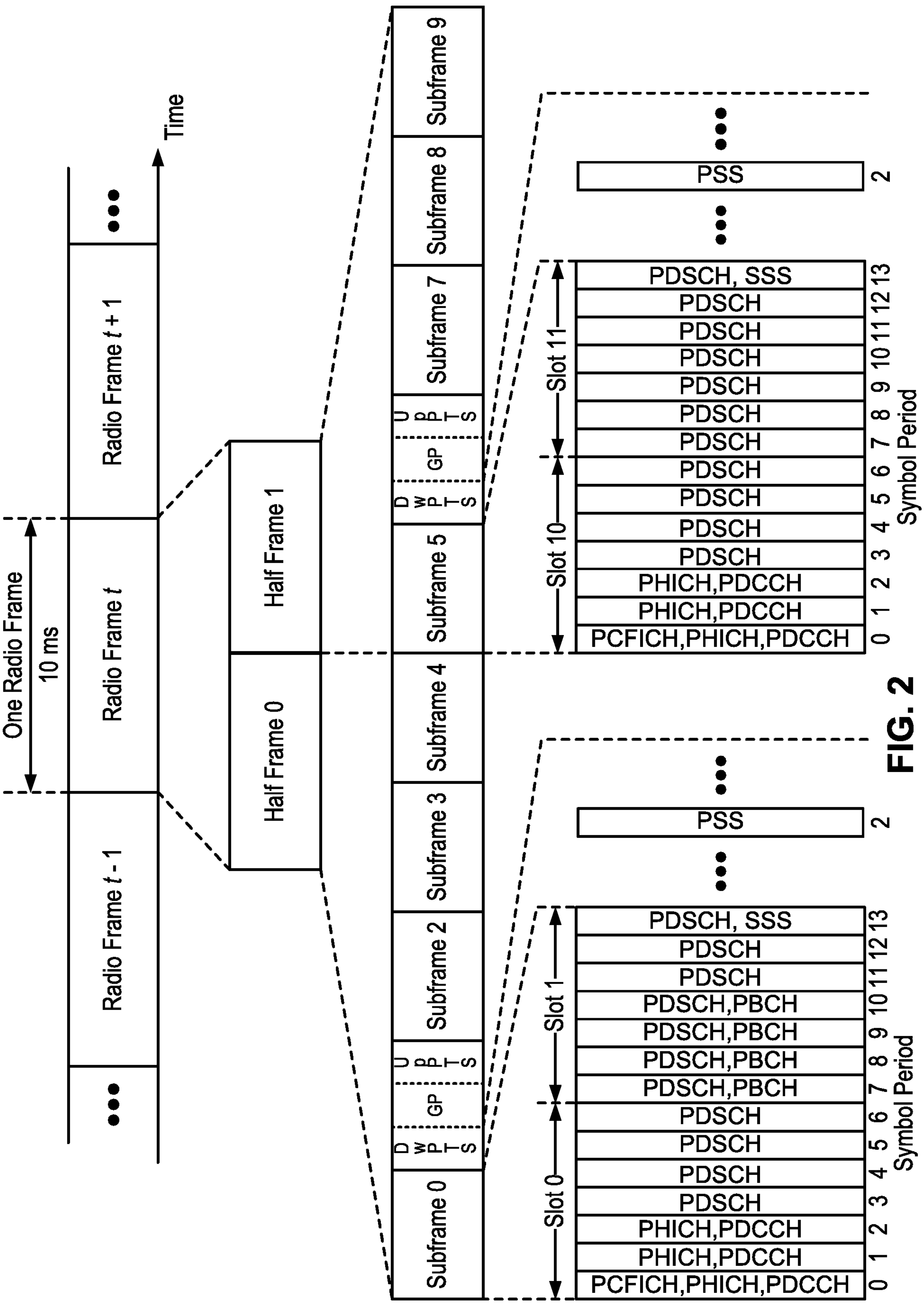
One Radio Frame
10 ms
Time
Radio Frame t - 1
Radio Frame t
Radio Frame t + 1
Half Frame 0
Half Frame 1
Subframe 0
DwPTS
GP
UpPTS
Subframe 2
Subframe 3
Subframe 4
Subframe 5
DwPTS
GP
UpPTS
Subframe 7
Subframe 8
Subframe 9
Slot 0
Slot 1
Slot 10
Slot 11
PCFICH,PHICH,PDCCH
PHICH,PDCCH
PHICH,PDCCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH,PBCH
PDSCH,PBCH
PDSCH,PBCH
PDSCH,PBCH
PDSCH
PDSCH
PDSCH, SSS
PSS
PCFICH,PHICH,PDCCH
PHICH,PDCCH
PHICH,PDCCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH, SSS
PSS
0 1 2 3 4 5 6 7 8 9 10 11 12 13
2
Symbol Period

FIG. 2

UL/DL configuration	Period (ms)	Subframe									
		0	1	2	3	4	5	6	7	8	9
0	5	D	S	U	U	U	D	S	U	U	U
1		D	S	U	U	D	D	S	U	U	D
2		D	S	U	D	D	D	S	U	D	D
3	10	D	S	U	U	U	D	D	D	D	D
4		D	S	U	U	D	D	D	D	D	D
5		D	S	U	D	D	D	D	D	D	D
6	5	D	S	U	U	U	D	S	U	U	D

FIG. 3

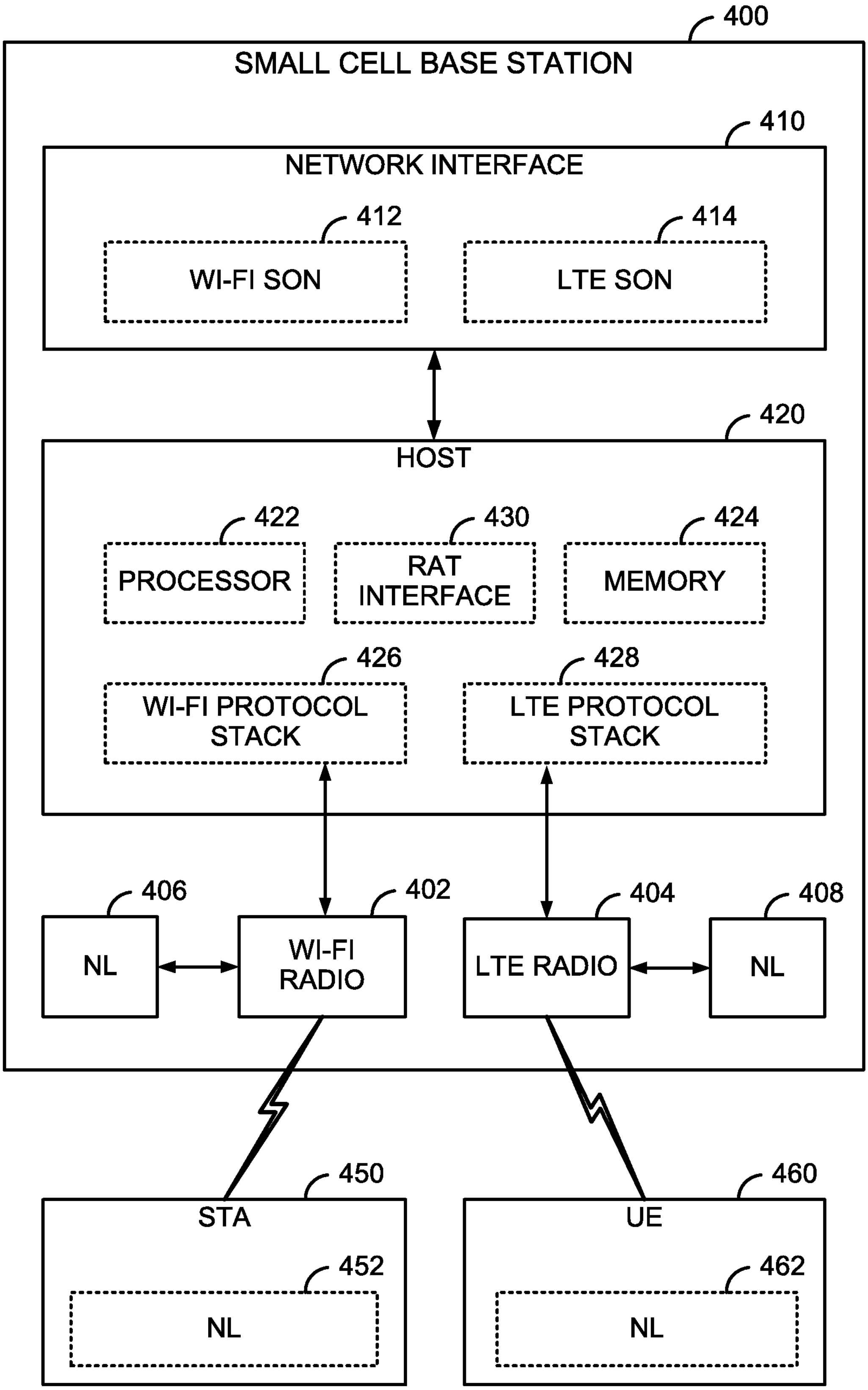
400
SMALL CELL BASE STATION
410
NETWORK INTERFACE
412
WI-FI SON
414
LTE SON
420
HOST
422
PROCESSOR
430
RAT
INTERFACE
424
MEMORY
426
WI-FI PROTOCOL
STACK
428
LTE PROTOCOL
STACK
406
NL
402
WI-FI
RADIO
404
LTE RADIO
408
NL
450
STA
452
NL
460
UE
462
NL

FIG. 4

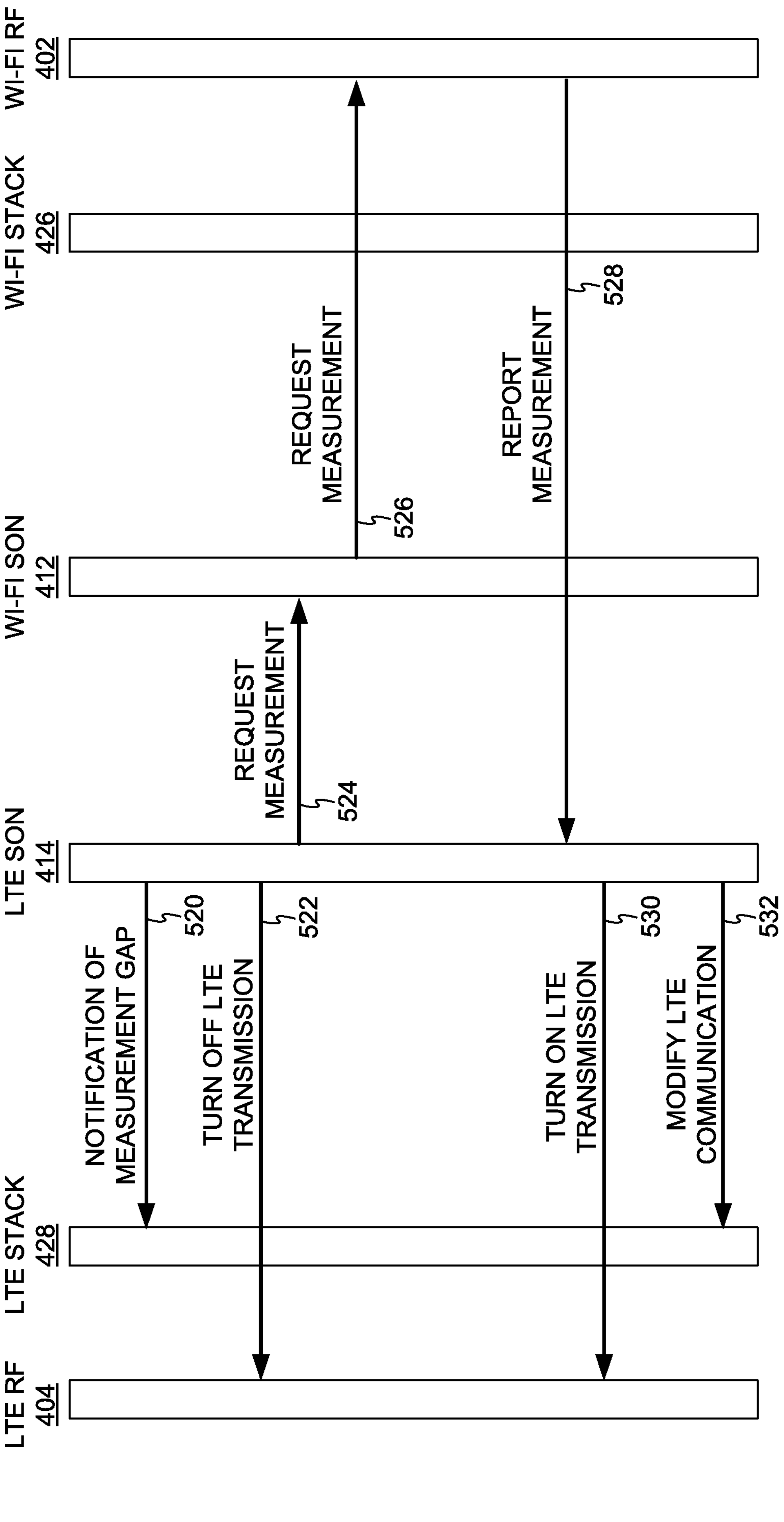
WI-FI RF
402
WI-FI STACK
426
WI-FI SON
412
LTE SON
414
LTE STACK
428
LTE RF
404
REQUEST MEASUREMENT
526
REPORT MEASUREMENT
528
REQUEST MEASUREMENT
524
NOTIFICATION OF MEASUREMENT GAP
520
TURN OFF LTE TRANSMISSION
522
TURN ON LTE TRANSMISSION
530
MODIFY LTE COMMUNICATION
532

FIG. 5

CARRIER SENSE ADAPTIVE TRANSMISSION (CSAT) SCHEME

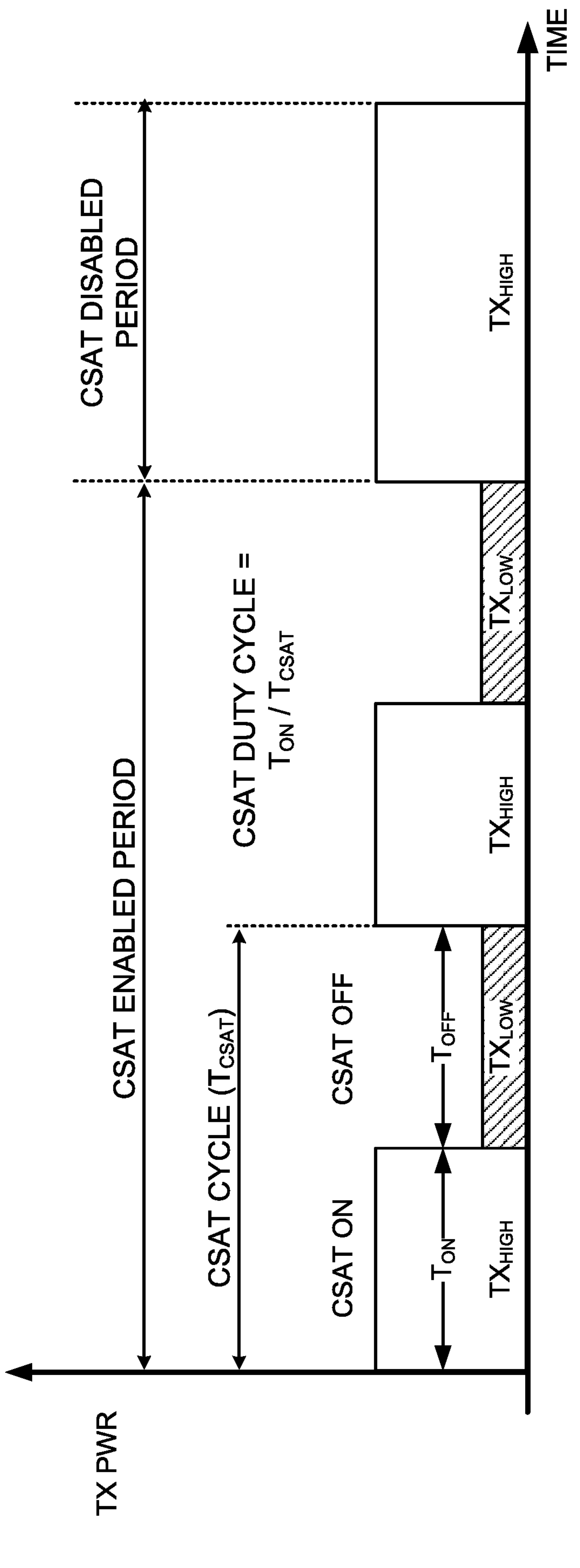

FIG. 6

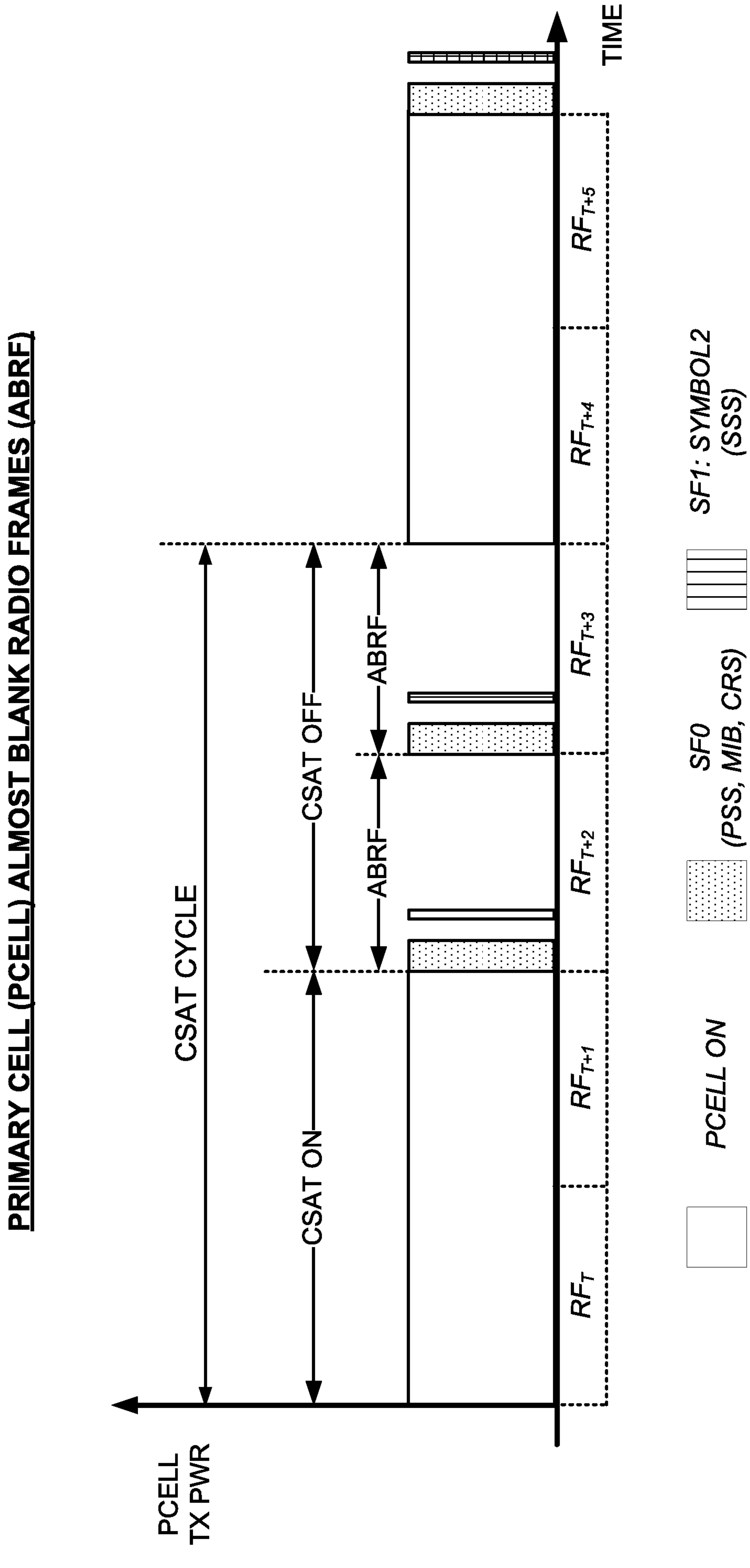
PRIMARY CELL (PCELL) ALMOST BLANK RADIO FRAMES (ABRF)
PCELL TX PWR
TIME
CSAT CYCLE
CSAT ON
CSAT OFF
ABRF
ABRF
RF_T
RF_T+1
RF_T+2
RF_T+3
RF_T+4
RF_T+5
PCELL ON
SF0 (PSS, MIB, CRS)
SF1: SYMBOL2 (SSS)

FIG. 7

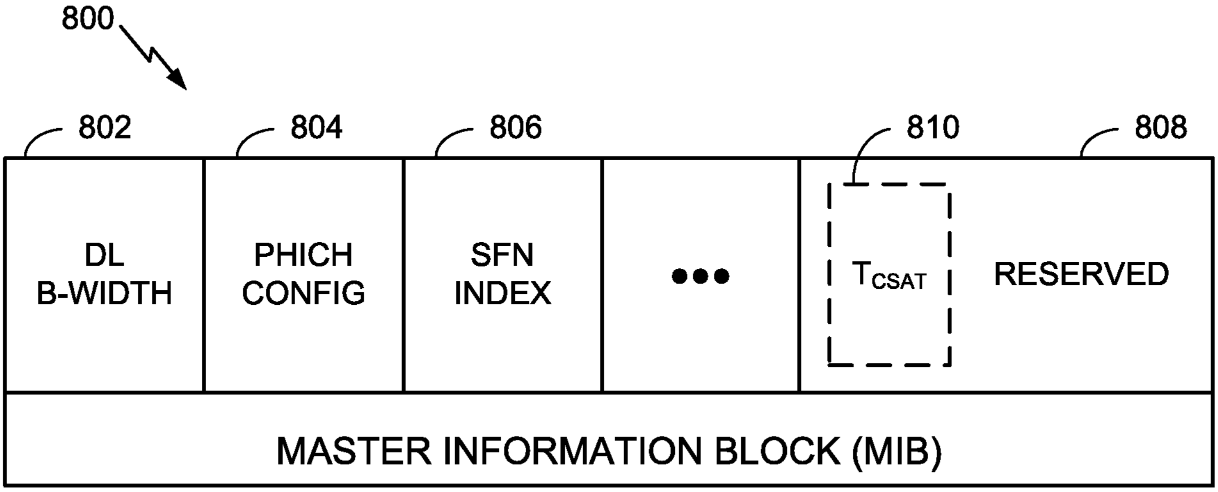
800
802
804
806
810
808
DL
B-WIDTH
PHICH
CONFIG
SFN
INDEX
•••
T_{CSAT}
RESERVED
MASTER INFORMATION BLOCK (MIB)

FIG. 8

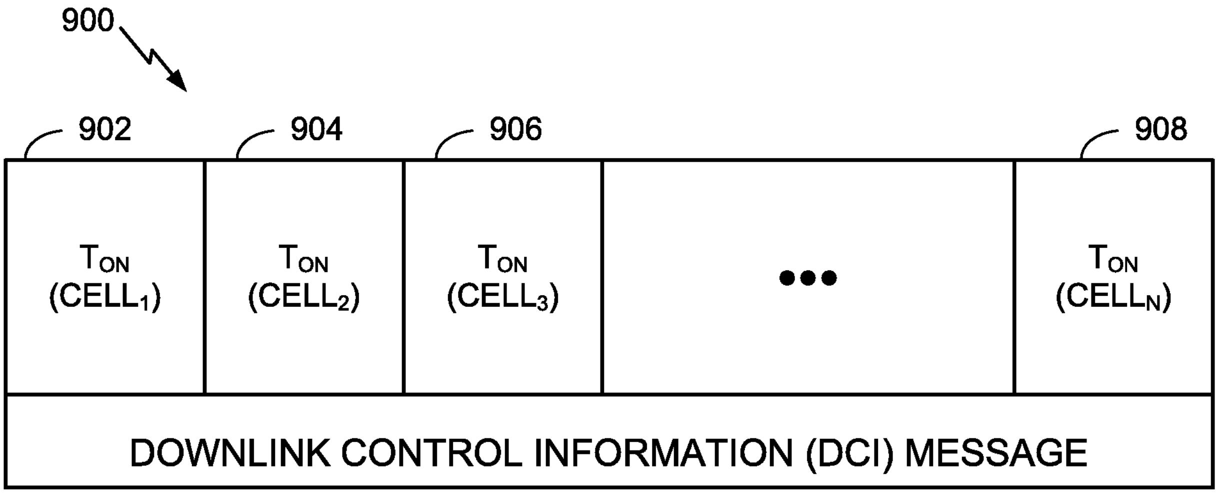
900
902
904
906
908
T_{ON}
($CELL_1$)
T_{ON}
($CELL_2$)
T_{ON}
($CELL_3$)
•••
T_{ON}
($CELL_N$)
DOWNLINK CONTROL INFORMATION (DCI) MESSAGE

FIG. 9

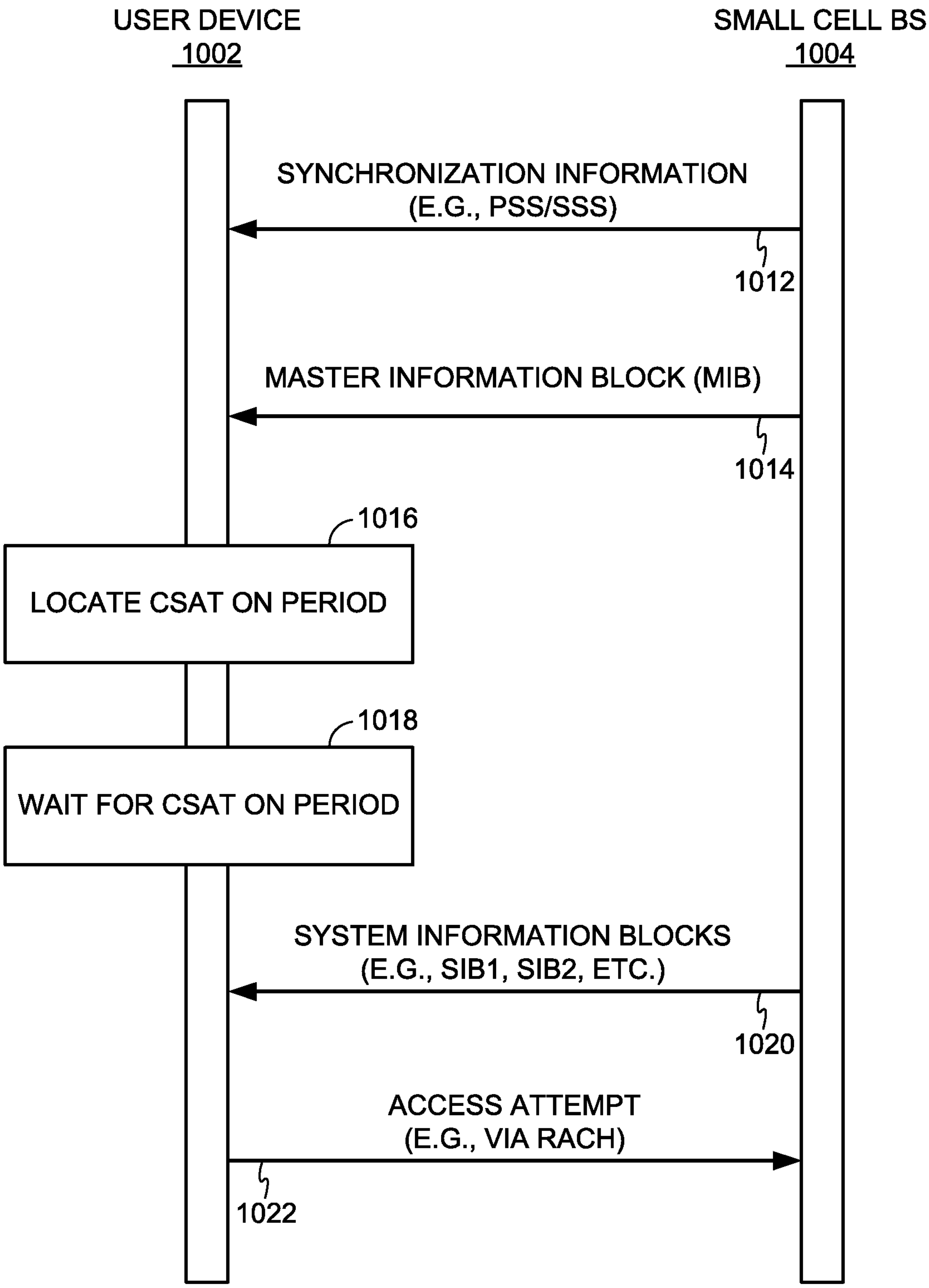
USER DEVICE
1002
SMALL CELL BS
1004
SYNCHRONIZATION INFORMATION
(E.G., PSS/SSS)
1012
MASTER INFORMATION BLOCK (MIB)
1014
1016
LOCATE CSAT ON PERIOD
1018
WAIT FOR CSAT ON PERIOD
SYSTEM INFORMATION BLOCKS
(E.G., SIB1, SIB2, ETC.)
1020
ACCESS ATTEMPT
(E.G., VIA RACH)
1022

FIG. 10

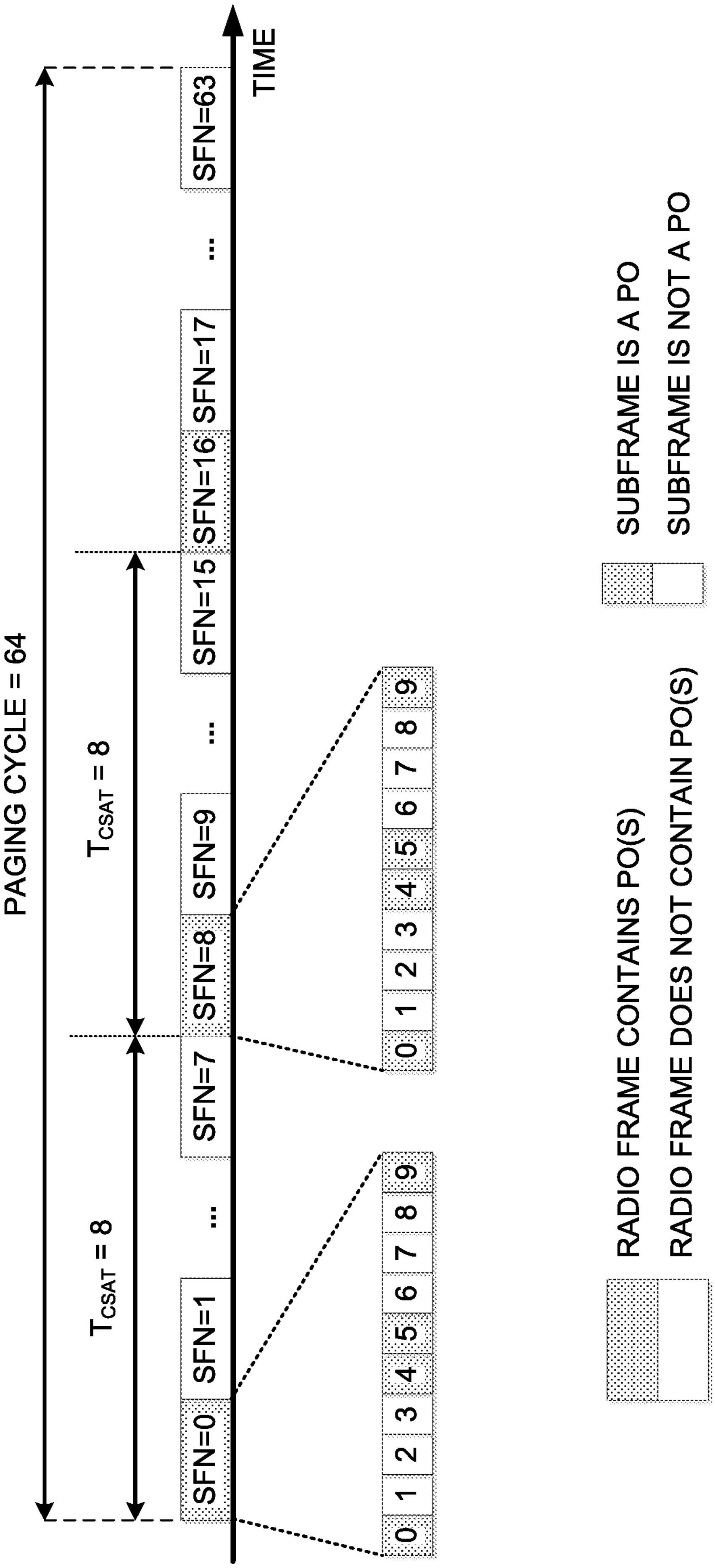
TIME
PAGING CYCLE = 64
T_{CSAT} = 8
T_{CSAT} = 8
SFN=0
SFN=1
...
SFN=7
SFN=8
SFN=9
...
SFN=15
SFN=16
SFN=17
...
SFN=63
0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9
RADIO FRAME CONTAINS PO(S)
RADIO FRAME DOES NOT CONTAIN PO(S)
SUBFRAME IS A PO
SUBFRAME IS NOT A PO

FIG. 11

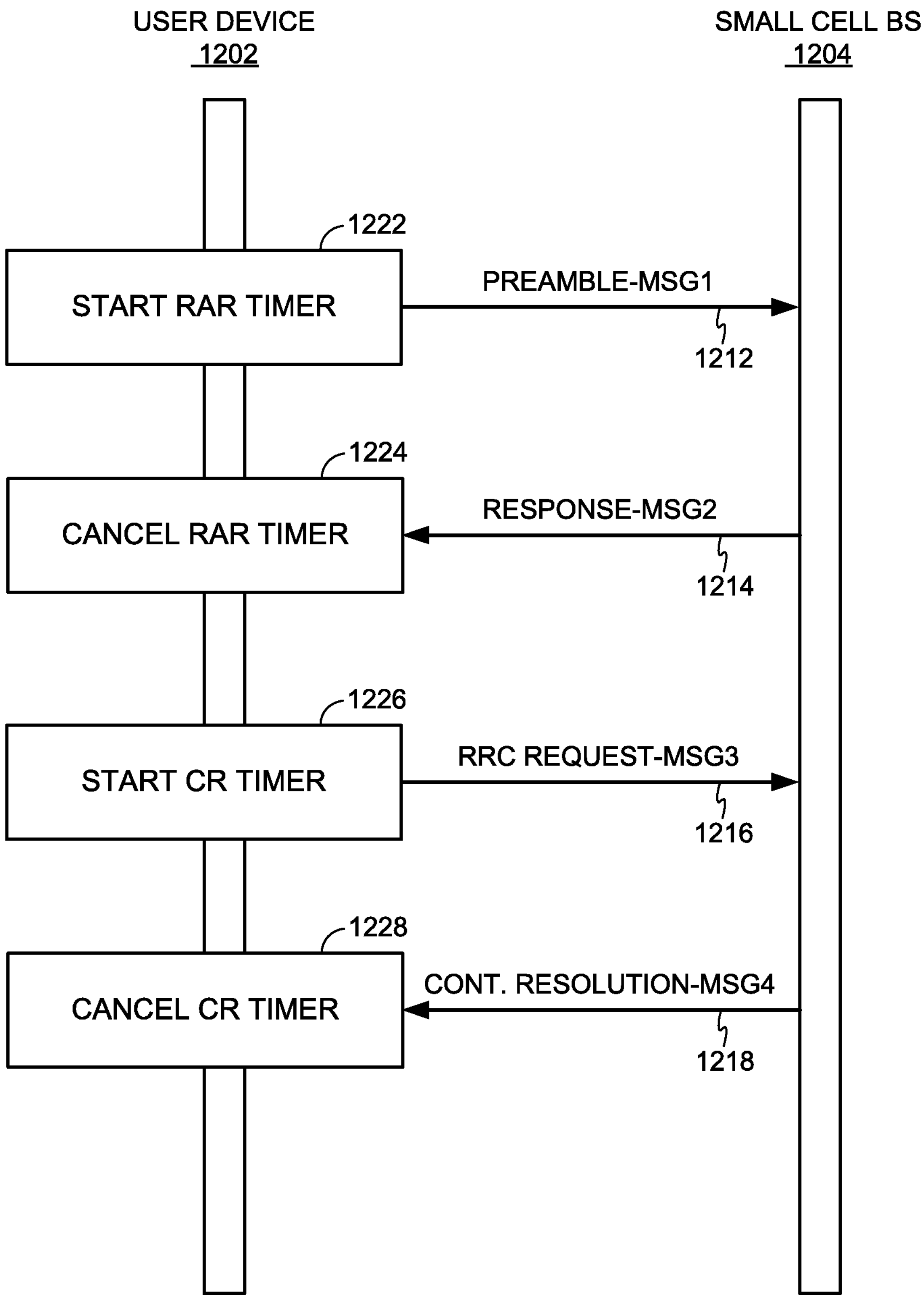
USER DEVICE
1202
SMALL CELL BS
1204
1222
START RAR TIMER
PREAMBLE-MSG1
1212
1224
CANCEL RAR TIMER
RESPONSE-MSG2
1214
1226
START CR TIMER
RRC REQUEST-MSG3
1216
1228
CANCEL CR TIMER
CONT. RESOLUTION-MSG4
1218

FIG. 12

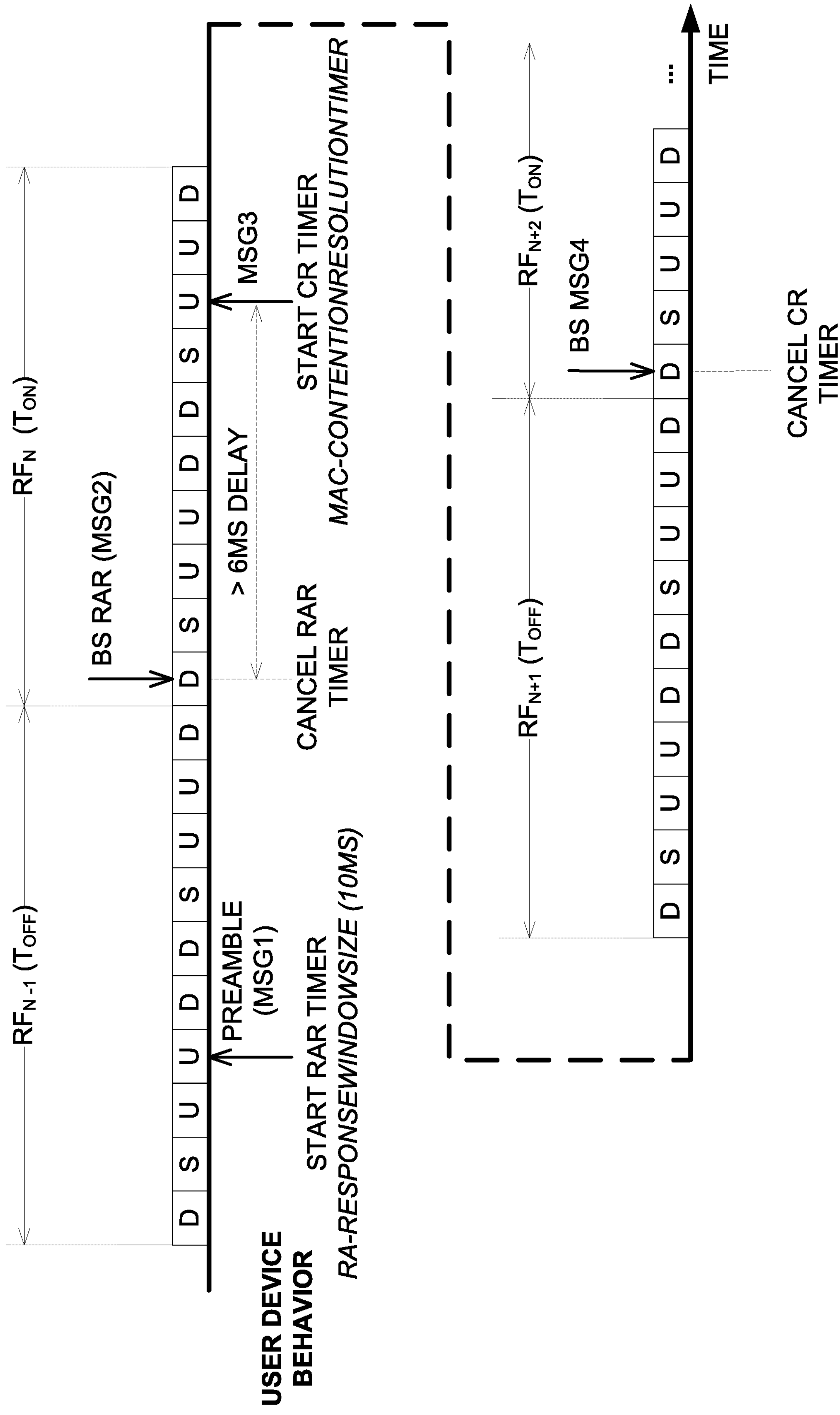
USER DEVICE BEHAVIOR
RF$_{N-1}$ (T_{OFF})
RF$_N$ (T_{ON})
D S U U D D S U U D D S U U D D S U U D
PREAMBLE (MSG1)
START RAR TIMER
RA-RESPONSEWINDOWSIZE (10MS)
BS RAR (MSG2)
CANCEL RAR TIMER
> 6MS DELAY
MSG3
START CR TIMER
MAC-CONTENTIONRESOLUTIONTIMER
RF$_{N+1}$ (T_{OFF})
RF$_{N+2}$ (T_{ON})
D S U U D D S U U D D S U U D
BS MSG4
CANCEL CR TIMER
...
TIME

FIG. 13

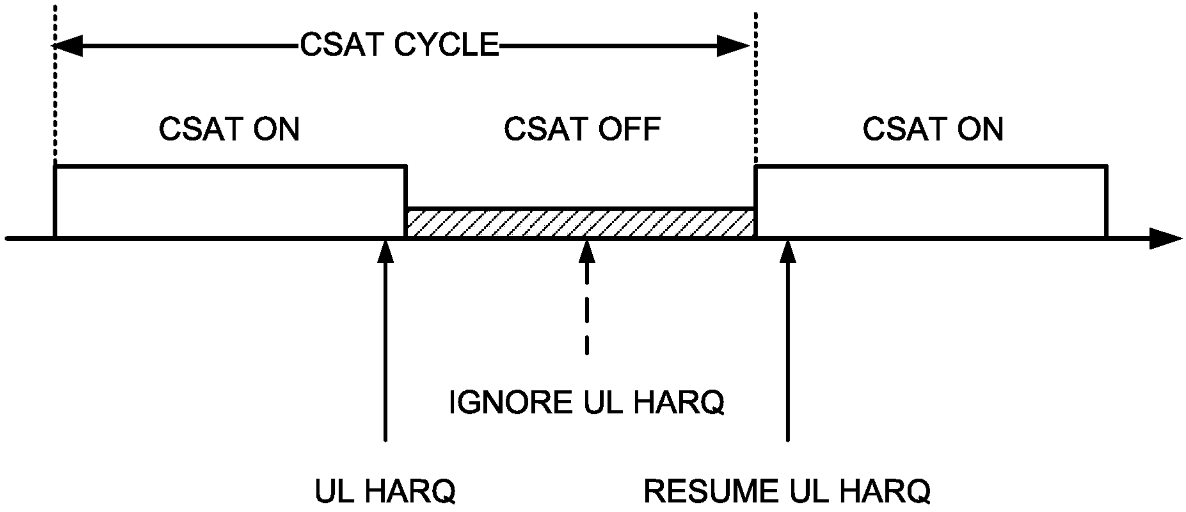
CSAT CYCLE
CSAT ON
CSAT OFF
CSAT ON
IGNORE UL HARQ
UL HARQ
RESUME UL HARQ

FIG. 14

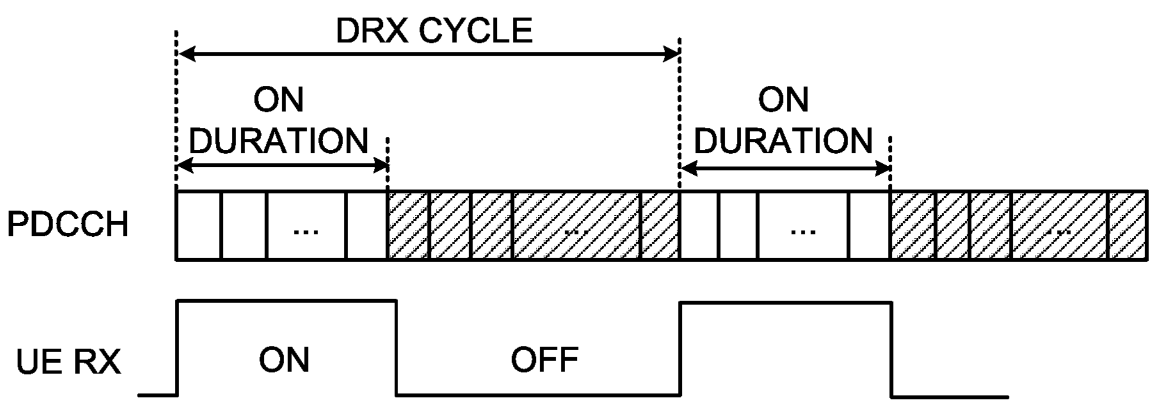
DRX CYCLE
ON DURATION
ON DURATION
PDCCH
...
...
UE RX
ON
OFF

FIG. 15

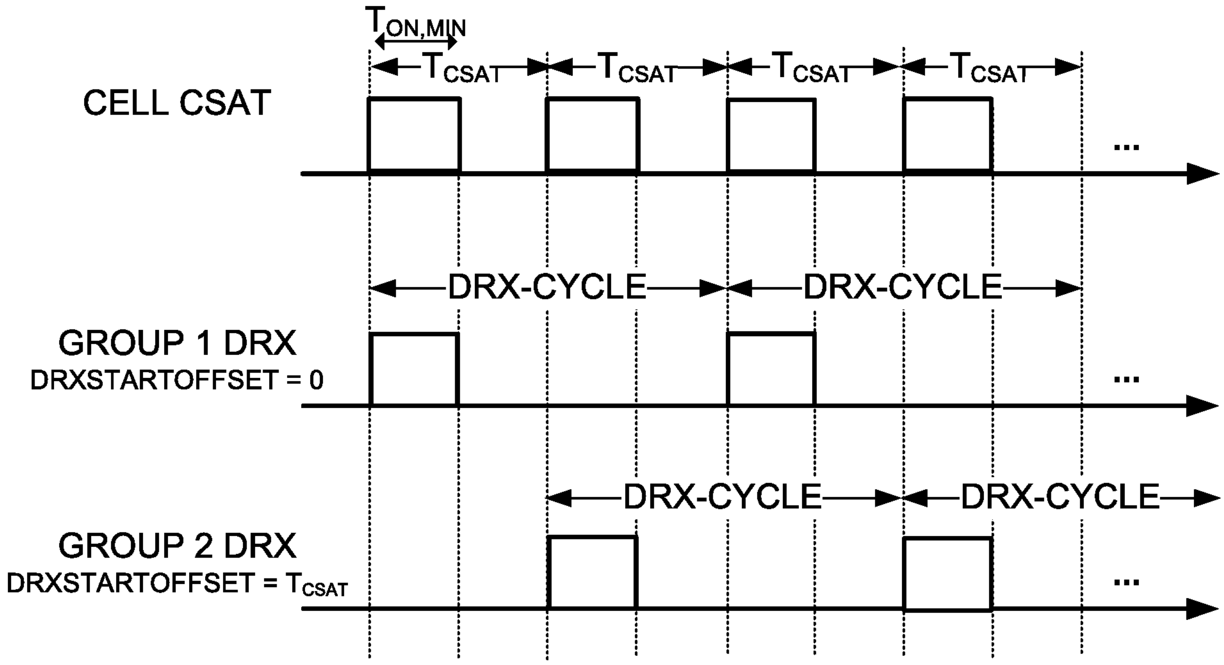
T ON,MIN
T CSAT
T CSAT
T CSAT
T CSAT
CELL CSAT
...
DRX-CYCLE
DRX-CYCLE
GROUP 1 DRX
DRXSTARTOFFSET = 0
...
DRX-CYCLE
DRX-CYCLE
GROUP 2 DRX
DRXSTARTOFFSET = T CSAT
...

FIG. 16

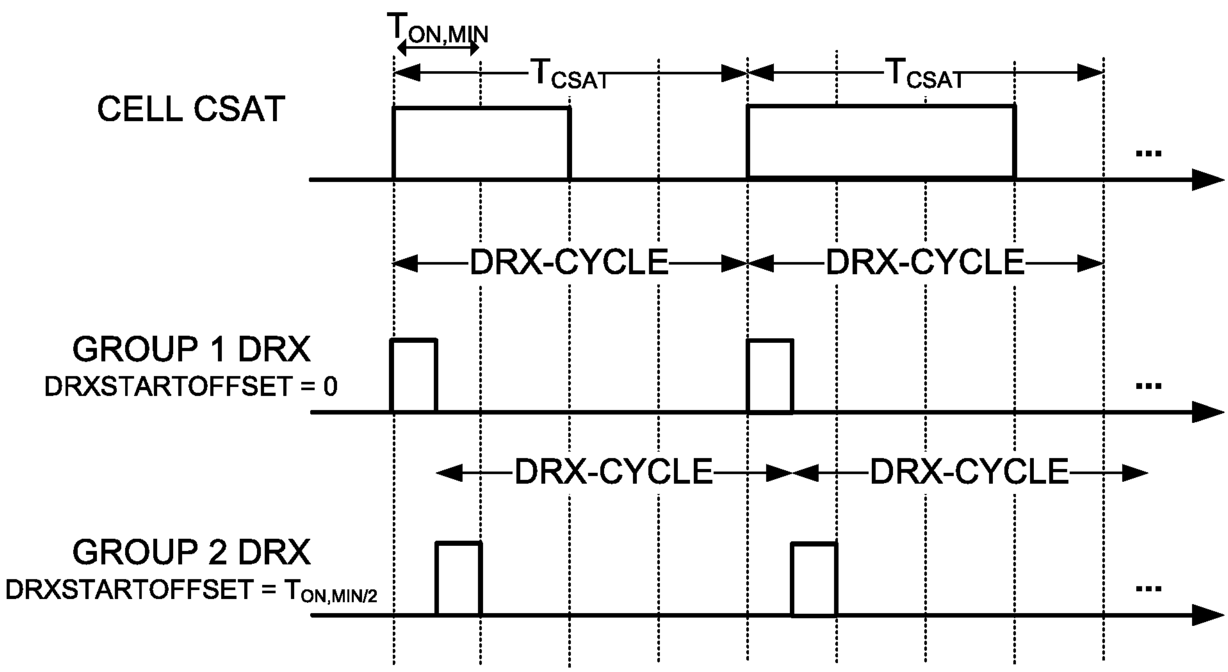
T ON,MIN
T CSAT
T CSAT
CELL CSAT
...
DRX-CYCLE
DRX-CYCLE
GROUP 1 DRX
DRXSTARTOFFSET = 0
...
DRX-CYCLE
DRX-CYCLE
GROUP 2 DRX
DRXSTARTOFFSET = T ON,MIN/2
...

FIG. 17

DOWN LINK (DL) LITE CSAT CONFIGURATION

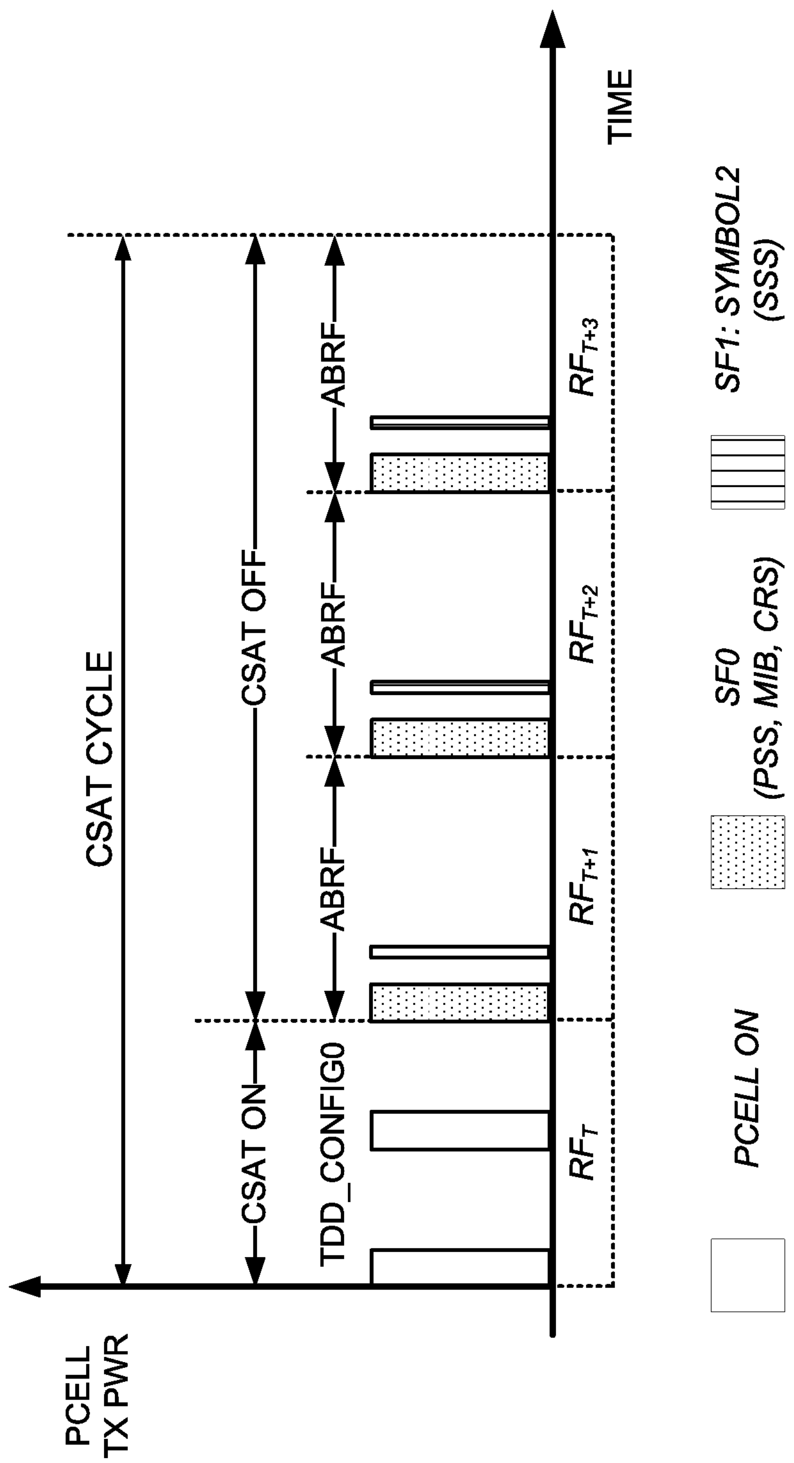

FIG. 18

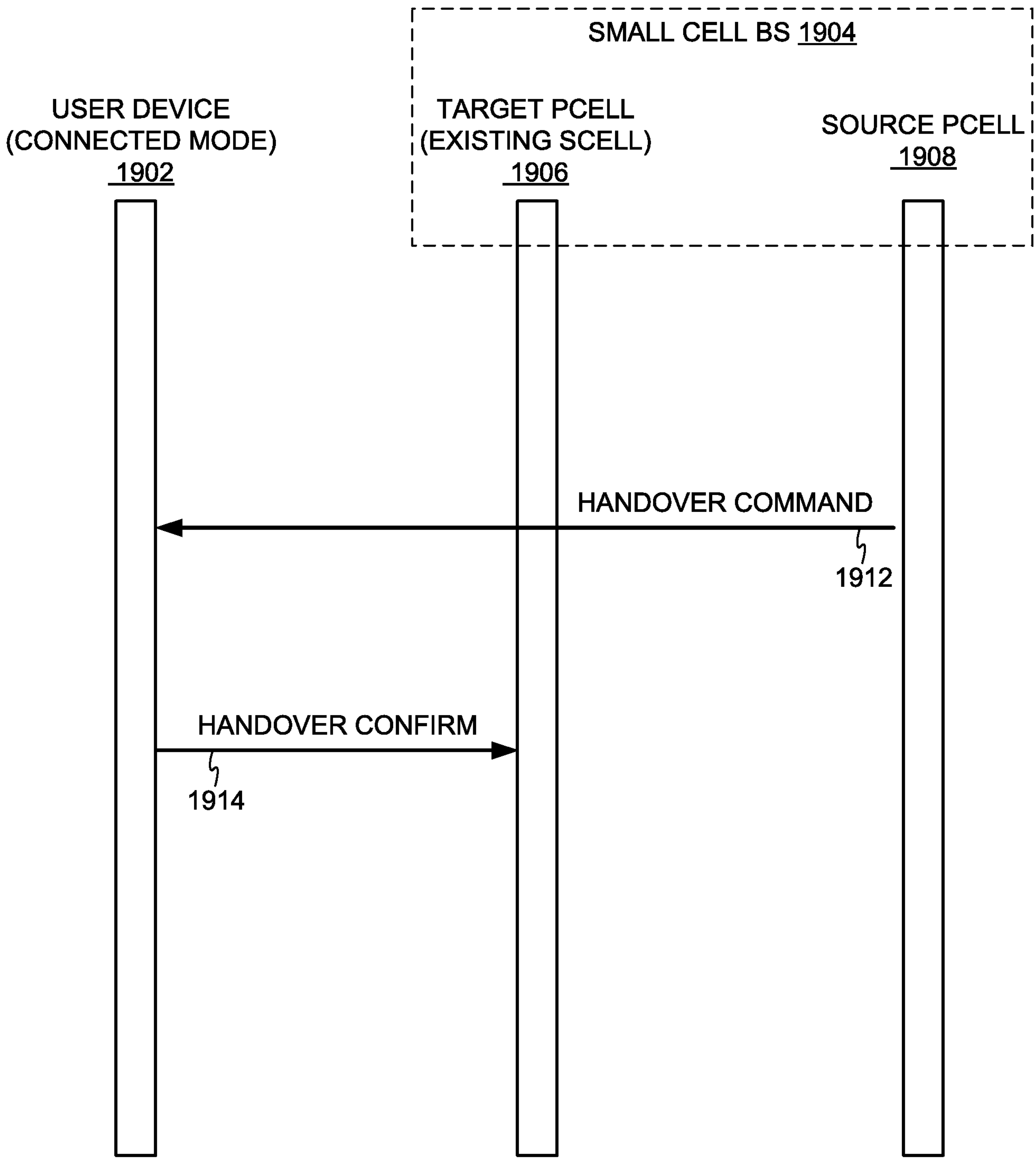
SMALL CELL BS 1904
USER DEVICE
(CONNECTED MODE)
1902
TARGET PCELL
(EXISTING SCELL)
1906
SOURCE PCELL
1908
HANDOVER COMMAND
1912
HANDOVER CONFIRM
1914

FIG. 19

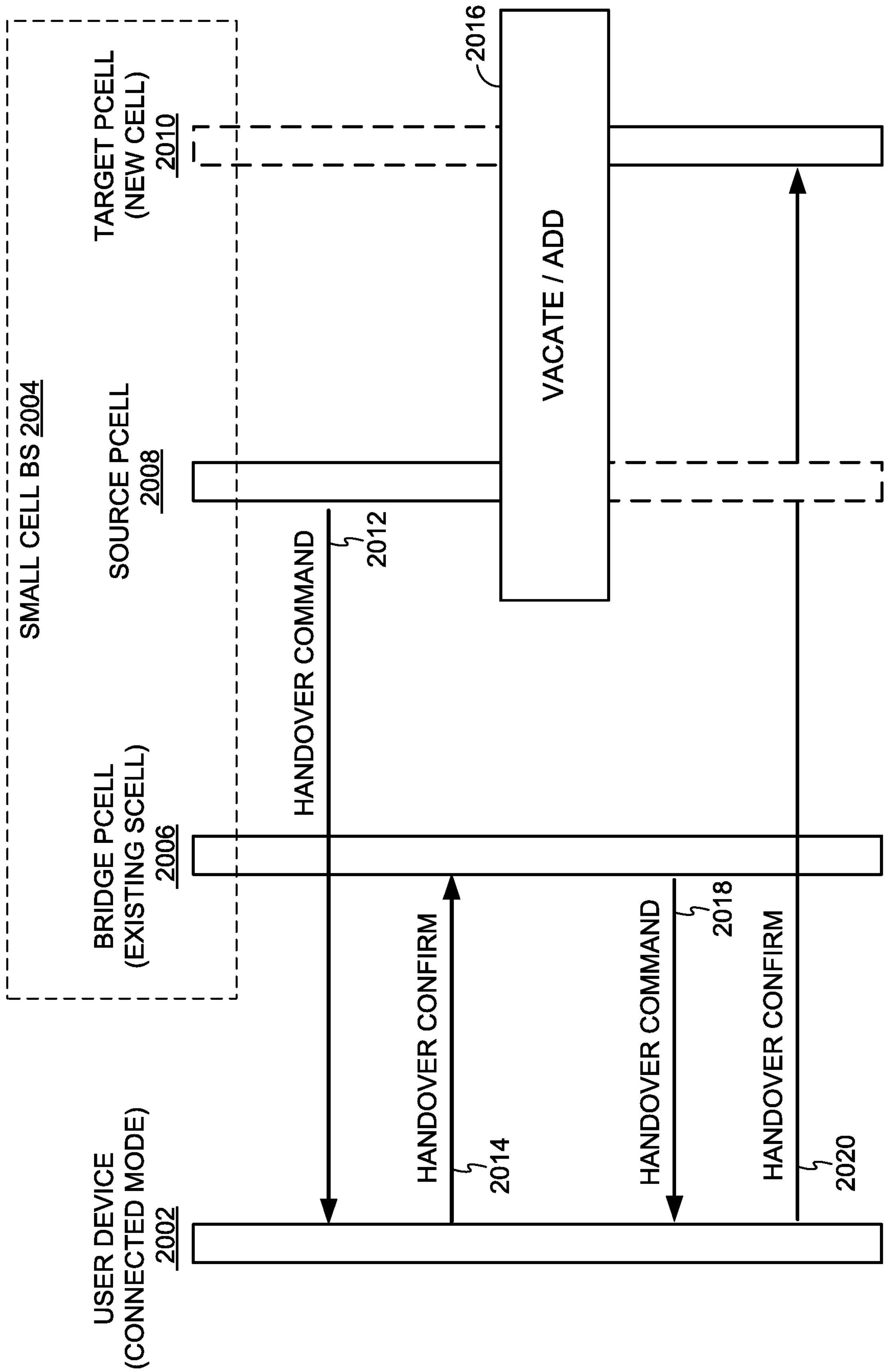
SMALL CELL BS 2004
USER DEVICE
(CONNECTED MODE)
2002
BRIDGE PCELL
(EXISTING SCELL)
2006
SOURCE PCELL
2008
TARGET PCELL
(NEW CELL)
2010
HANDOVER COMMAND
2012
HANDOVER CONFIRM
2014
2016
VACATE / ADD
HANDOVER COMMAND
2018
HANDOVER CONFIRM
2020

FIG. 20

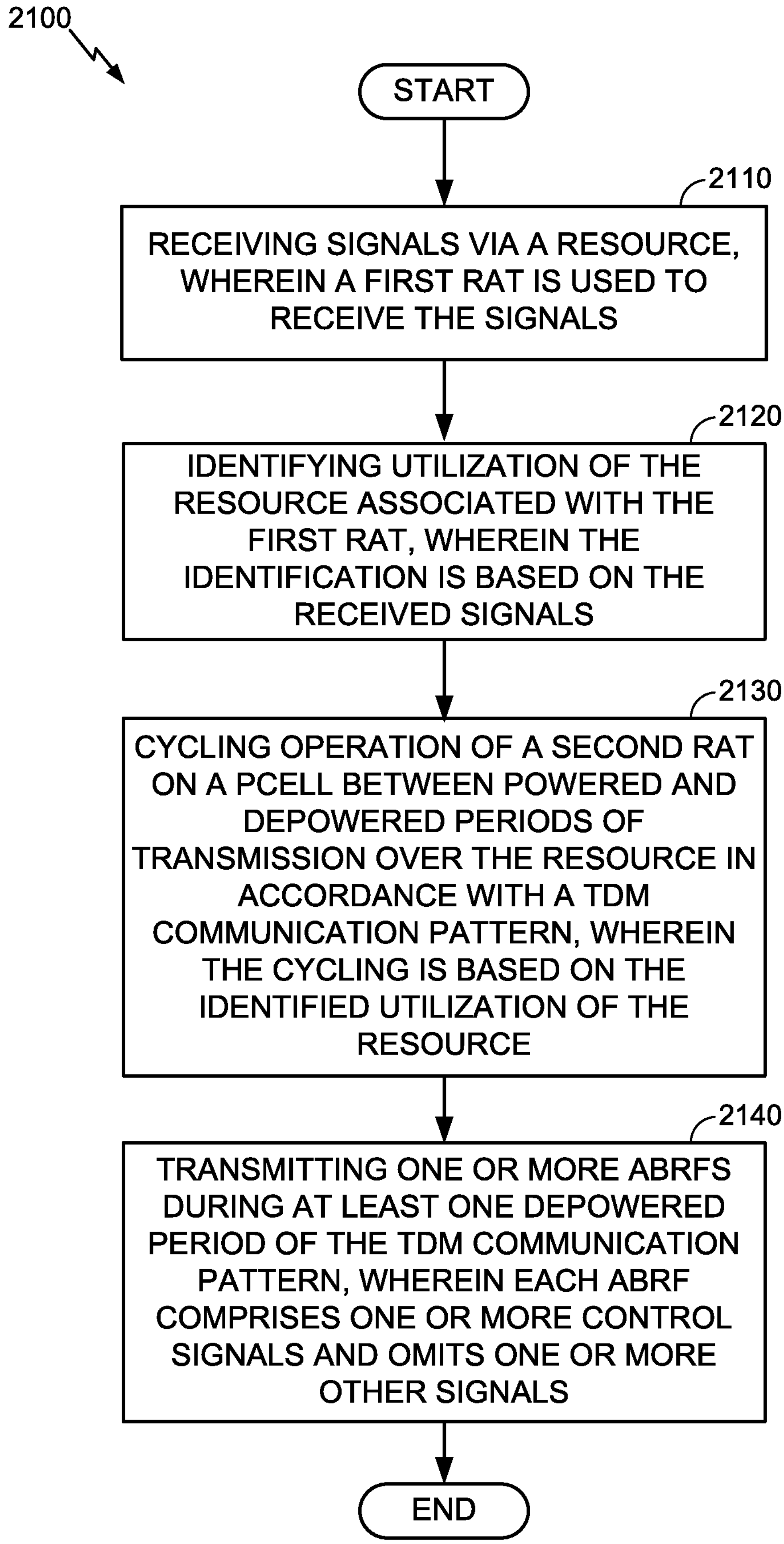
2100
START
2110
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2120
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2130
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2140
TRANSMITTING ONE OR MORE ABRFS DURING AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN EACH ABRF COMPRISES ONE OR MORE CONTROL SIGNALS AND OMITS ONE OR MORE OTHER SIGNALS
END

FIG. 21

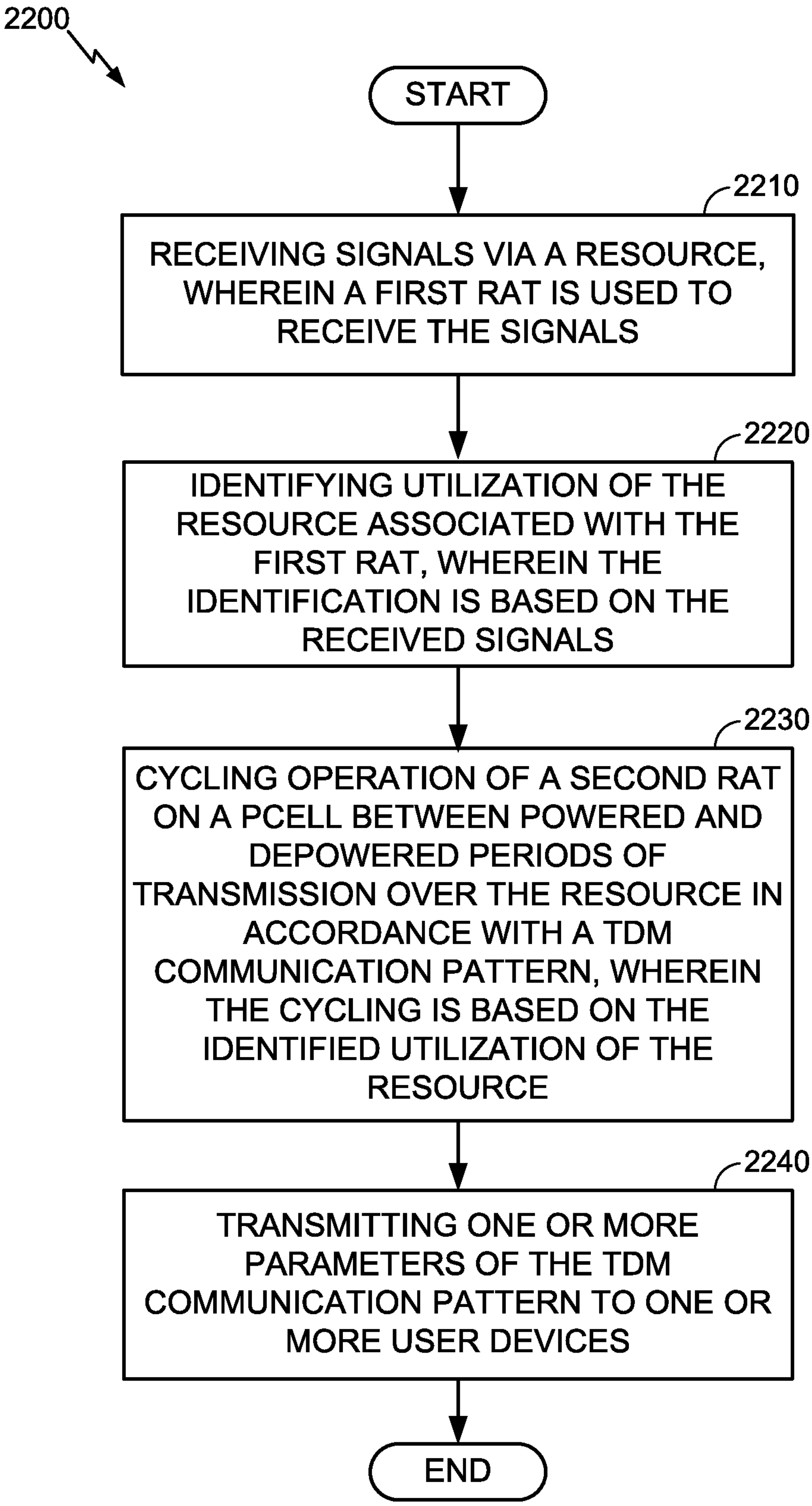
2200
START
2210
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2220
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2230
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2240
TRANSMITTING ONE OR MORE PARAMETERS OF THE TDM COMMUNICATION PATTERN TO ONE OR MORE USER DEVICES
END

FIG. 22

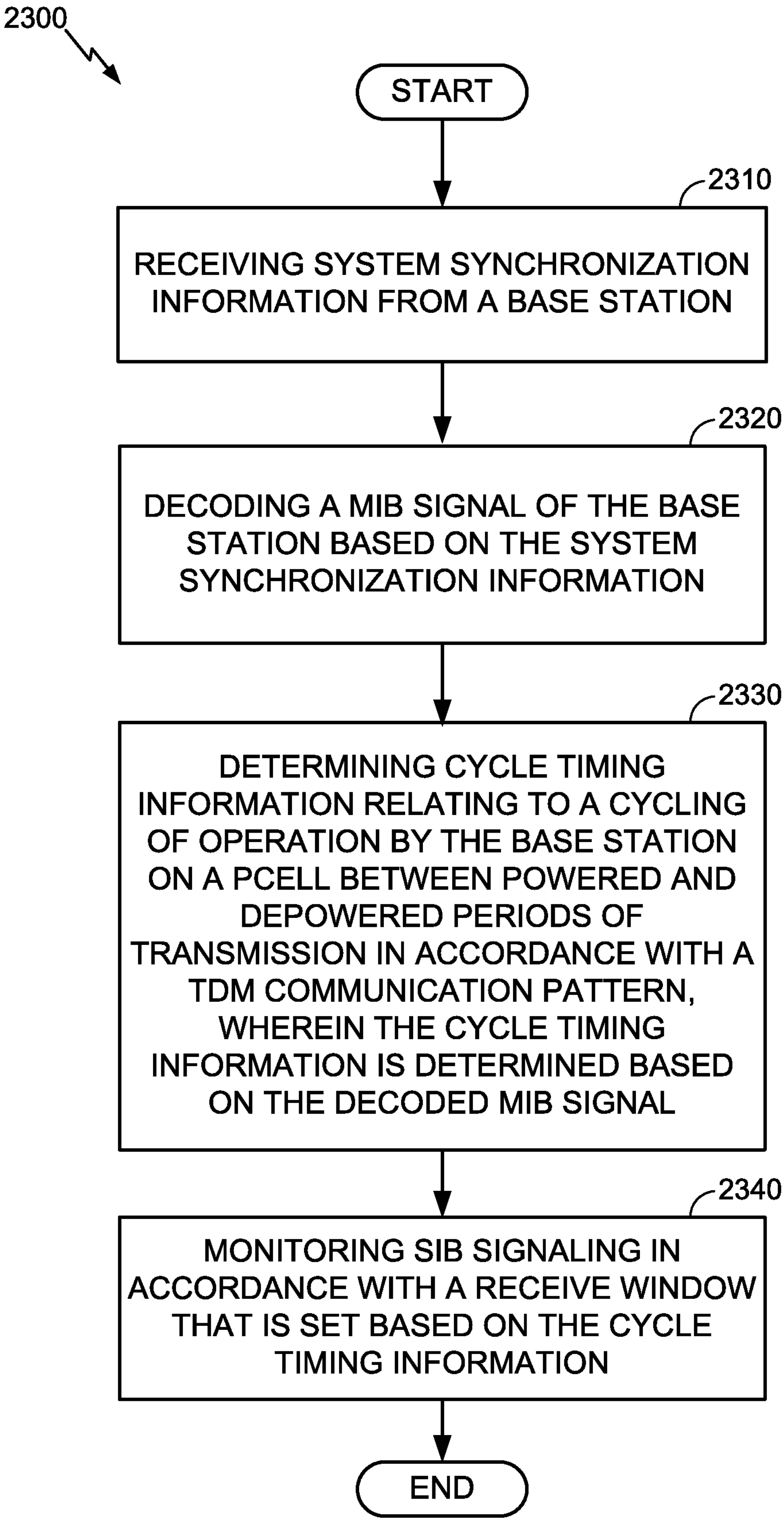
2300
START
2310
RECEIVING SYSTEM SYNCHRONIZATION INFORMATION FROM A BASE STATION
2320
DECODING A MIB SIGNAL OF THE BASE STATION BASED ON THE SYSTEM SYNCHRONIZATION INFORMATION
2330
DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY THE BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLE TIMING INFORMATION IS DETERMINED BASED ON THE DECODED MIB SIGNAL
2340
MONITORING SIB SIGNALING IN ACCORDANCE WITH A RECEIVE WINDOW THAT IS SET BASED ON THE CYCLE TIMING INFORMATION
END

FIG. 23

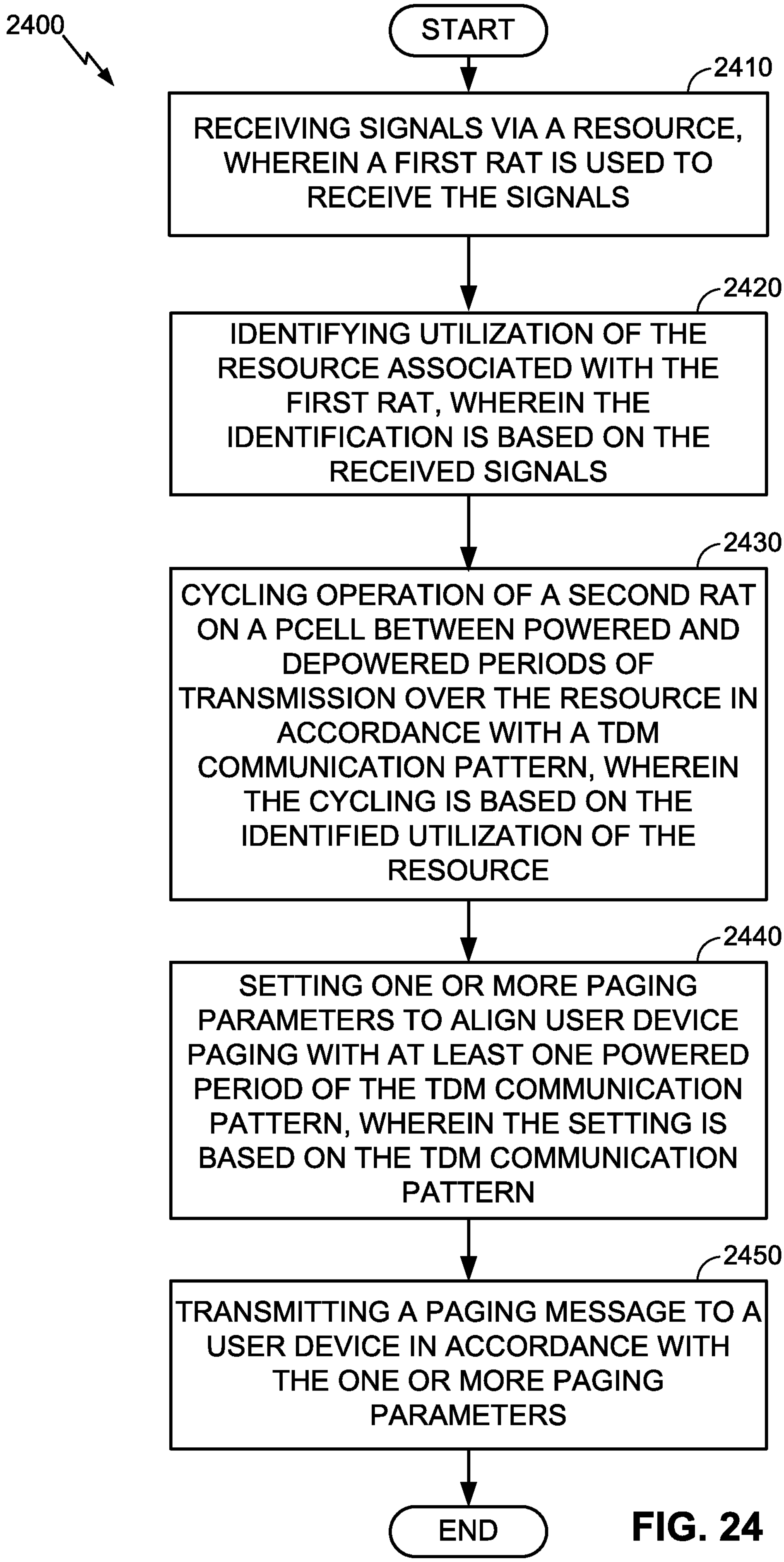
2400
START
2410
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2420
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2430
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2440
SETTING ONE OR MORE PAGING PARAMETERS TO ALIGN USER DEVICE PAGING WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
2450
TRANSMITTING A PAGING MESSAGE TO A USER DEVICE IN ACCORDANCE WITH THE ONE OR MORE PAGING PARAMETERS
END

FIG. 24

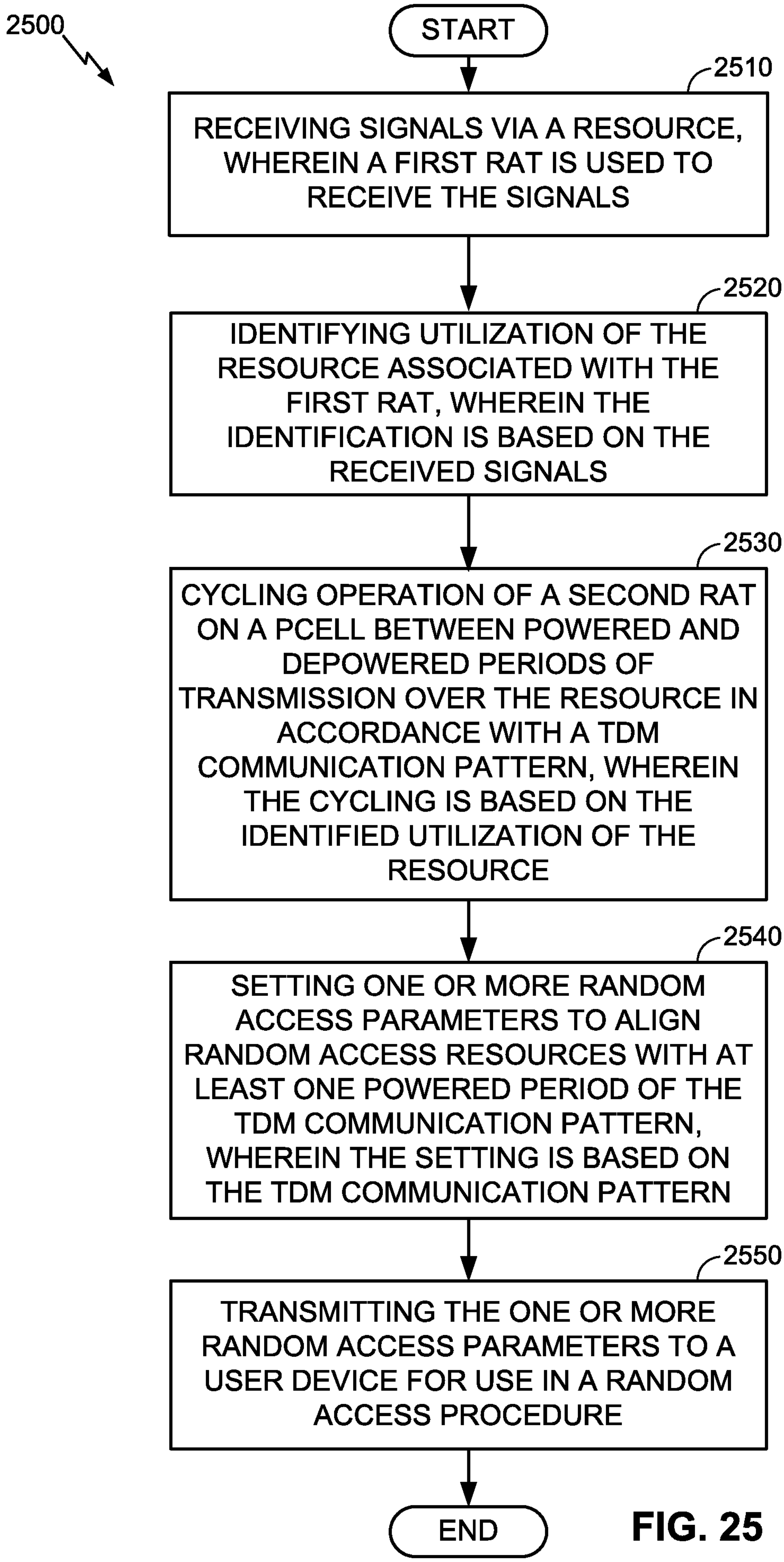
2500
START
2510
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2520
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2530
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2540
SETTING ONE OR MORE RANDOM ACCESS PARAMETERS TO ALIGN RANDOM ACCESS RESOURCES WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
2550
TRANSMITTING THE ONE OR MORE RANDOM ACCESS PARAMETERS TO A USER DEVICE FOR USE IN A RANDOM ACCESS PROCEDURE
END

FIG. 25

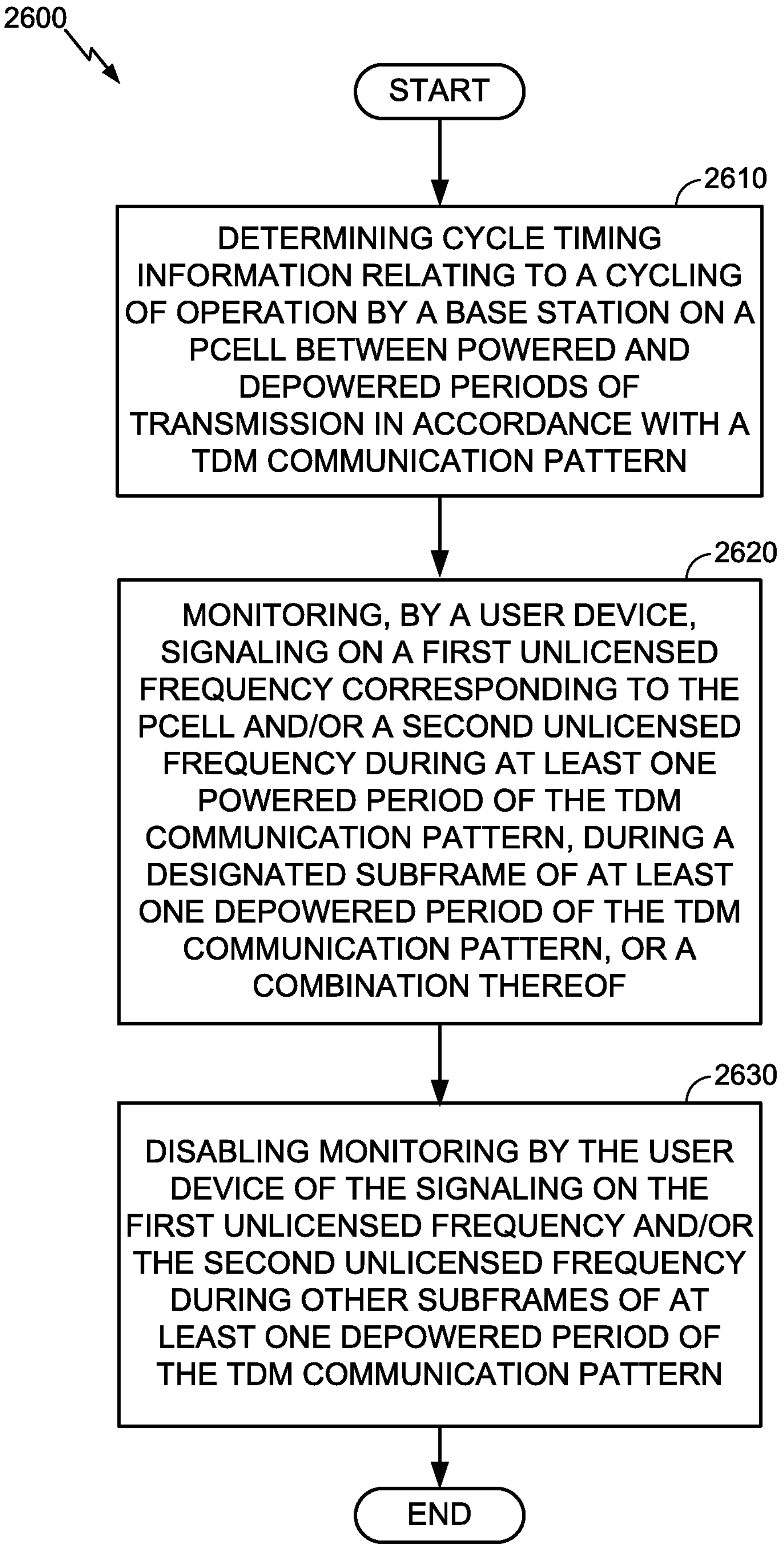
2600
START
2610
DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY A BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN
2620
MONITORING, BY A USER DEVICE, SIGNALING ON A FIRST UNLICENSED FREQUENCY CORRESPONDING TO THE PCELL AND/OR A SECOND UNLICENSED FREQUENCY DURING AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, DURING A DESIGNATED SUBFRAME OF AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN, OR A COMBINATION THEREOF
2630
DISABLING MONITORING BY THE USER DEVICE OF THE SIGNALING ON THE FIRST UNLICENSED FREQUENCY AND/OR THE SECOND UNLICENSED FREQUENCY DURING OTHER SUBFRAMES OF AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN
END

FIG. 26

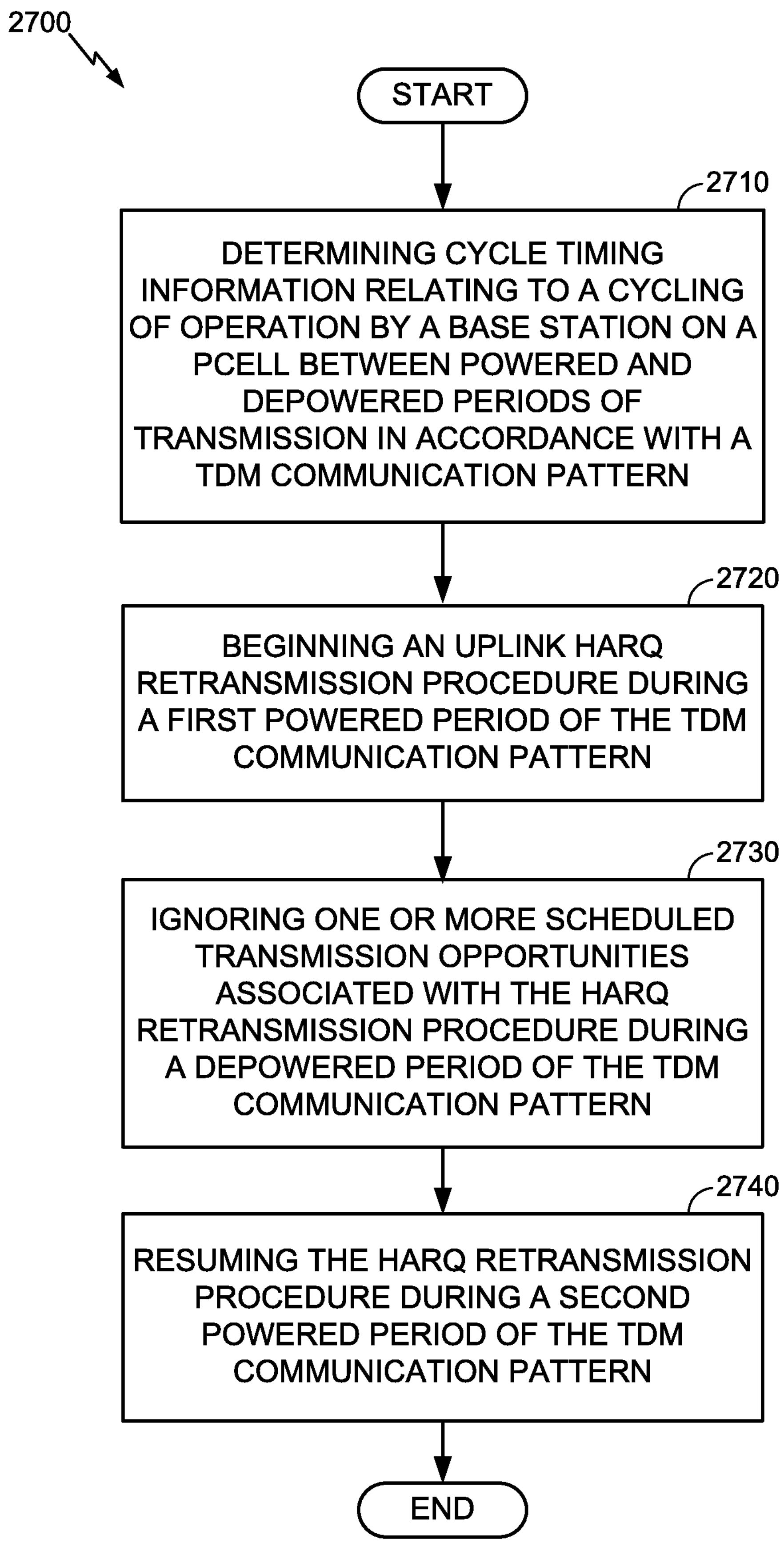
2700
START
2710
DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY A BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN
2720
BEGINNING AN UPLINK HARQ RETRANSMISSION PROCEDURE DURING A FIRST POWERED PERIOD OF THE TDM COMMUNICATION PATTERN
2730
IGNORING ONE OR MORE SCHEDULED TRANSMISSION OPPORTUNITIES ASSOCIATED WITH THE HARQ RETRANSMISSION PROCEDURE DURING A DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN
2740
RESUMING THE HARQ RETRANSMISSION PROCEDURE DURING A SECOND POWERED PERIOD OF THE TDM COMMUNICATION PATTERN
END

FIG. 27

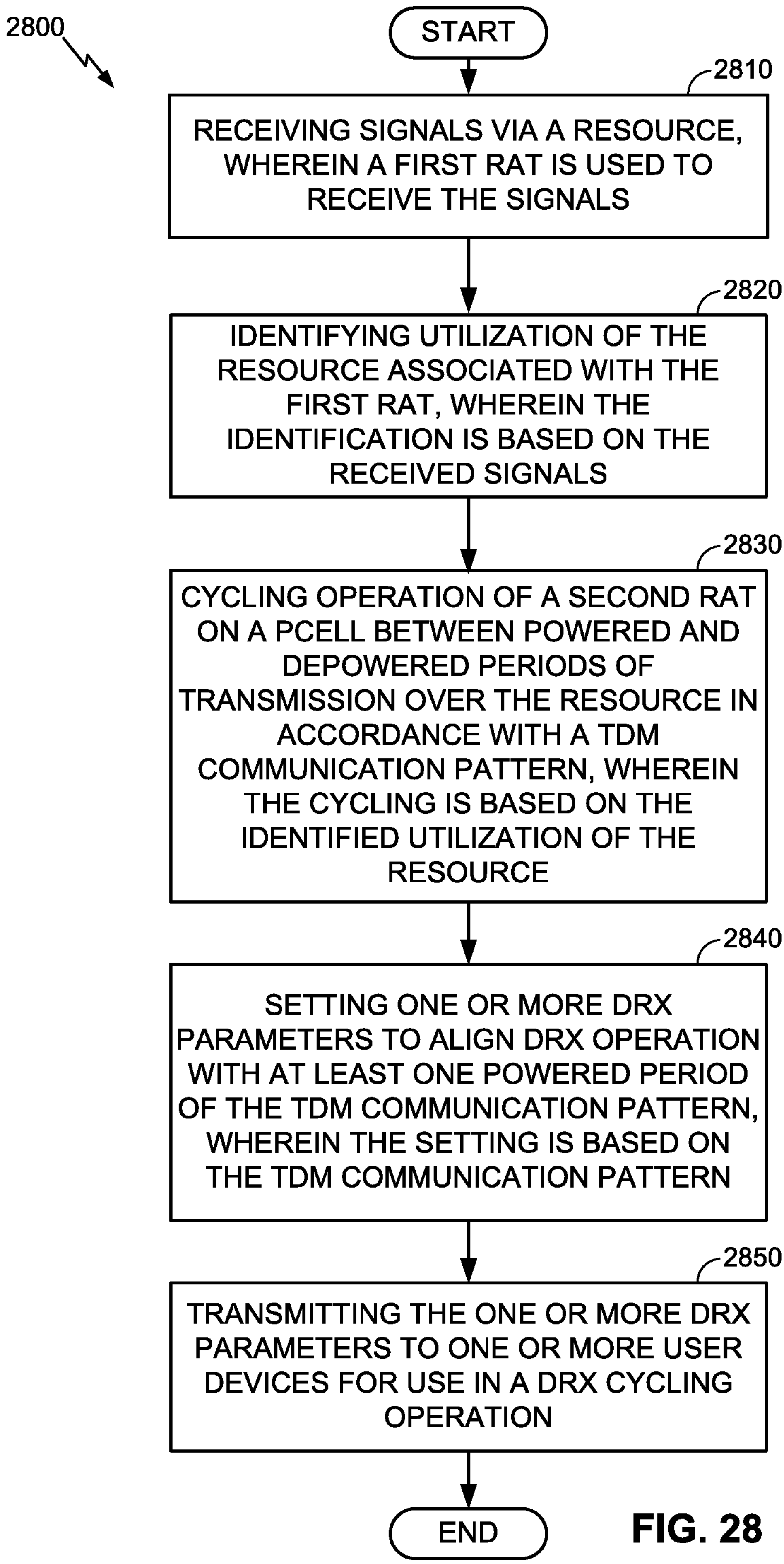
2800
START
2810
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2820
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2830
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2840
SETTING ONE OR MORE DRX PARAMETERS TO ALIGN DRX OPERATION WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
2850
TRANSMITTING THE ONE OR MORE DRX PARAMETERS TO ONE OR MORE USER DEVICES FOR USE IN A DRX CYCLING OPERATION
END

FIG. 28

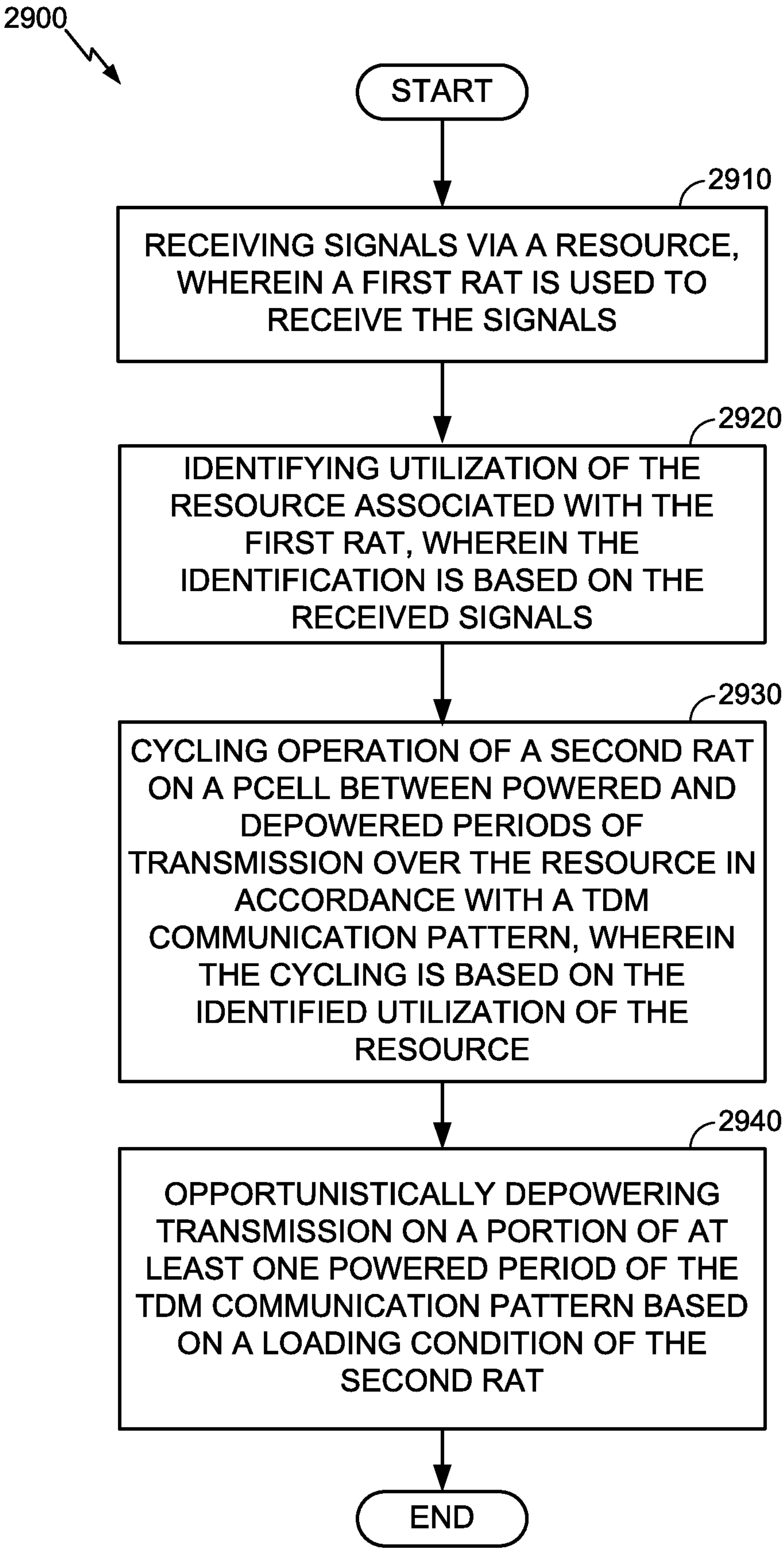
2900
START
2910
RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
2920
IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
2930
CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
2940
OPPORTUNISTICALLY DEPOWERING TRANSMISSION ON A PORTION OF AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN BASED ON A LOADING CONDITION OF THE SECOND RAT
END

FIG. 29

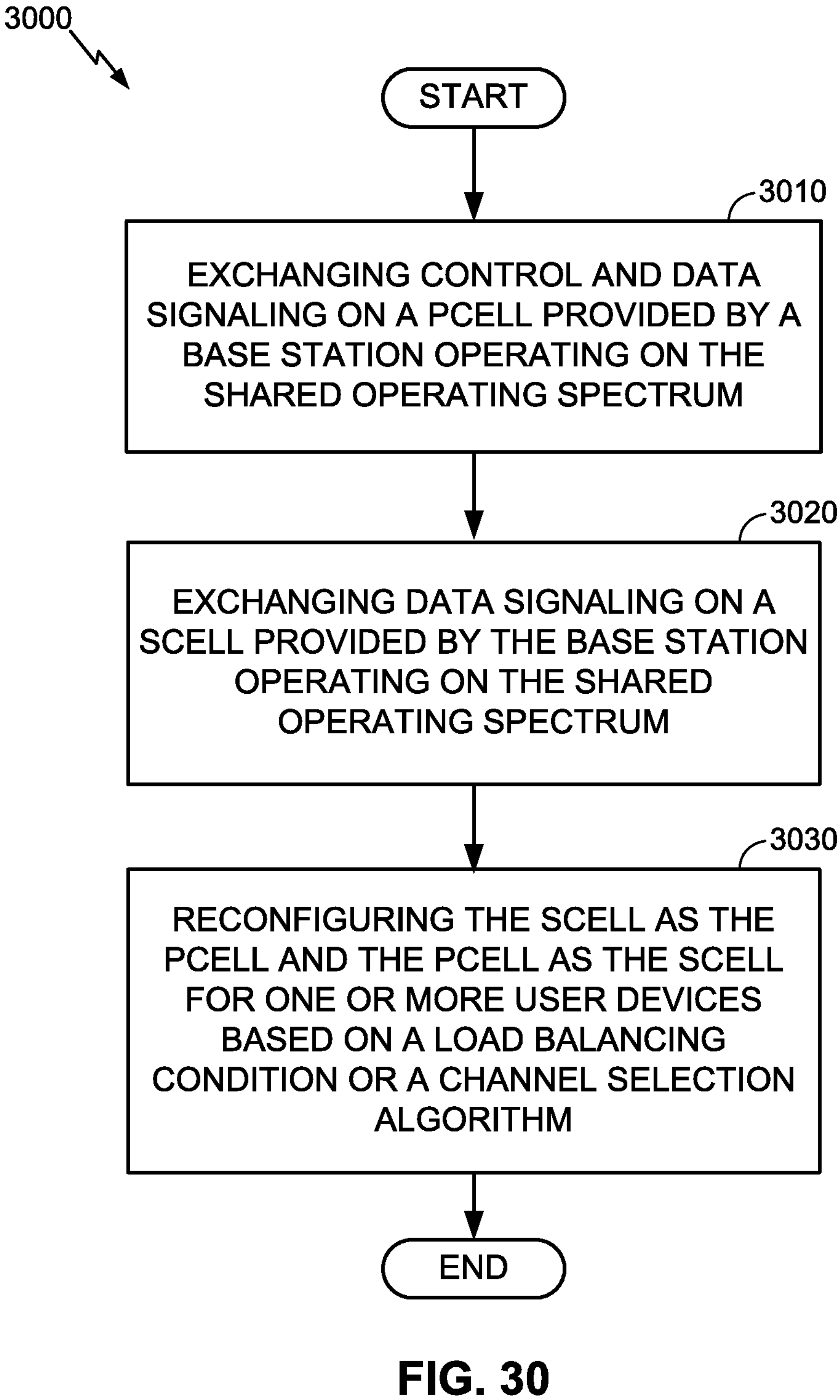
3000
START
3010
EXCHANGING CONTROL AND DATA SIGNALING ON A PCELL PROVIDED BY A BASE STATION OPERATING ON THE SHARED OPERATING SPECTRUM
3020
EXCHANGING DATA SIGNALING ON A SCELL PROVIDED BY THE BASE STATION OPERATING ON THE SHARED OPERATING SPECTRUM
3030
RECONFIGURING THE SCELL AS THE PCELL AND THE PCELL AS THE SCELL FOR ONE OR MORE USER DEVICES BASED ON A LOAD BALANCING CONDITION OR A CHANNEL SELECTION ALGORITHM
END

FIG. 30

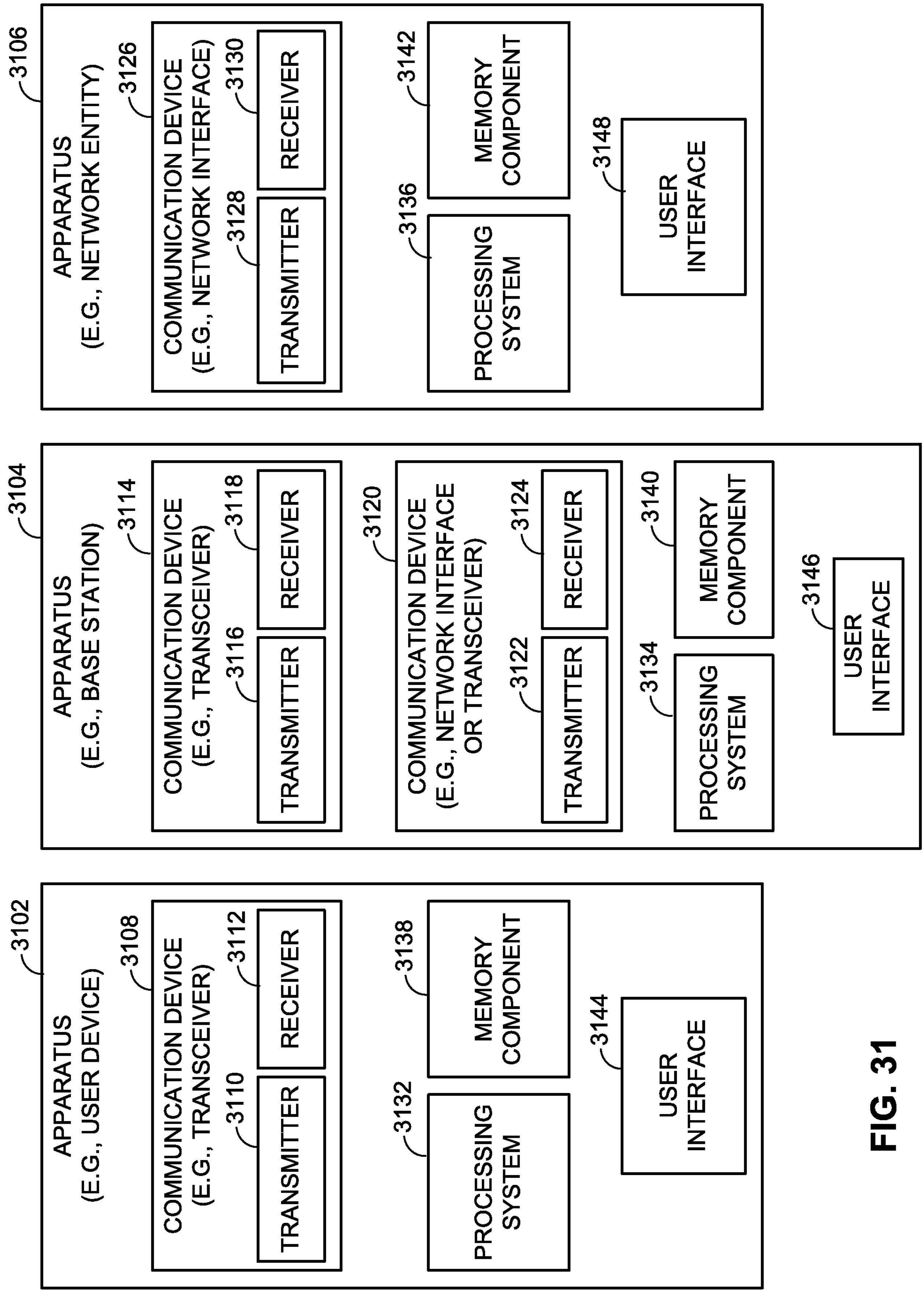
3102
APPARATUS
(E.G., USER DEVICE)
3108
COMMUNICATION DEVICE
(E.G., TRANSCEIVER)
3110
TRANSMITTER
3112
RECEIVER
3132
PROCESSING
SYSTEM
3138
MEMORY
COMPONENT
3144
USER
INTERFACE
3104
APPARATUS
(E.G., BASE STATION)
3114
COMMUNICATION DEVICE
(E.G., TRANSCEIVER)
3116
TRANSMITTER
3118
RECEIVER
3120
COMMUNICATION DEVICE
(E.G., NETWORK INTERFACE
OR TRANSCEIVER)
3122
TRANSMITTER
3124
RECEIVER
3134
PROCESSING
SYSTEM
3140
MEMORY
COMPONENT
3146
USER
INTERFACE
3106
APPARATUS
(E.G., NETWORK ENTITY)
3126
COMMUNICATION DEVICE
(E.G., NETWORK INTERFACE)
3128
TRANSMITTER
3130
RECEIVER
3136
PROCESSING
SYSTEM
3142
MEMORY
COMPONENT
3148
USER
INTERFACE

FIG. 31

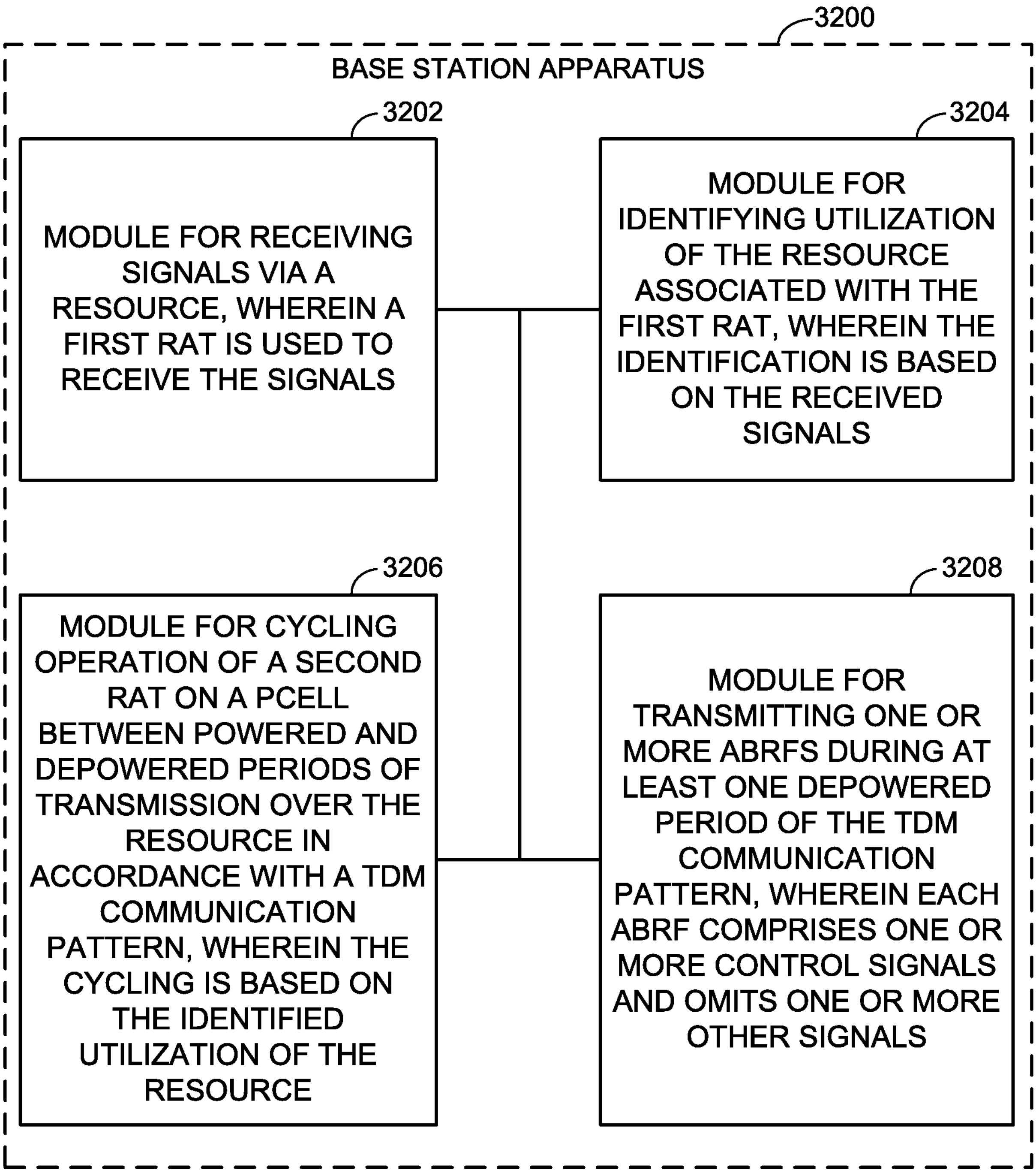
3200
BASE STATION APPARATUS
3202
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
3204
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
3206
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
3208
MODULE FOR TRANSMITTING ONE OR MORE ABRFS DURING AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN EACH ABRF COMPRISES ONE OR MORE CONTROL SIGNALS AND OMITS ONE OR MORE OTHER SIGNALS

FIG. 32

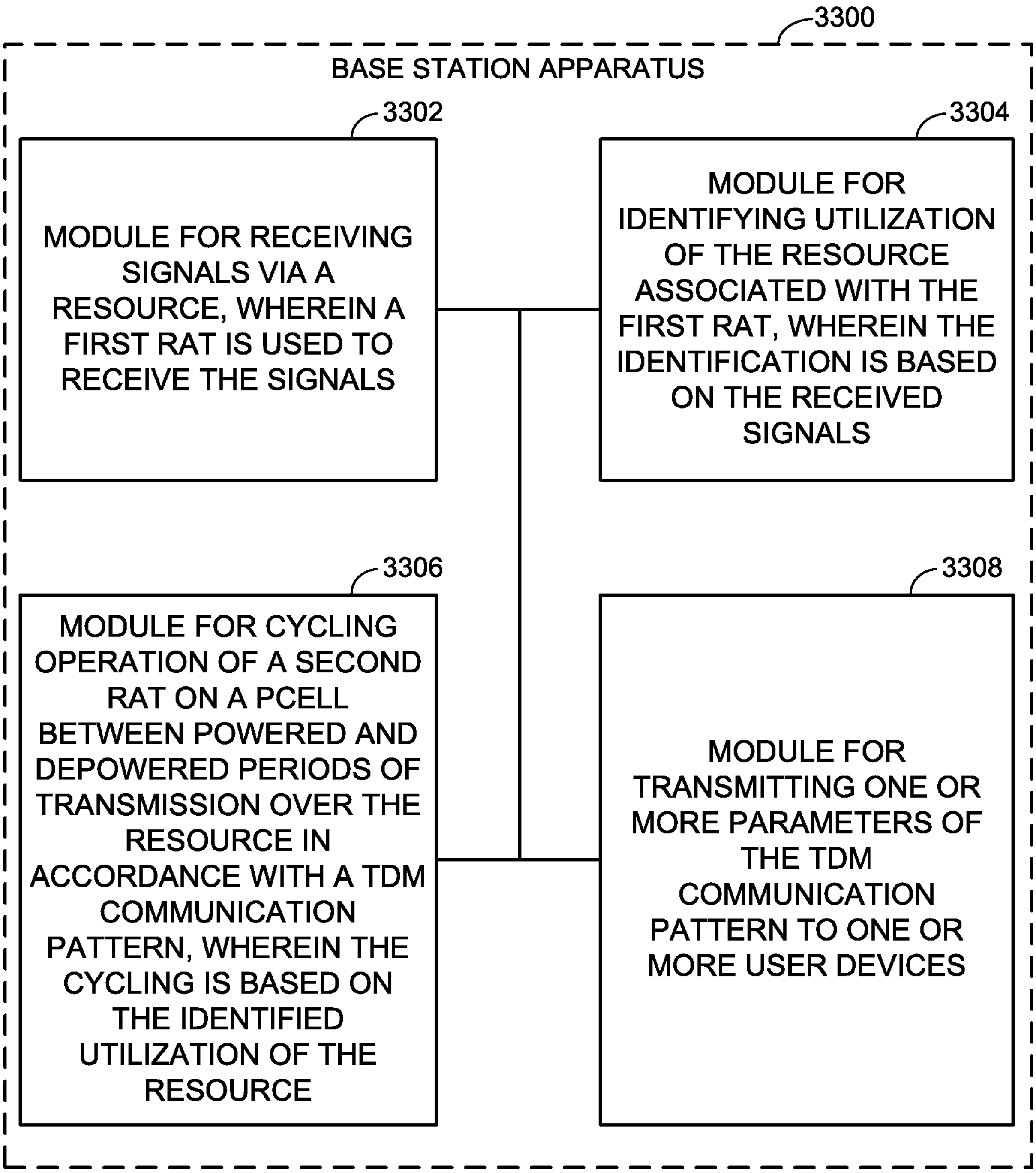
3300
BASE STATION APPARATUS
3302
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
3304
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
3306
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
3308
MODULE FOR TRANSMITTING ONE OR MORE PARAMETERS OF THE TDM COMMUNICATION PATTERN TO ONE OR MORE USER DEVICES

FIG. 33

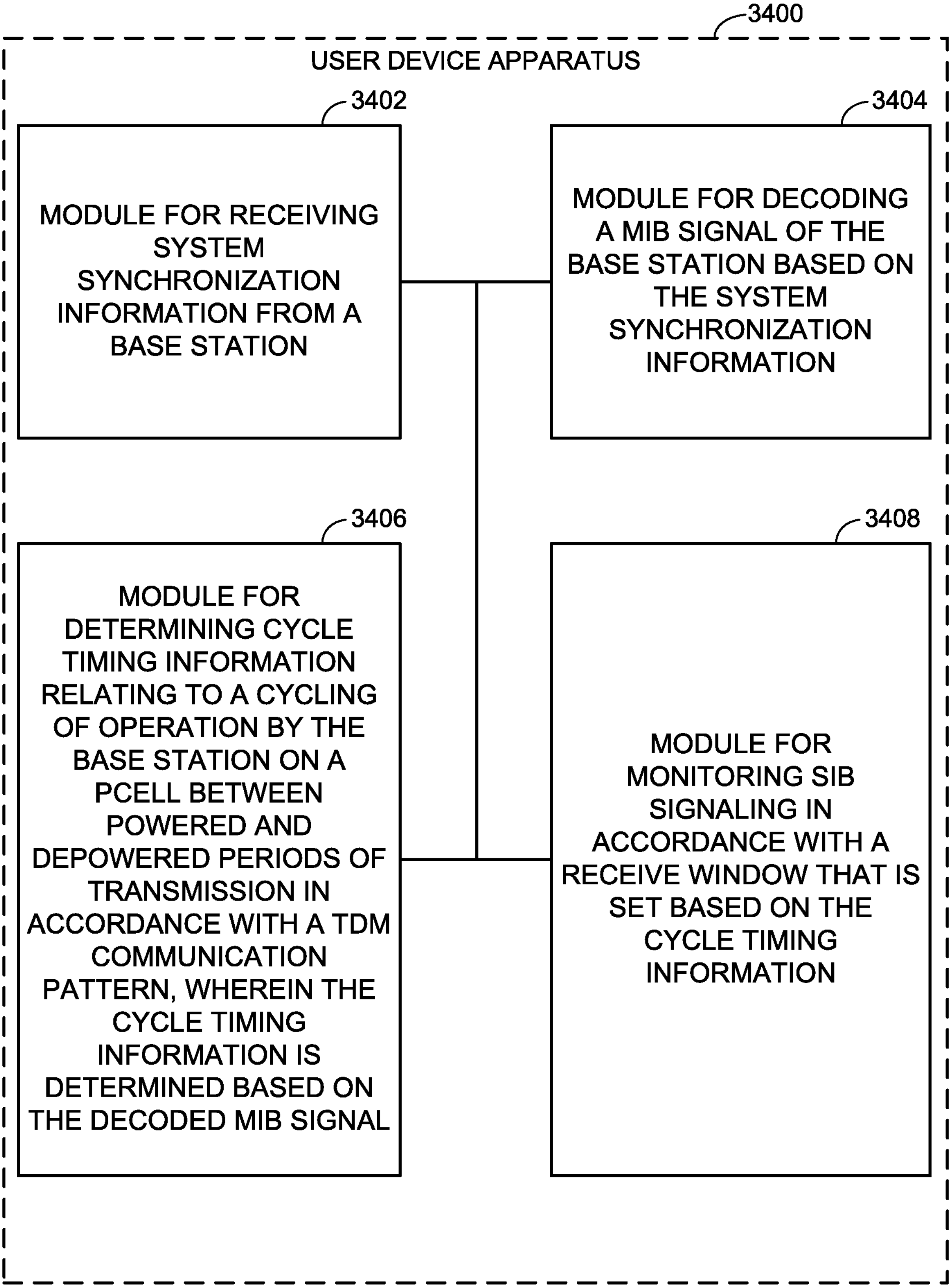
3400
USER DEVICE APPARATUS
3402
MODULE FOR RECEIVING SYSTEM SYNCHRONIZATION INFORMATION FROM A BASE STATION
3404
MODULE FOR DECODING A MIB SIGNAL OF THE BASE STATION BASED ON THE SYSTEM SYNCHRONIZATION INFORMATION
3406
MODULE FOR DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY THE BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLE TIMING INFORMATION IS DETERMINED BASED ON THE DECODED MIB SIGNAL
3408
MODULE FOR MONITORING SIB SIGNALING IN ACCORDANCE WITH A RECEIVE WINDOW THAT IS SET BASED ON THE CYCLE TIMING INFORMATION

FIG. 34

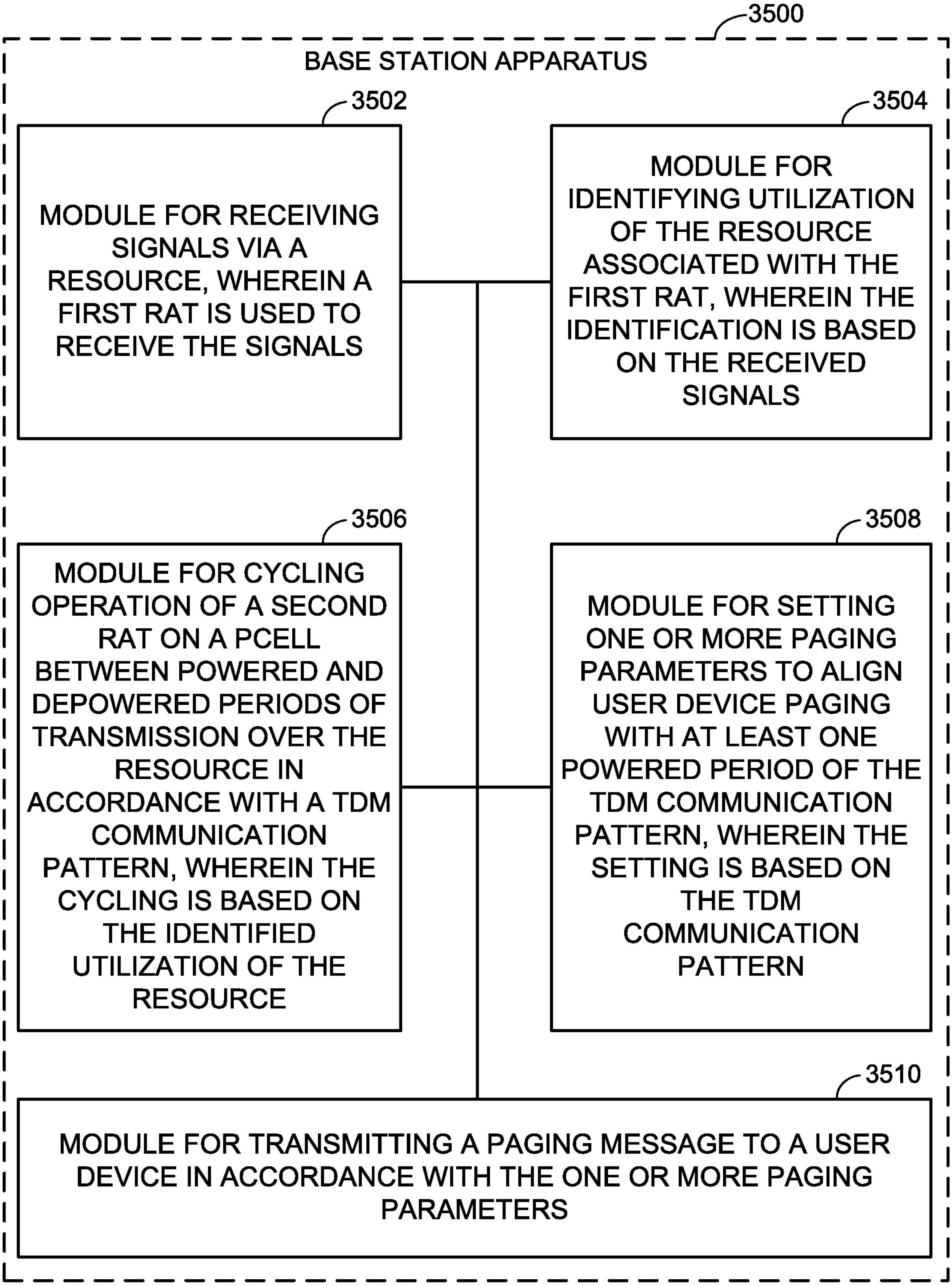
3500
BASE STATION APPARATUS
3502
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
3504
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
3506
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
3508
MODULE FOR SETTING ONE OR MORE PAGING PARAMETERS TO ALIGN USER DEVICE PAGING WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
3510
MODULE FOR TRANSMITTING A PAGING MESSAGE TO A USER DEVICE IN ACCORDANCE WITH THE ONE OR MORE PAGING PARAMETERS

FIG. 35

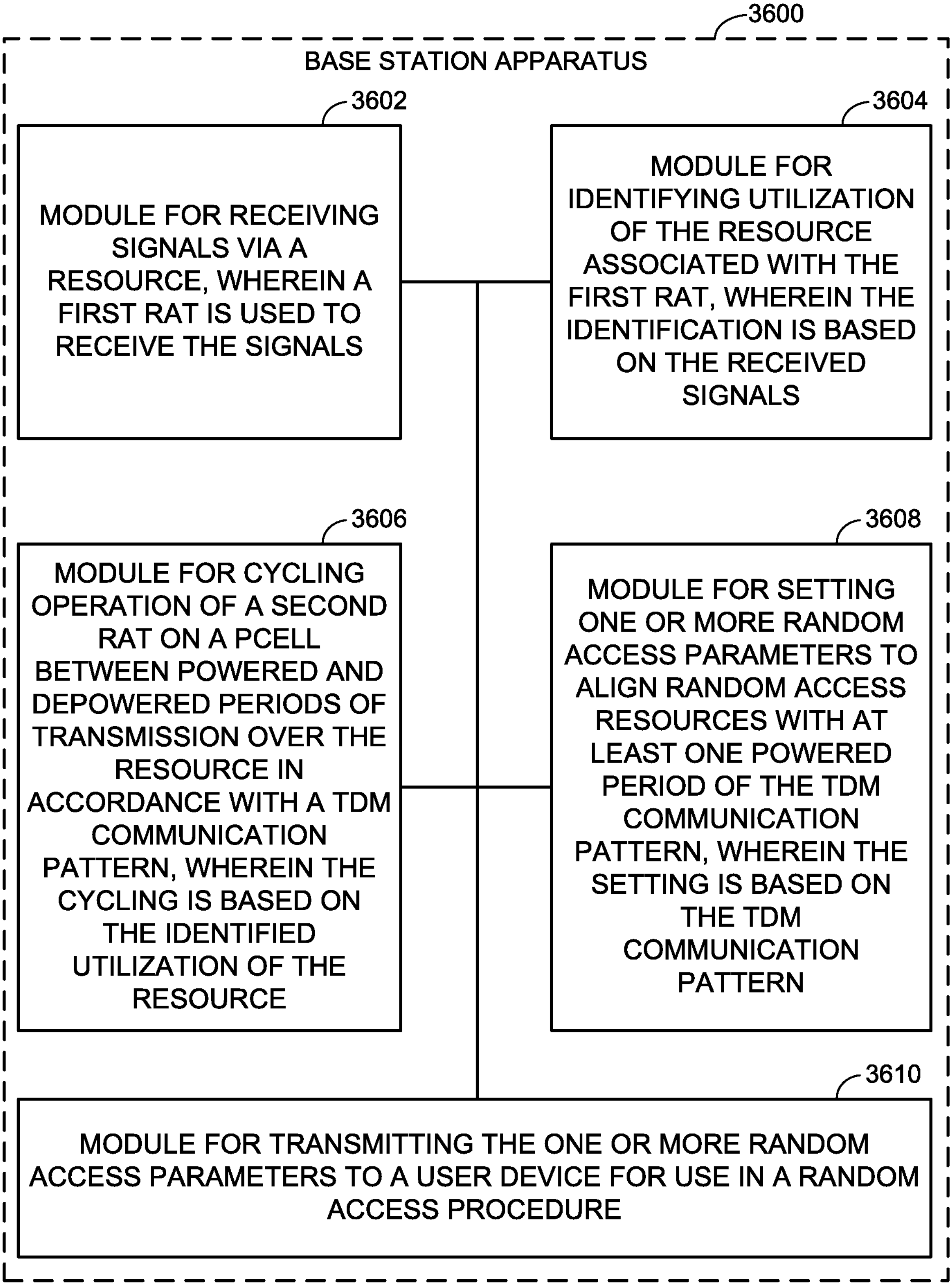
3600
BASE STATION APPARATUS
3602
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
3604
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
3606
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
3608
MODULE FOR SETTING ONE OR MORE RANDOM ACCESS PARAMETERS TO ALIGN RANDOM ACCESS RESOURCES WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
3610
MODULE FOR TRANSMITTING THE ONE OR MORE RANDOM ACCESS PARAMETERS TO A USER DEVICE FOR USE IN A RANDOM ACCESS PROCEDURE

FIG. 36

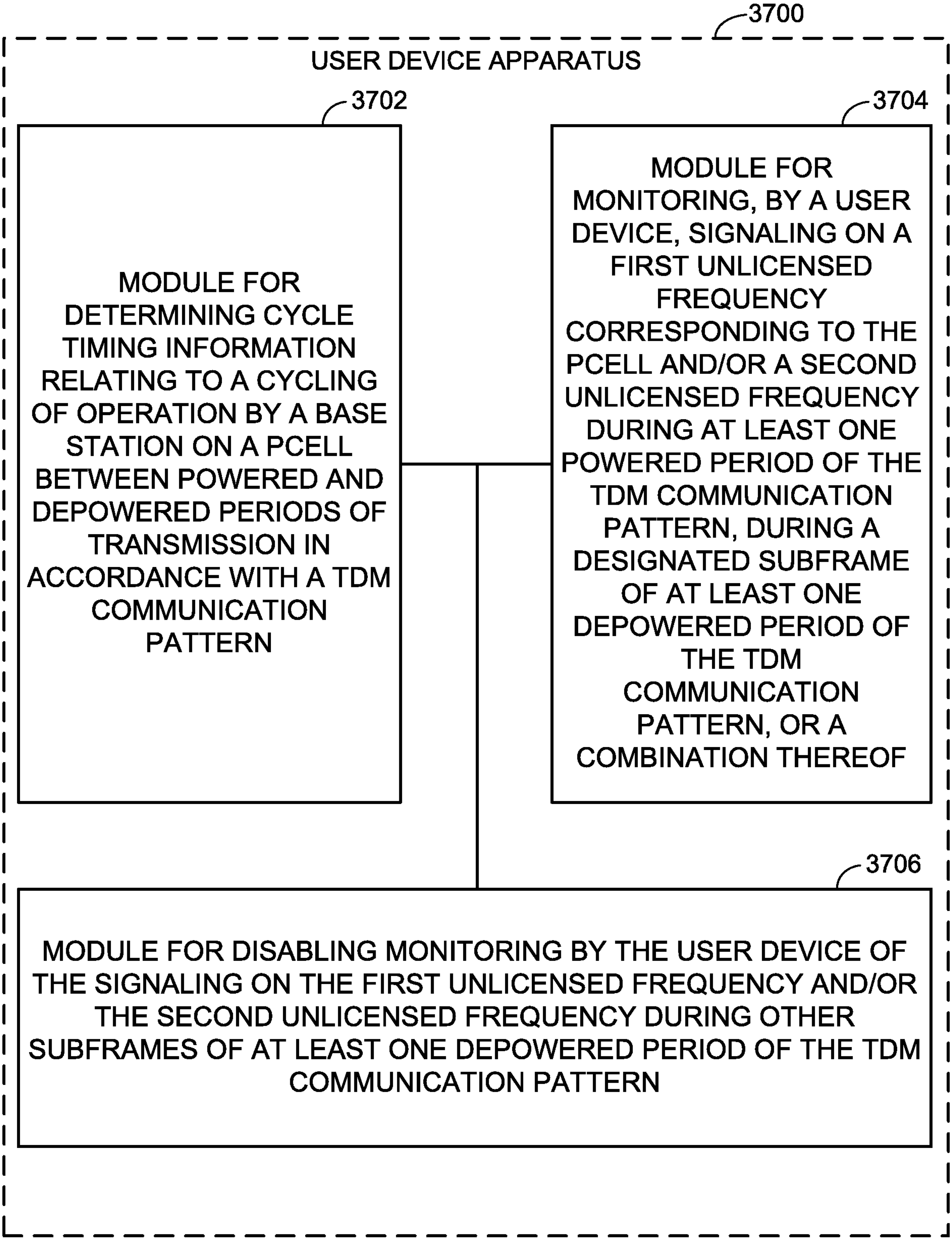
3700
USER DEVICE APPARATUS
3702
MODULE FOR DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY A BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN
3704
MODULE FOR MONITORING, BY A USER DEVICE, SIGNALING ON A FIRST UNLICENSED FREQUENCY CORRESPONDING TO THE PCELL AND/OR A SECOND UNLICENSED FREQUENCY DURING AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, DURING A DESIGNATED SUBFRAME OF AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN, OR A COMBINATION THEREOF
3706
MODULE FOR DISABLING MONITORING BY THE USER DEVICE OF THE SIGNALING ON THE FIRST UNLICENSED FREQUENCY AND/OR THE SECOND UNLICENSED FREQUENCY DURING OTHER SUBFRAMES OF AT LEAST ONE DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN

FIG. 37

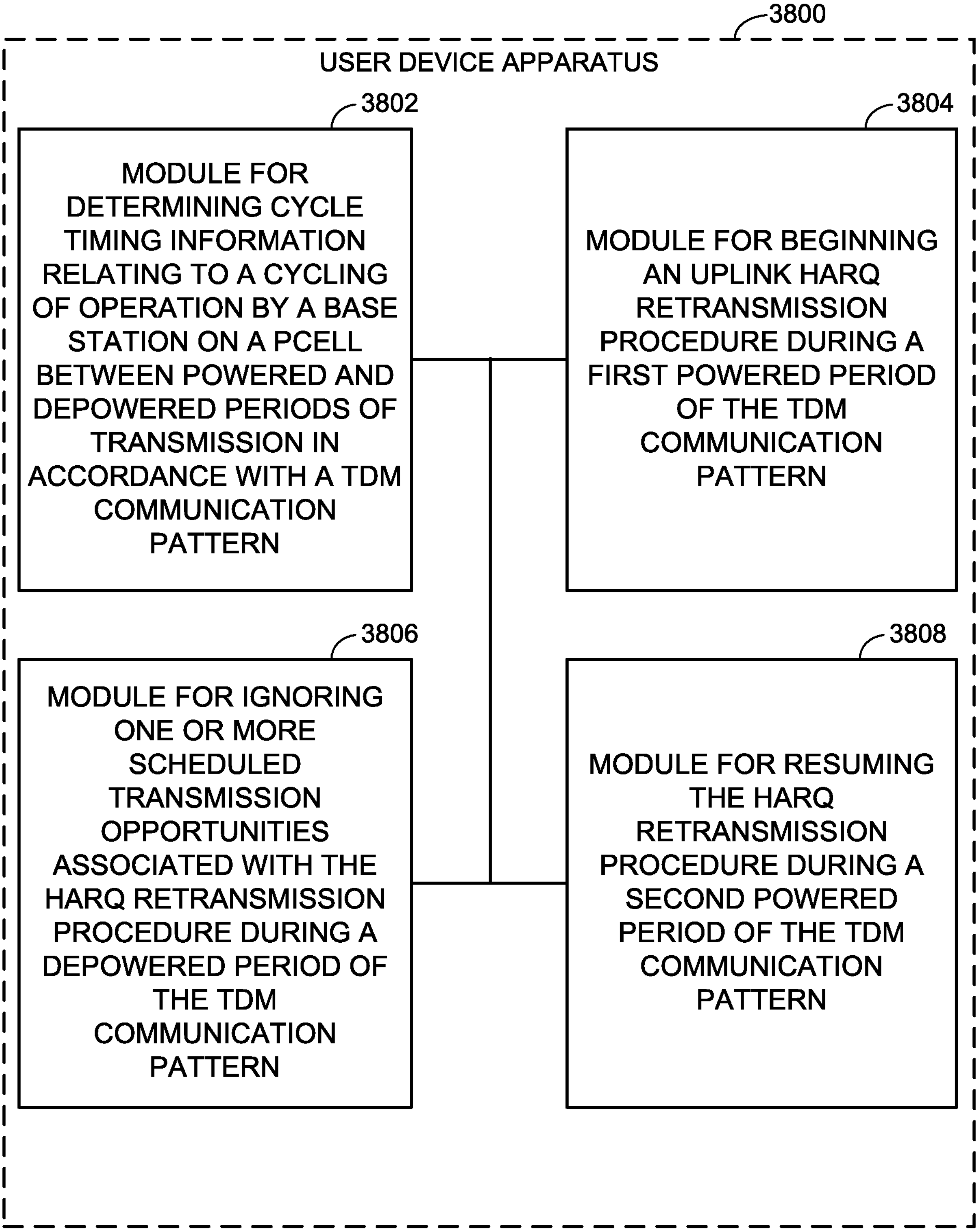
3800
USER DEVICE APPARATUS
3802
MODULE FOR DETERMINING CYCLE TIMING INFORMATION RELATING TO A CYCLING OF OPERATION BY A BASE STATION ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN
3804
MODULE FOR BEGINNING AN UPLINK HARQ RETRANSMISSION PROCEDURE DURING A FIRST POWERED PERIOD OF THE TDM COMMUNICATION PATTERN
3806
MODULE FOR IGNORING ONE OR MORE SCHEDULED TRANSMISSION OPPORTUNITIES ASSOCIATED WITH THE HARQ RETRANSMISSION PROCEDURE DURING A DEPOWERED PERIOD OF THE TDM COMMUNICATION PATTERN
3808
MODULE FOR RESUMING THE HARQ RETRANSMISSION PROCEDURE DURING A SECOND POWERED PERIOD OF THE TDM COMMUNICATION PATTERN

FIG. 38

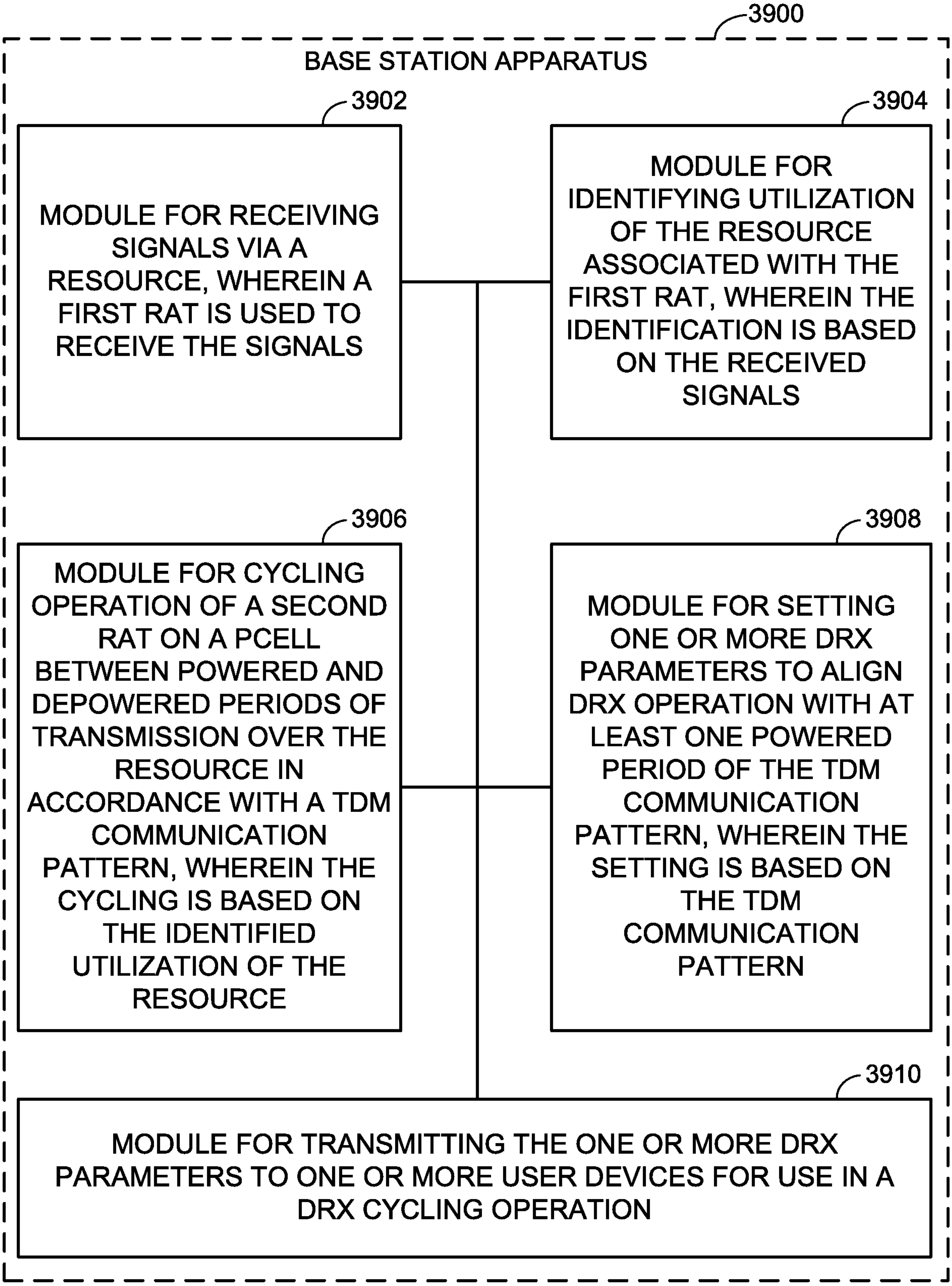
3900
BASE STATION APPARATUS
3902
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
3904
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
3906
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
3908
MODULE FOR SETTING ONE OR MORE DRX PARAMETERS TO ALIGN DRX OPERATION WITH AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN, WHEREIN THE SETTING IS BASED ON THE TDM COMMUNICATION PATTERN
3910
MODULE FOR TRANSMITTING THE ONE OR MORE DRX PARAMETERS TO ONE OR MORE USER DEVICES FOR USE IN A DRX CYCLING OPERATION

FIG. 39

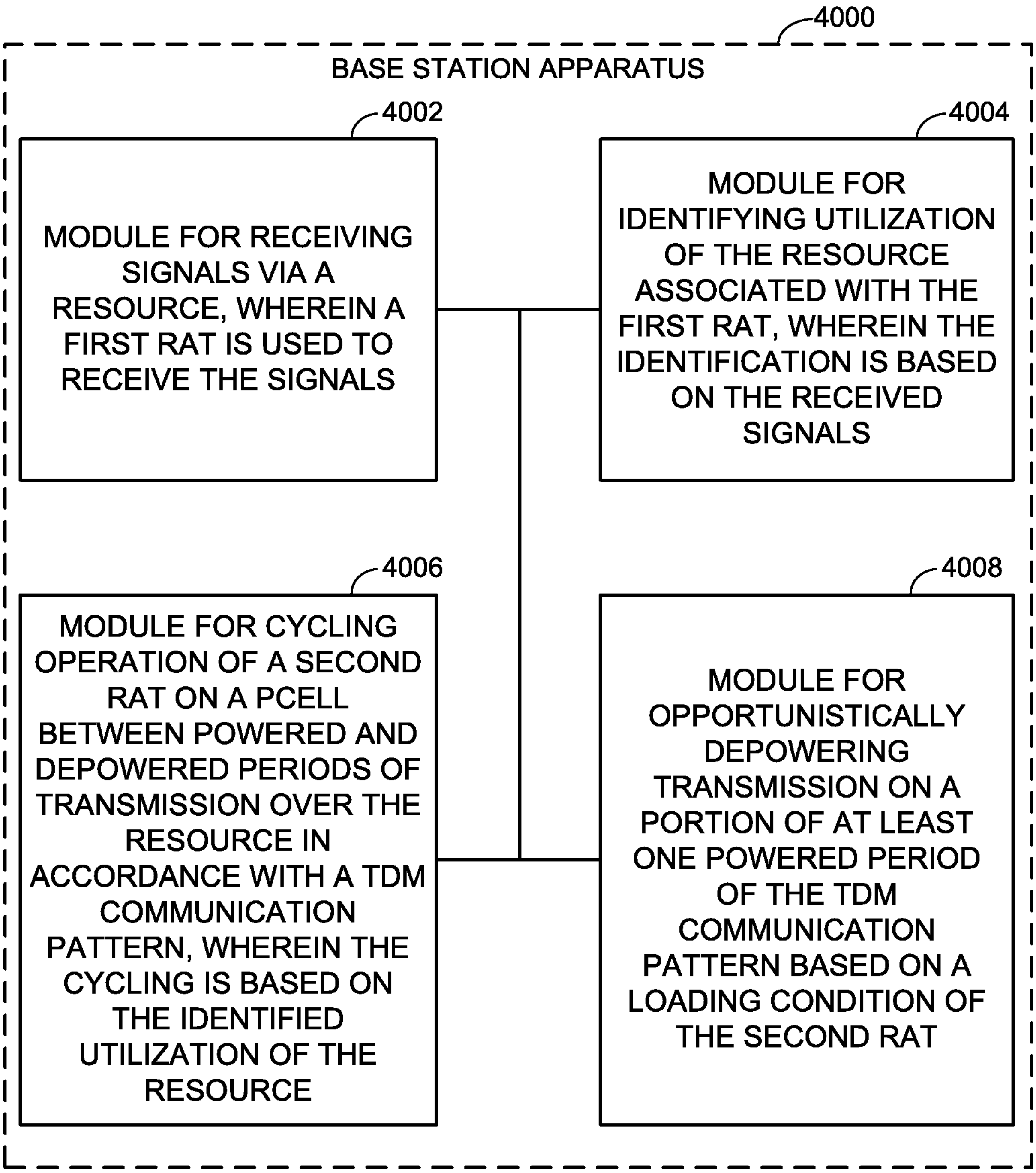
4000
BASE STATION APPARATUS
4002
MODULE FOR RECEIVING SIGNALS VIA A RESOURCE, WHEREIN A FIRST RAT IS USED TO RECEIVE THE SIGNALS
4004
MODULE FOR IDENTIFYING UTILIZATION OF THE RESOURCE ASSOCIATED WITH THE FIRST RAT, WHEREIN THE IDENTIFICATION IS BASED ON THE RECEIVED SIGNALS
4006
MODULE FOR CYCLING OPERATION OF A SECOND RAT ON A PCELL BETWEEN POWERED AND DEPOWERED PERIODS OF TRANSMISSION OVER THE RESOURCE IN ACCORDANCE WITH A TDM COMMUNICATION PATTERN, WHEREIN THE CYCLING IS BASED ON THE IDENTIFIED UTILIZATION OF THE RESOURCE
4008
MODULE FOR OPPORTUNISTICALLY DEPOWERING TRANSMISSION ON A PORTION OF AT LEAST ONE POWERED PERIOD OF THE TDM COMMUNICATION PATTERN BASED ON A LOADING CONDITION OF THE SECOND RAT

FIG. 40

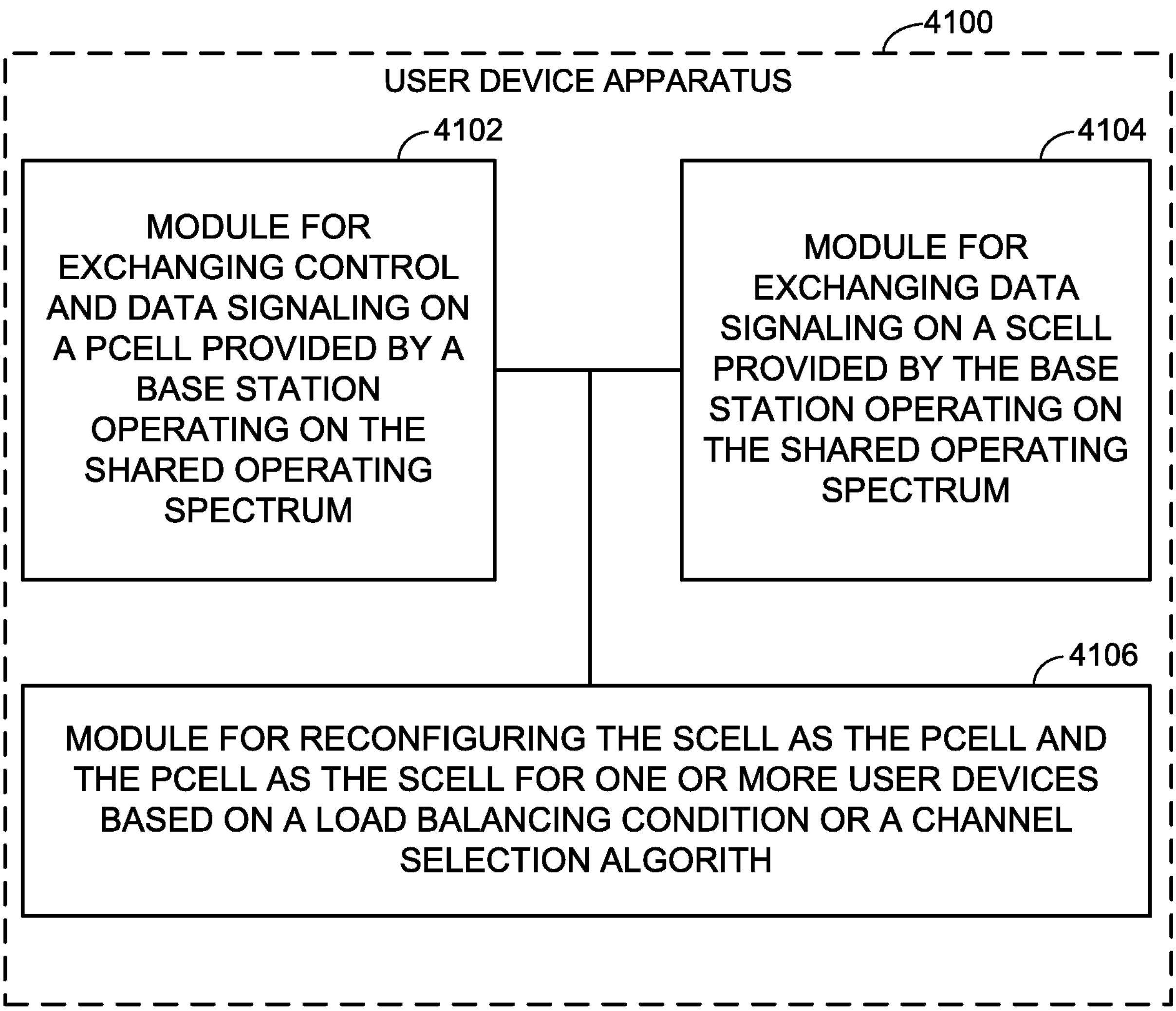
4100
USER DEVICE APPARATUS
4102
MODULE FOR EXCHANGING CONTROL AND DATA SIGNALING ON A PCELL PROVIDED BY A BASE STATION OPERATING ON THE SHARED OPERATING SPECTRUM
4104
MODULE FOR EXCHANGING DATA SIGNALING ON A SCELL PROVIDED BY THE BASE STATION OPERATING ON THE SHARED OPERATING SPECTRUM
4106
MODULE FOR RECONFIGURING THE SCELL AS THE PCELL AND THE PCELL AS THE SCELL FOR ONE OR MORE USER DEVICES BASED ON A LOAD BALANCING CONDITION OR A CHANNEL SELECTION ALGORITH

FIG. 41

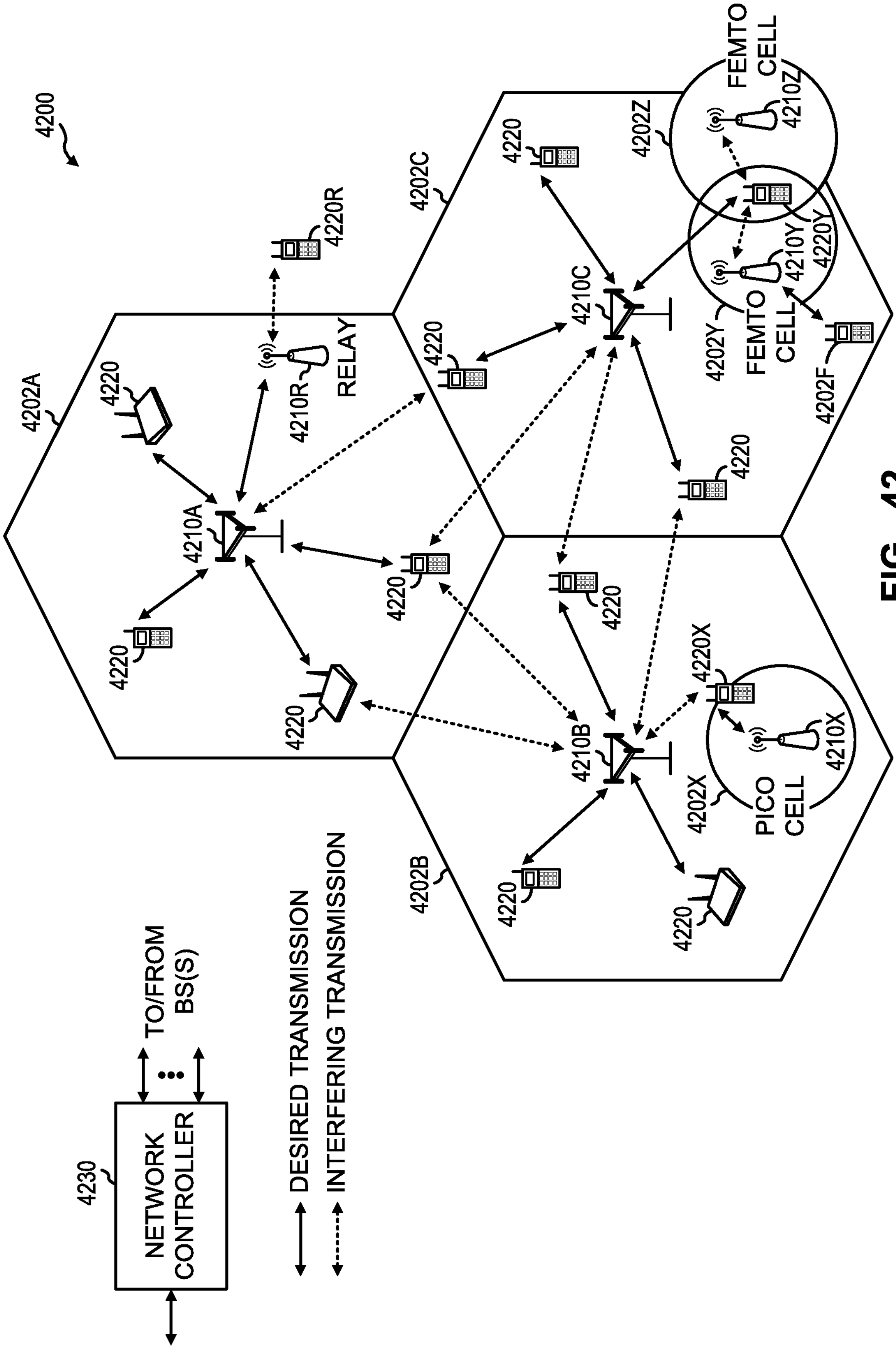
4200
4230
NETWORK CONTROLLER
TO/FROM BS(S)
DESIRED TRANSMISSION
INTERFERING TRANSMISSION
4202A
4202B
4202C
4210A
4210B
4210C
4210R
RELAY
4220R
4220
4202X
4210X
4220X
PICO CELL
4202Y
4210Y
4220Y
FEMTO CELL
4202Z
4210Z
FEMTO CELL
4202F

FIG. 42

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2014/090973

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/12(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT,WPI,EPODOC,CNKI,IEEE:interference,RAT,radio access technology,resource,cell TDM, ABRFs,MIB,DRX,gap

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013112983 A2 (INTERDIGITAL PATENT HOLDINGS, INC.) 01 August 2013 (2013-08-01) paragraphs [0002]-[0014], [0101-0218], [0229]-[0314], [0407], [0408], [0465]-[0508]	1-25
A	US 2013201884 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 08 August 2013 (2013-08-08) the whole document	1-25
A	US 2013235814 A1 (QUALCOMM INCORPORATED) 12 September 2013 (2013-09-12) the whole document	1-25
A	CN 102474489 A (QUALCOMM INCORPORATED) 23 May 2012 (2012-05-23) the whole document	1-25

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 July 2015	**17 August 2015**

Name and mailing address of the ISA/CN	Authorized officer
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Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)82245512**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2014/090973

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2013112983	A2	01 August 2013	CN	104247488	A	24 December 2014
				TW	201345278	A	01 November 2013
				KR	20140125408		28 October 2014
				EP	2807850	A2	03 December 2014
				JP	2015508958	A	23 March 2015
				US	2013208587	A1	15 August 2013
US	2013201884	A1	08 August 2013	EP	2823683	A1	14 January 2015
				TW	201347425	A	16 November 2013
				WO	2013116662	A1	08 August 2013
				JP	2015515160	A	21 May 2015
US	2013235814	A1	12 September 2013	WO	2013133911	A1	12 September 2013
				WO	2013133928	A1	12 September 2013
				US	2014050146	A1	20 February 2014
				JP	2015513265	A	30 April 2015
				KR	20150016213	A	11 February 2015
				EP	2823658	A1	14 January 2015
				CN	104186007	A	03 December 2014
CN	102474489	A	23 May 2012	US	2011158211	A1	30 June 2011
				TW	201138386	A	01 November 2011
				EP	2446598	A2	02 May 2012
				WO	2010151849	A2	29 December 2010
				KR	20120040220	A	26 April 2012
				JP	2012531833	A	10 December 2012
				INMUMNP201200013		E	18 May 2012