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(54) **RF CHAIN USAGE IN A DUAL NETWORK ARCHITECTURE**

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(Continued)

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See application file for complete search history.

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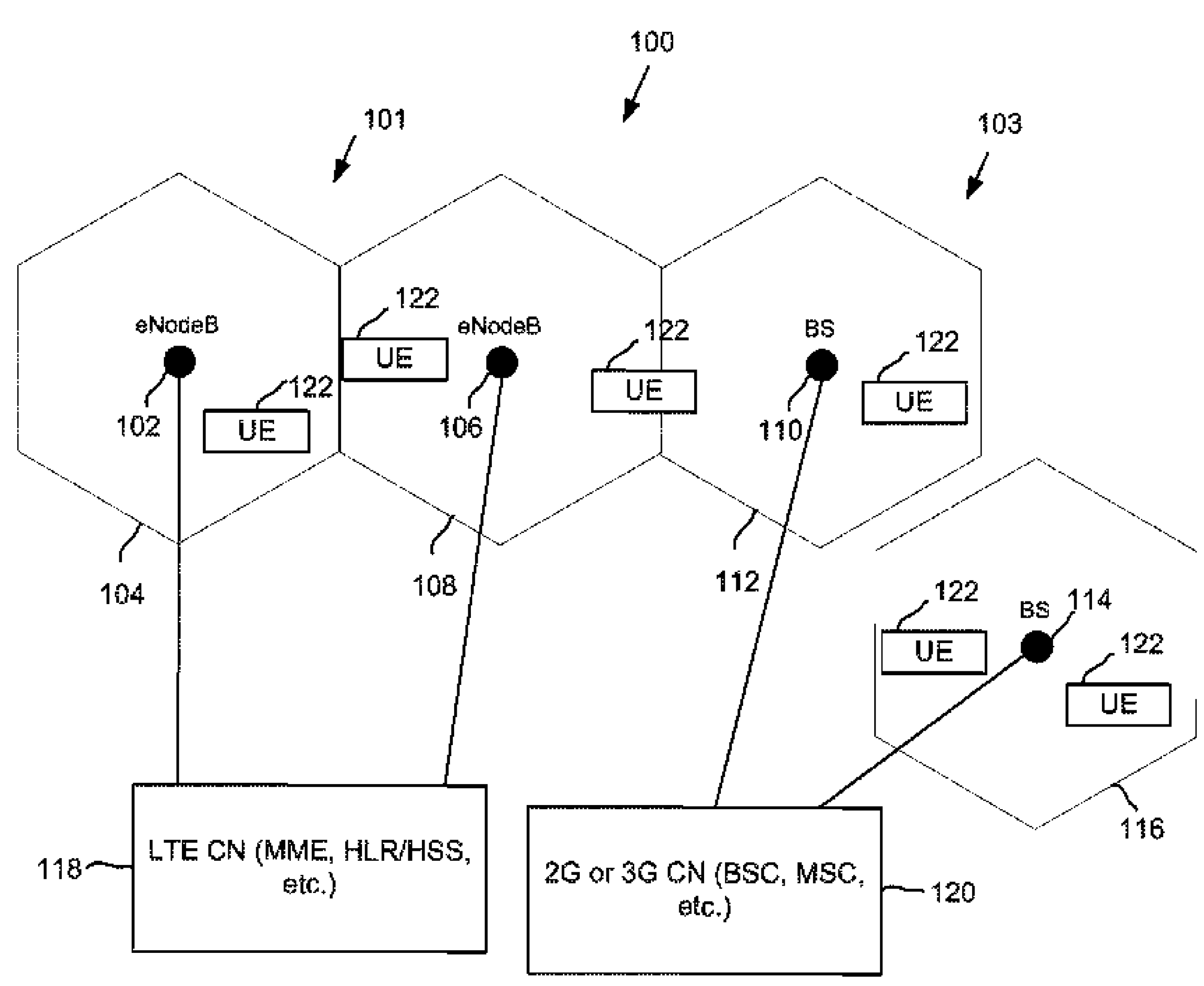
(57) **ABSTRACT**

An apparatus and method for using a radio frequency (RF chain) in a dual-network architecture are disclosed herein. An evolved node B (eNodeB) receives RF chain sharing information from user equipment (UE) associated with the eNodeB. The RF chain sharing information comprises indication of a non-usable frequency band or indication of which frequency band is supported for each of a first network and a second network that an RF chain is switchable between. The RF chain is included in the UE and at least a frequency band is shared between the first and second networks. The eNodeB transmits radio resource control (RRC) connection reconfiguration signaling to the UE to release a secondary cell (SCell) or perform inter-frequency handover of a primary cell (PCell) in response to the RF chain sharing information.

10 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

H04W 52/14	(2009.01)
H04W 24/02	(2009.01)
H04W 4/06	(2009.01)
H04W 72/12	(2009.01)
H04W 74/08	(2009.01)
H04N 21/414	(2011.01)
H04N 21/6408	(2011.01)
H04L 5/00	(2006.01)
H04L 5/14	(2006.01)
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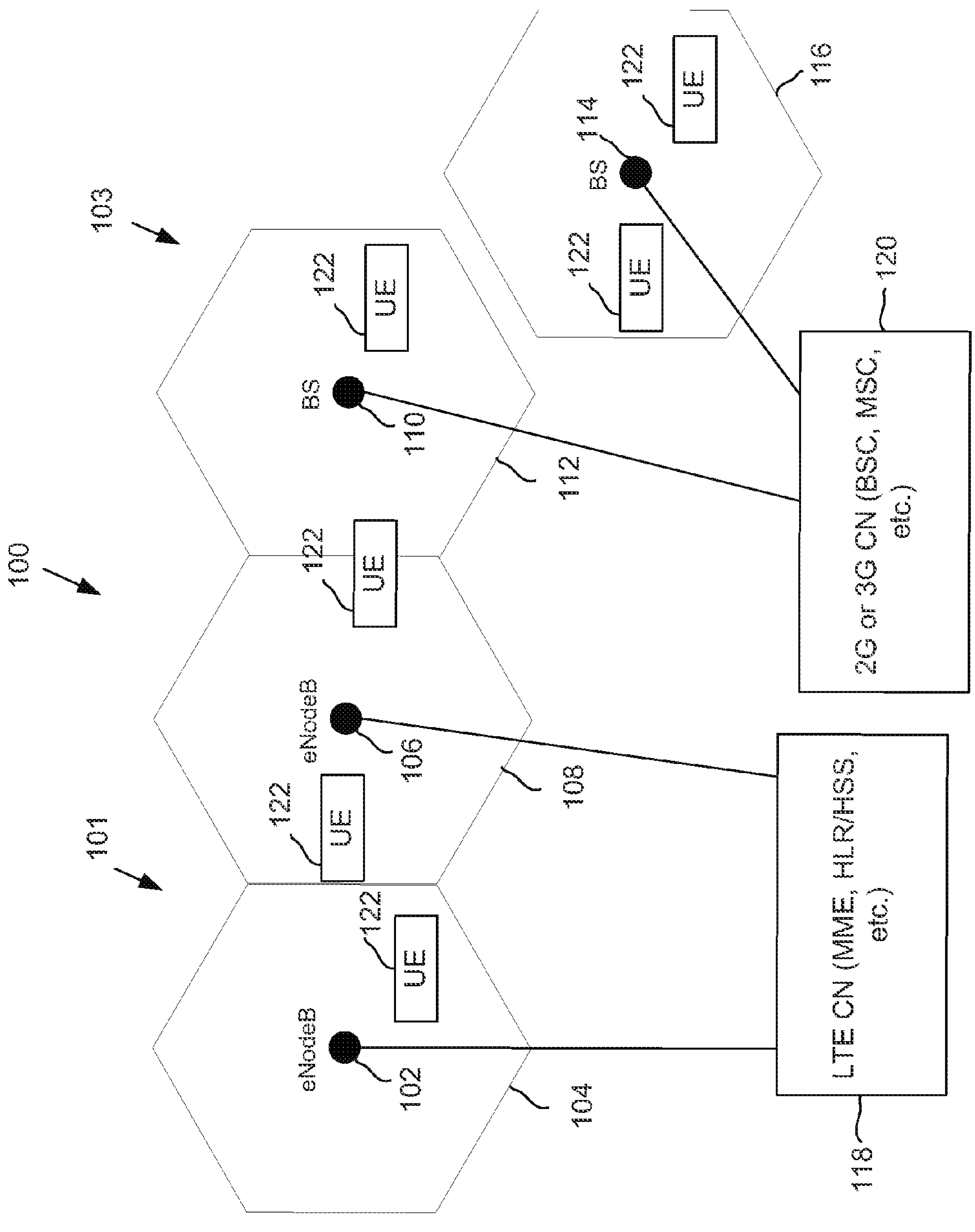

100
101
103
eNodeB
102
104
eNodeB
106
108
BS
110
112
BS
114
116
UE
122
LTE CN (MME, HLR/HSS, etc.)
118
2G or 3G CN (BSC, MSC, etc.)
120

FIG. 1

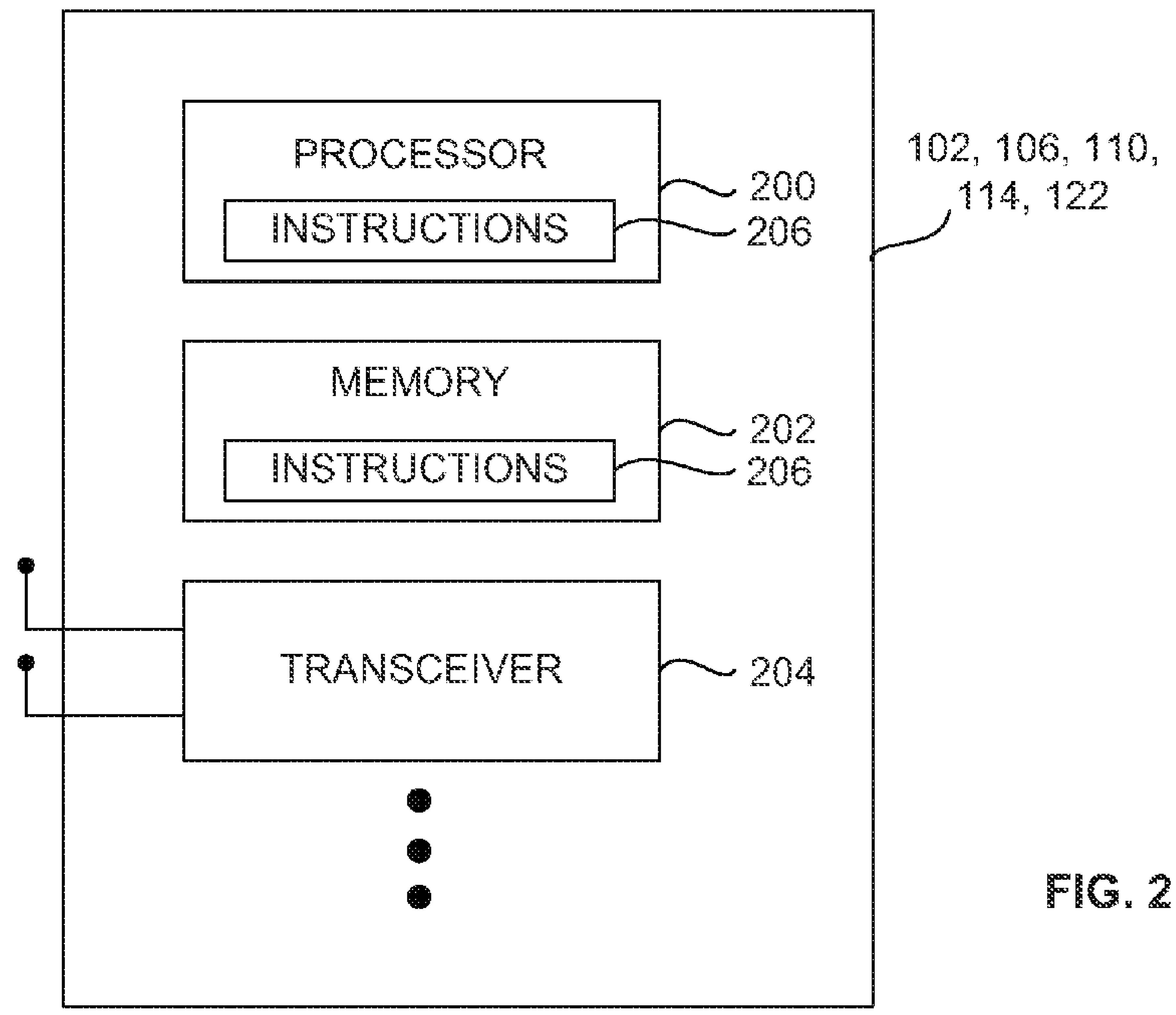

PROCESSOR
INSTRUCTIONS
200
206
102, 106, 110, 114, 122
MEMORY
INSTRUCTIONS
202
206
TRANSCEIVER
204

FIG. 2

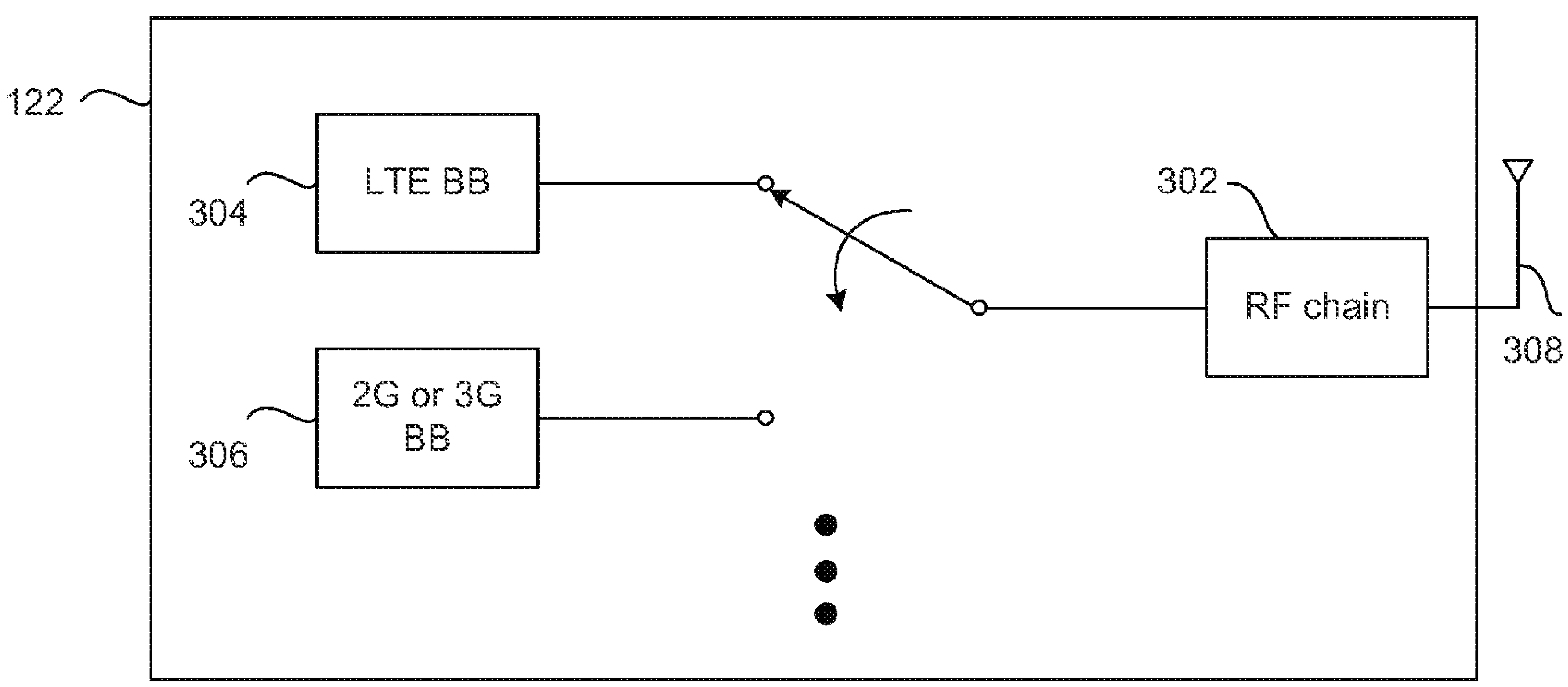

122
LTE BB
304
2G or 3G BB
306
302
RF chain
308

FIG. 3

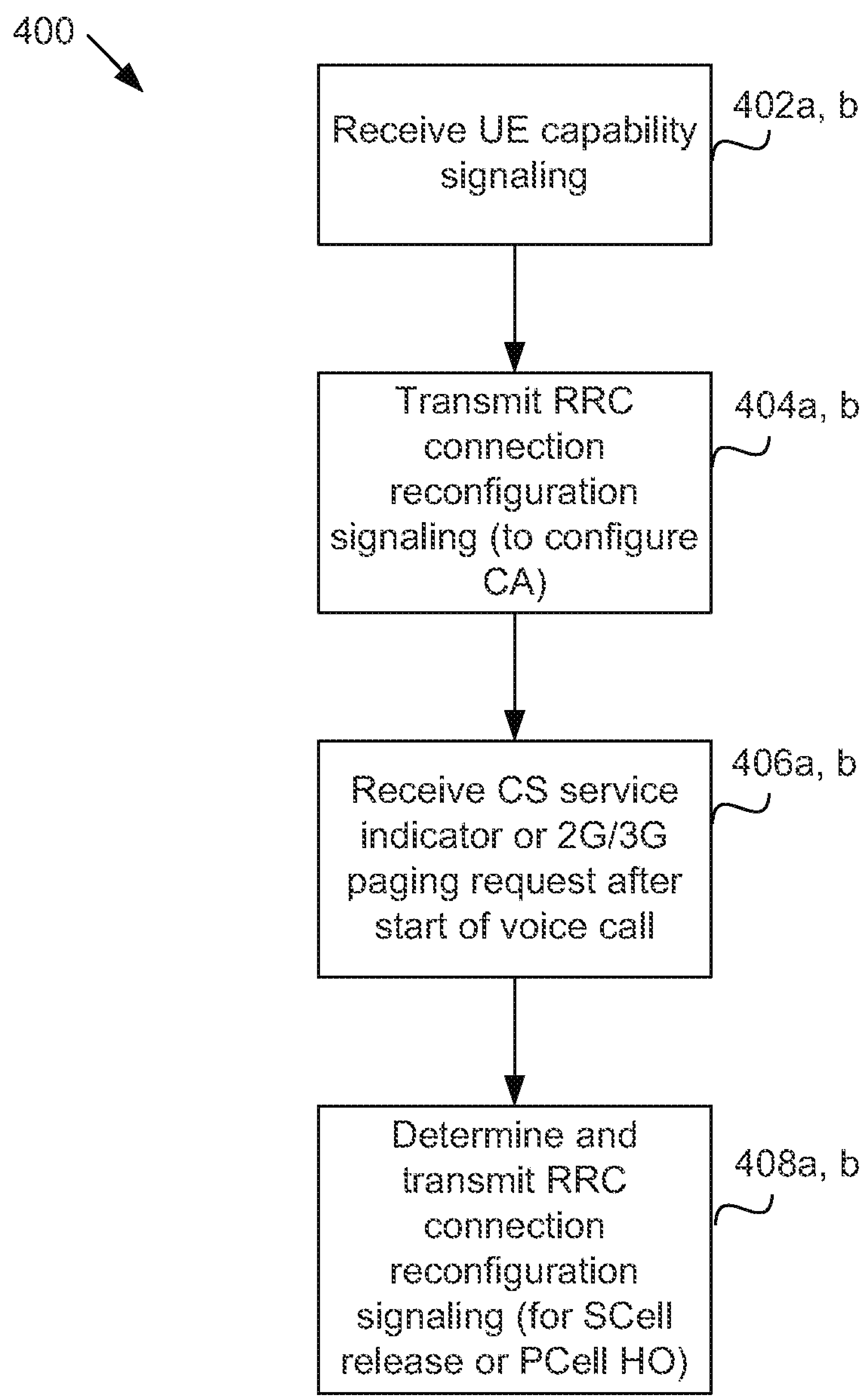

400
Receive UE capability signaling
402a, b
Transmit RRC connection reconfiguration signaling (to configure CA)
404a, b
Receive CS service indicator or 2G/3G paging request after start of voice call
406a, b
Determine and transmit RRC connection reconfiguration signaling (for SCell release or PCell HO)
408a, b

FIG. 4A

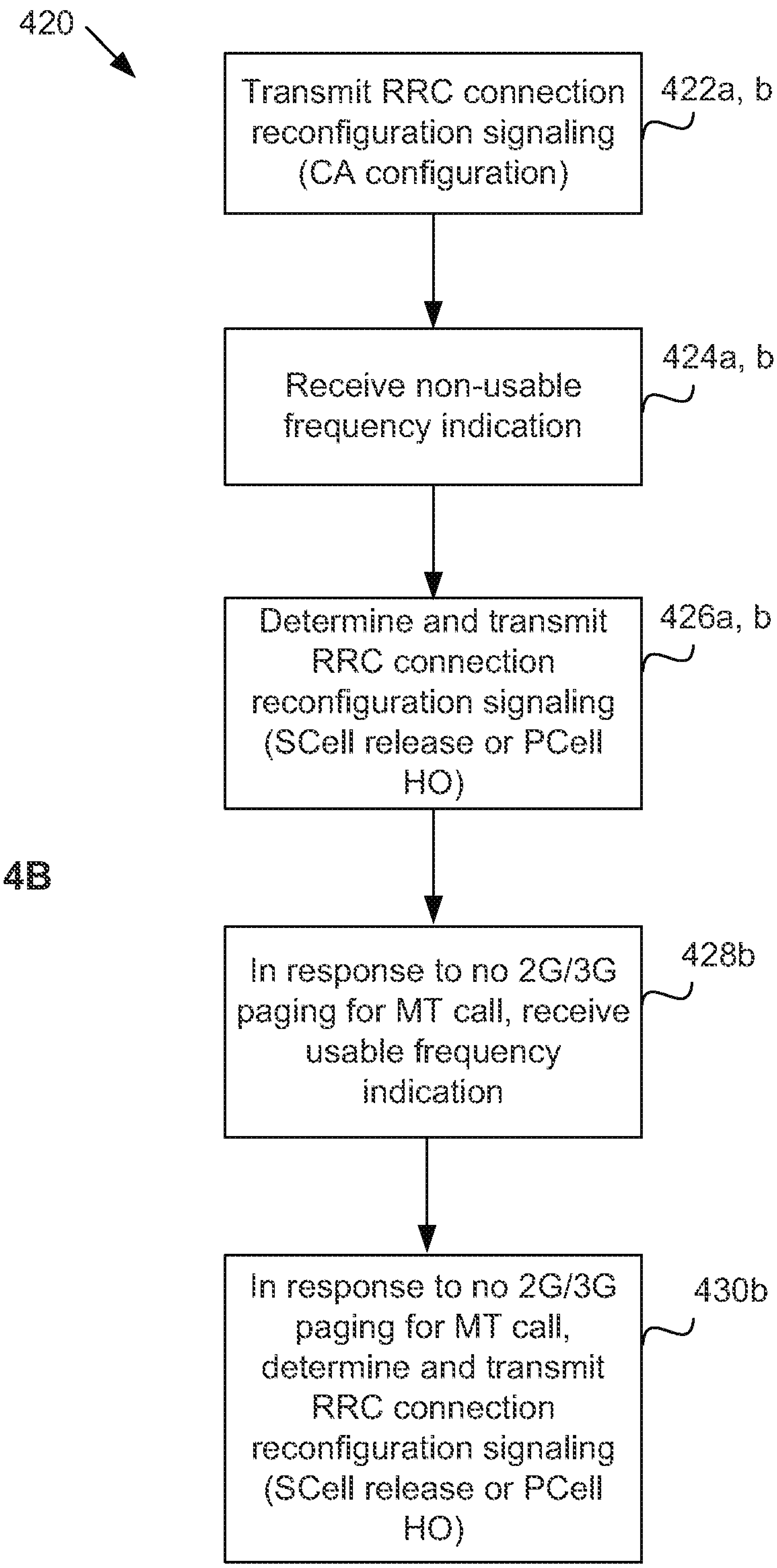

420
Transmit RRC connection reconfiguration signaling (CA configuration)
422a, b
Receive non-usable frequency indication
424a, b
Determine and transmit RRC connection reconfiguration signaling (SCell release or PCell HO)
426a, b
In response to no 2G/3G paging for MT call, receive usable frequency indication
428b
In response to no 2G/3G paging for MT call, determine and transmit RRC connection reconfiguration signaling (SCell release or PCell HO)
430b

FIG. 4B

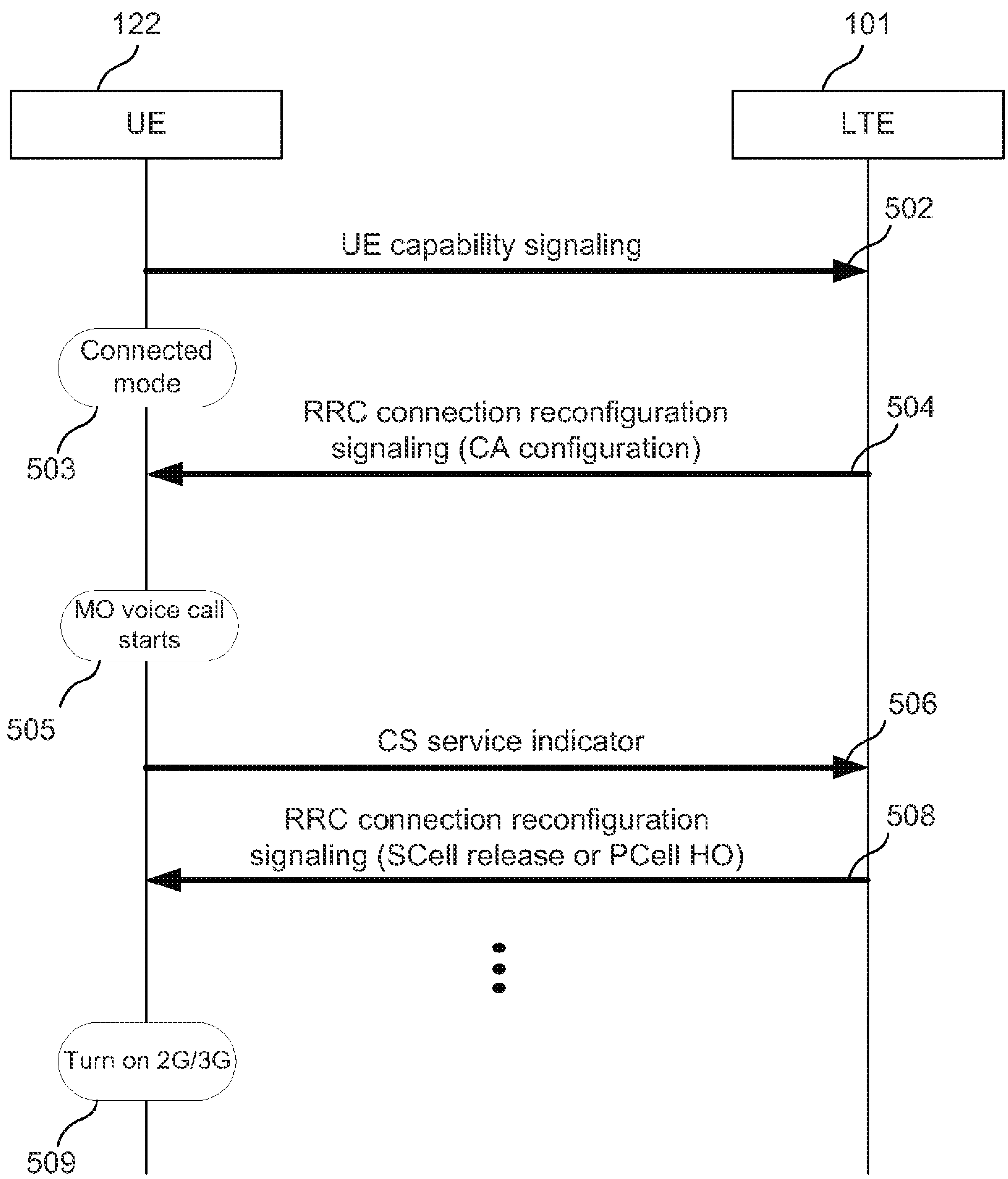

122
101
UE
LTE
502
UE capability signaling
Connected mode
503
RRC connection reconfiguration signaling (CA configuration)
504
MO voice call starts
505
506
CS service indicator
RRC connection reconfiguration signaling (SCell release or PCell HO)
508
Turn on 2G/3G
509

FIG. 5A

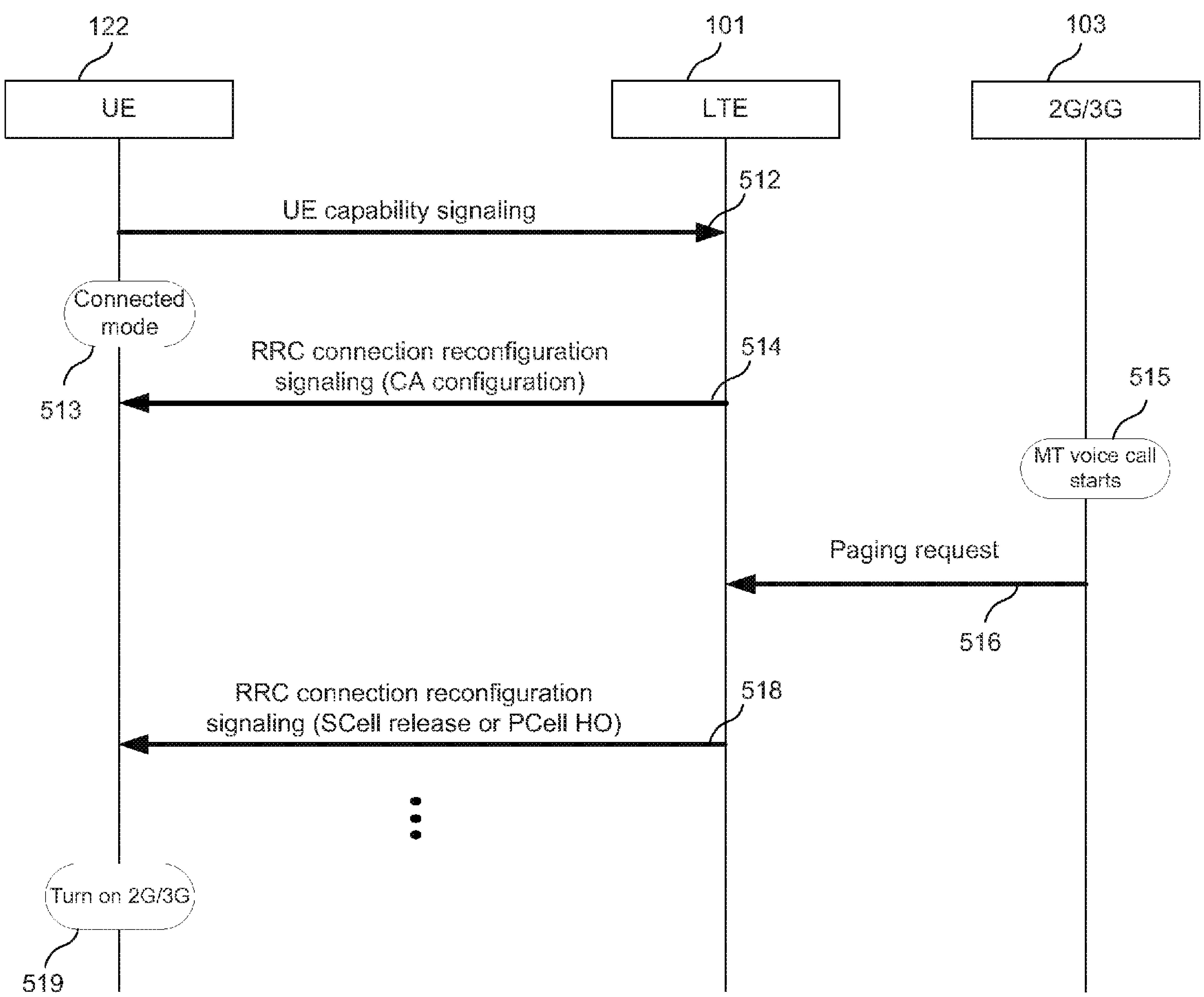

122
UE
101
LTE
103
2G/3G
512
UE capability signaling
Connected mode
513
RRC connection reconfiguration signaling (CA configuration)
514
515
MT voice call starts
Paging request
516
RRC connection reconfiguration signaling (SCell release or PCell HO)
518
Turn on 2G/3G
519

FIG. 5B

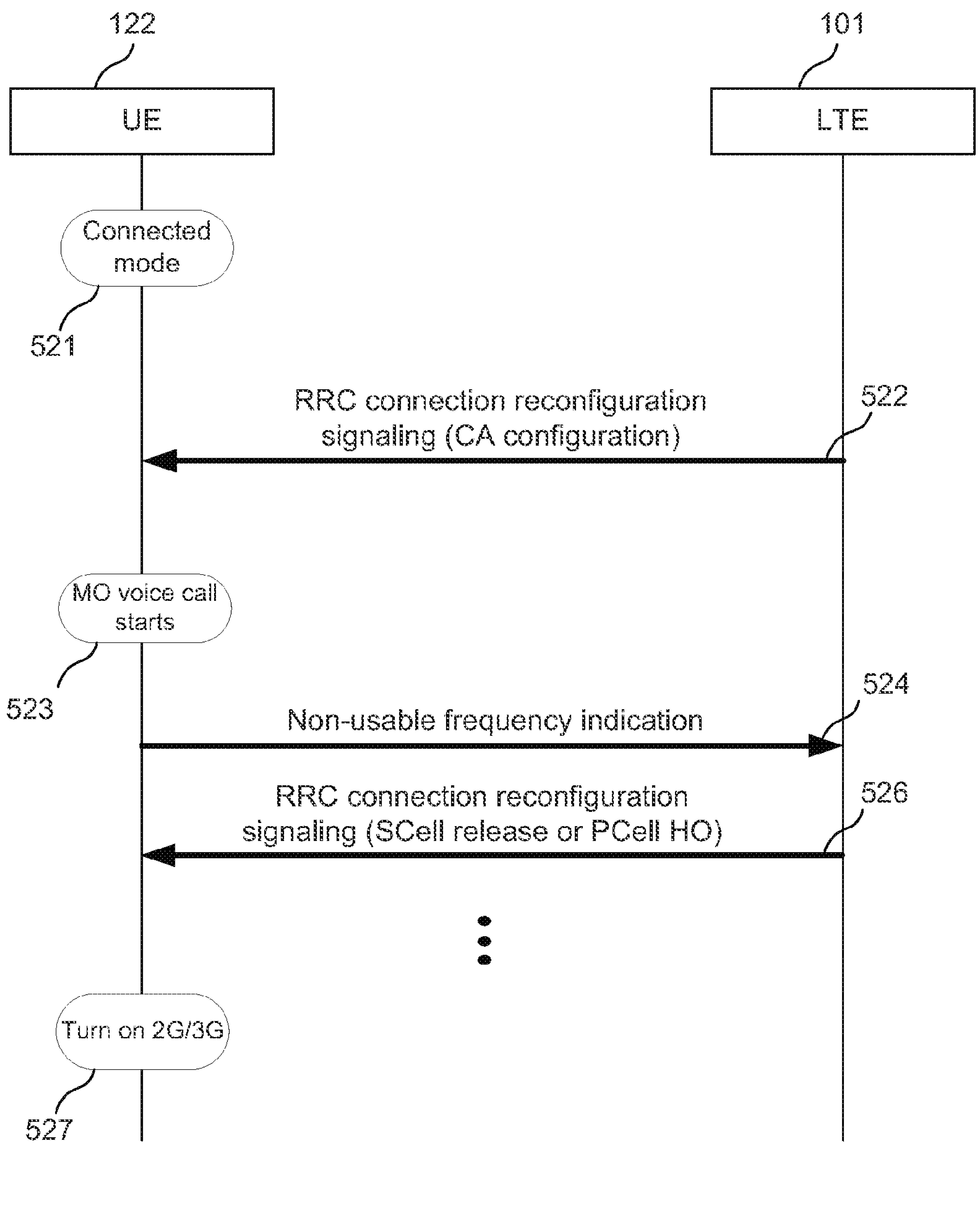

122
101
UE
LTE
Connected mode
521
RRC connection reconfiguration signaling (CA configuration)
522
MO voice call starts
523
Non-usable frequency indication
524
RRC connection reconfiguration signaling (SCell release or PCell HO)
526
Turn on 2G/3G
527

FIG. 5C

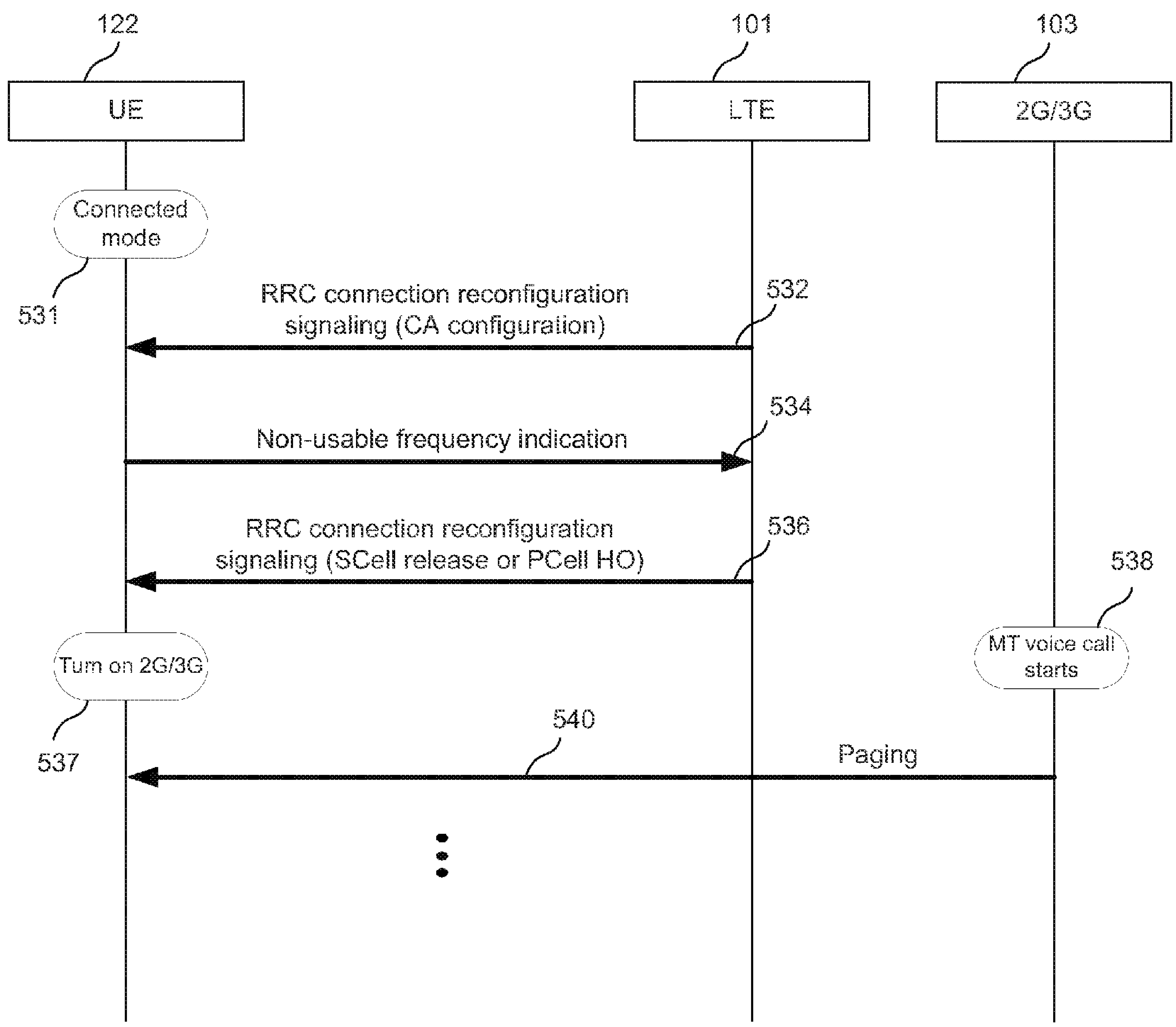
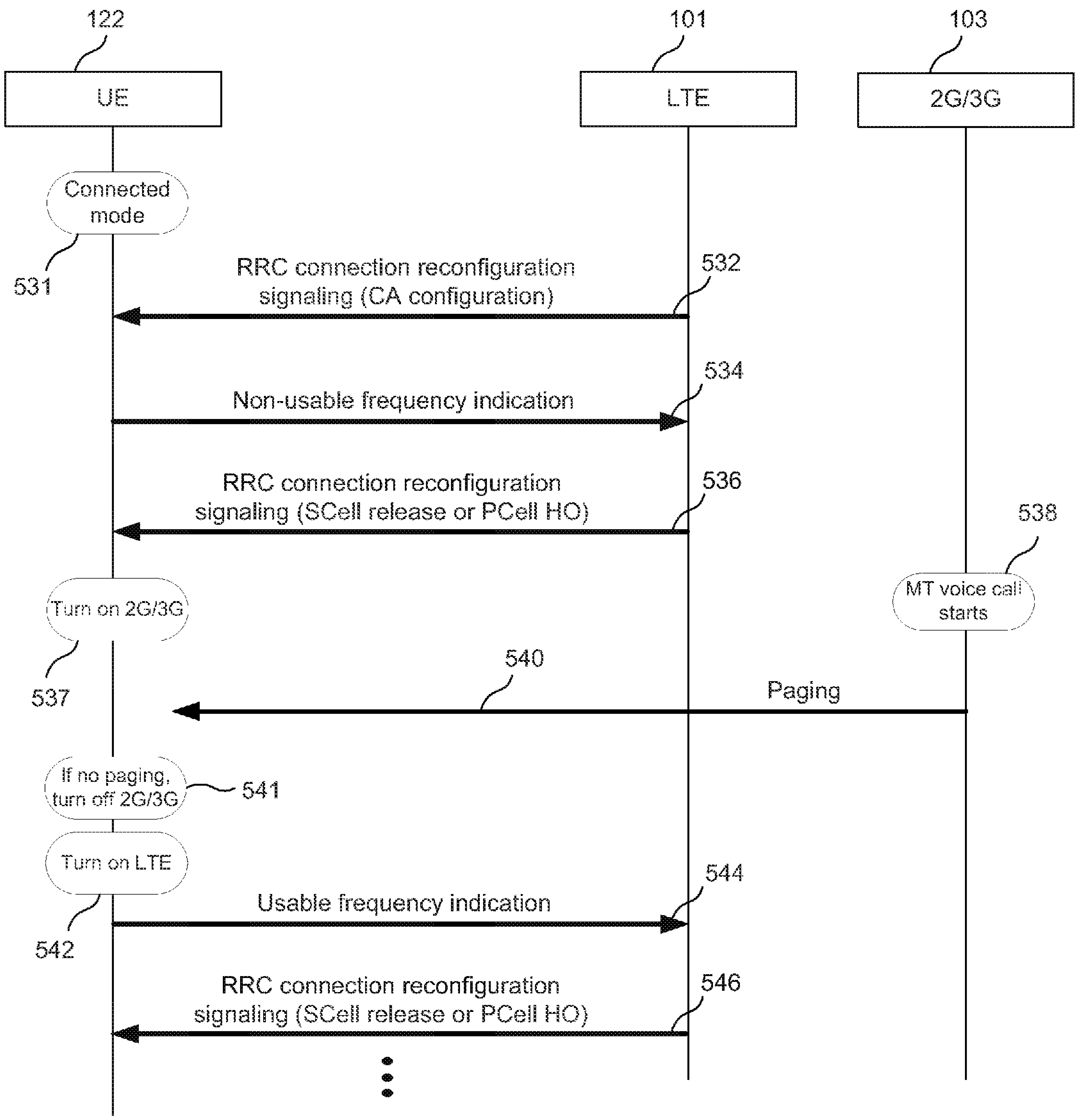

122
UE
101
LTE
103
2G/3G
Connected mode
531
RRC connection reconfiguration signaling (CA configuraiion)
532
Non-usable frequency indication
534
RRC connection reconfiguration signaling (SCell release or PCell HO)
536
538
MT voice call starts
Turn on 2G/3G
537
540
Paging

FIG. 5D



122
UE
101
LTE
103
2G/3G
Connected mode
531
RRC connection reconfiguration signaling (CA configuration)
532
Non-usable frequency indication
534
RRC connection reconfiguration signaling (SCell release or PCell HO)
536
538
MT voice call starts
Turn on 2G/3G
537
540
Paging
If no paging, turn off 2G/3G
541
Turn on LTE
542
Usable frequency indication
544
RRC connection reconfiguration signaling (SCell release or PCell HO)
546

FIG. 5E

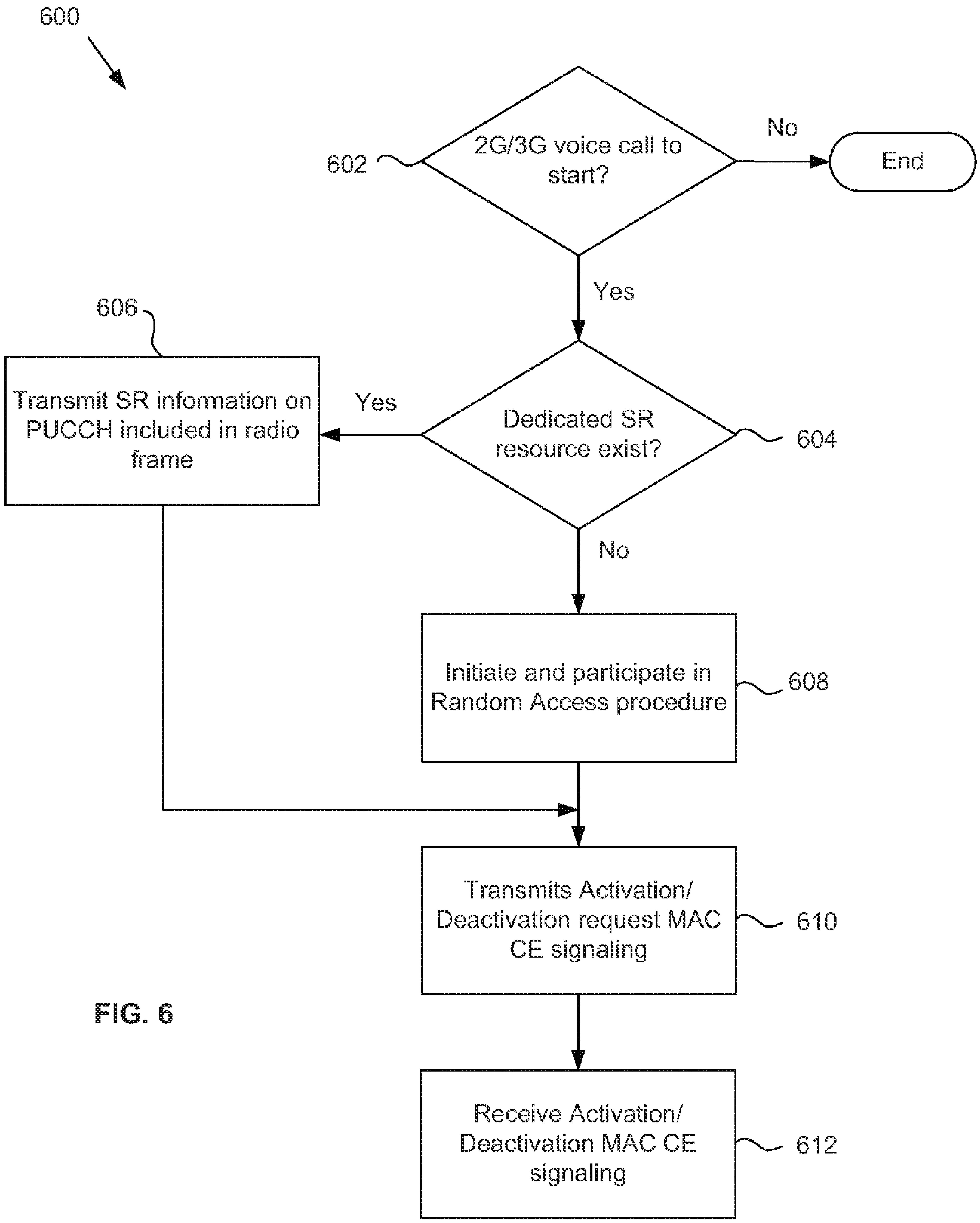

600
602
2G/3G voice call to start?
No
End
Yes
606
Transmit SR information on PUCCH included in radio frame
Yes
Dedicated SR resource exist?
604
No
Initiate and participate in Random Access procedure
608
Transmits Activation/ Deactivation request MAC CE signaling
610
Receive Activation/ Deactivation MAC CE signaling
612

FIG. 6

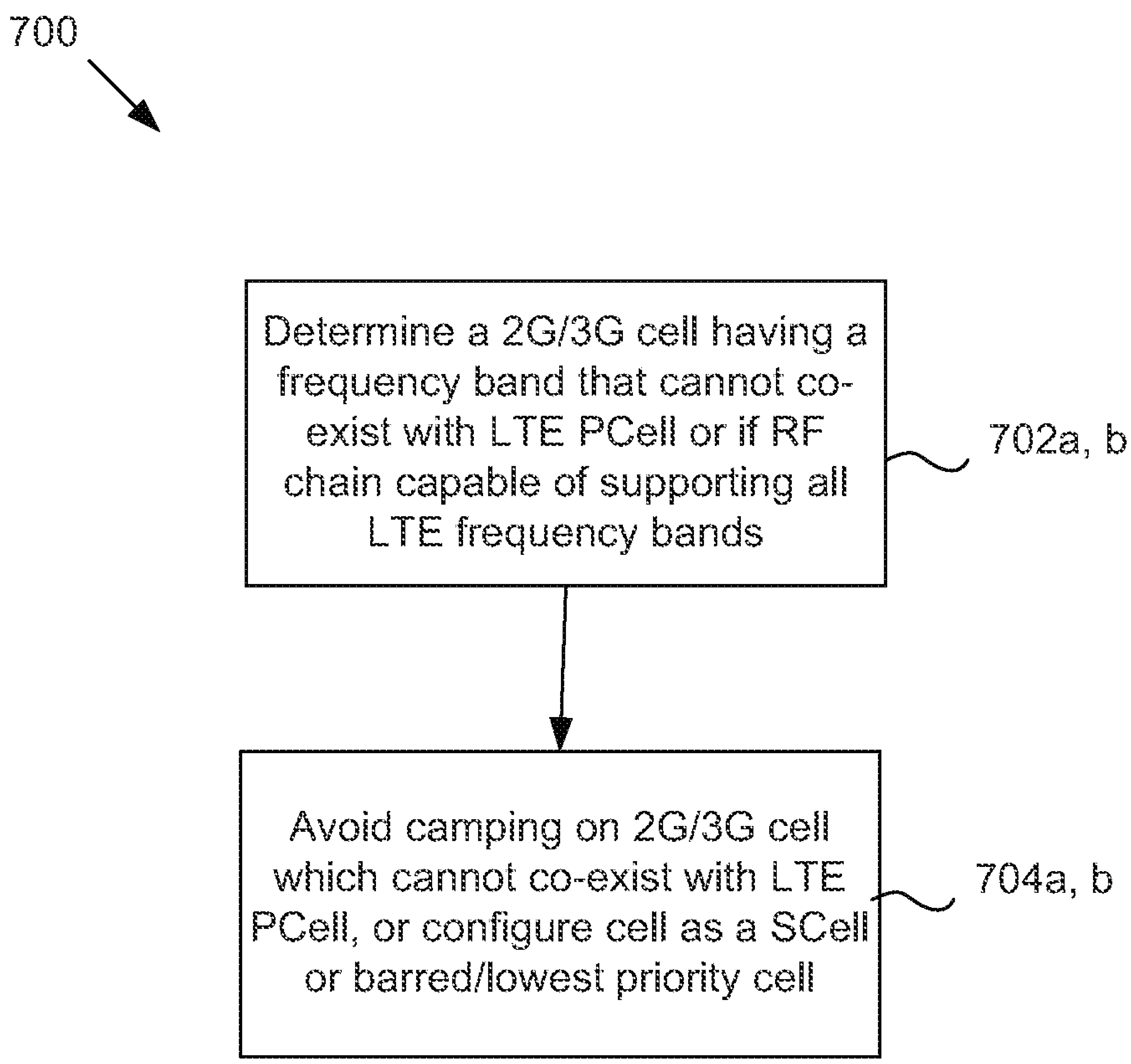

700
Determine a 2G/3G cell having a frequency band that cannot co-exist with LTE PCell or if RF chain capable of supporting all LTE frequency bands
702a, b
Avoid camping on 2G/3G cell which cannot co-exist with LTE PCell, or configure cell as a SCell or barred/lowest priority cell
704a, b

FIG. 7

RF CHAIN USAGE IN A DUAL NETWORK ARCHITECTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 61/612,188 entitled "Wireless Communication Systems and Methods" filed on Mar. 16, 2012, the content of which is incorporated herein by reference in its entirety.

TECHNICAL HELD

The present disclosure relates generally to wireless communications. More particularly, the present disclosure relates to carrier aggregation support in wireless communication systems.

BACKGROUND

Dual wireless technology architecture (also referred to as dual-standby architecture) comprises user equipment (UE) using a first wireless technology for voice communications (e.g., phone calls) and a second wireless technology for data communications (e.g., web browsing). As an example, the first wireless technology can be 2nd Generation (2G) or 3rd Generation (3G) cellular technology, and the second wireless technology can be a 3rd Generation Partnership Project (3GPP) long term evolution (LTE)-Advanced technology. In 3GPP LTE Release-10 system, carrier aggregation (CA) is supported. CA is used to extend communication up to 100 megahertz (MHz) in Release 10. Such large bandwidth communication is achieved by the simultaneous aggregation of more than one Release 8/9 component carrier having bandwidths of 1.4, 3, 5, 10, 15, and up to 20 MHz, hence the term carrier aggregation, in which each carrier within the aggregated set of carriers is referred to as a component carrier. Under Release 10, up to five component carriers may be aggregated together to achieve the maximum bandwidth of 100 MHz.

If CA is supported in dual-standby architecture, it may be possible for a UE to share a radio frequency (RF) chain between the 2G/3G network and LTE network if the two networks' respective frequency bands are close to each other. If a RF chain is to be shared, the evolved node B (eNodeB or eNB) should be notified of whether it will be used for 2G/3G or LTE service. Currently the eNodeB is not provided this information.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example (portion) of a dual radio access technology (RAT) network according to some embodiments.

FIG. **2** illustrates an example block diagram showing details of each of eNodeBs, BSs, and UEs according to some embodiments.

FIG. **3** illustrates an example block diagram showing additional components included in one or more of the UEs according to some embodiments.

FIGS. **4**A-**4**B illustrates example respective flow diagrams showing use of radio resource control (RRC) signaling to facilitate information sharing between a given UE and its associated eNodeB pertaining to which network the RF chain of the given UE is/will be supporting according to some embodiments.

FIGS. **5**A-**5**E illustrate example timing diagrams corresponding to FIGS. **4**A-**4**B according to some embodiments.

FIG. **6** illustrates an example flow diagram for using Activation/Deactivation MAC control element (CE) signaling according to some embodiments.

FIG. **7** illustrates an example flow diagram for assignment of PCell and SCells and/or CCs for the PCell and SCells for the UE **122** that can be controlled by the network to avoid frequency co-existence issues from occurring beforehand.

DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to create and use a computer system configuration and related method and article of manufacture to notify an eNodeB of which network a RF chain switchable between at least two disparate networks (e.g., LTE and 3G, LTE and 2G, etc.) will be supporting in connection with a service event (e.g., start of a voice call) are described herein. The switchable RF chain is included in a UE capable of dual-network operation. The dual network architecture supports CA. The UE provides notification to its associated eNodeB when the frequency band to be used for the service event (e.g., 2G/3G voice call) is the same as or close to the frequency band used for the other network service (e.g., LTE service). In some embodiments RRC signaling is used to provide the information about RF sharing to the eNodeB. In other embodiments Activation/Deactivation MAC CE signaling is triggered by RF sharing information provided by the HE to the eNodeB. In still other embodiments PCell and SCells and/or CCs for the PCell and SCells are judiciously assigned to the so as to minimize frequency co-existence issues.

Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the scope of the invention. Moreover, in the following description, numerous details are set forth for the purpose of explanation. However, one of ordinary skill in the art will realize that embodiments of the invention may be practiced without the use of these specific details. In other instances, well-known structures and processes are not shown in block diagram form in order not to obscure the description of the embodiments of the invention with unnecessary detail. Thus, the present disclosure is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

FIG. **1** illustrates an example (portion) of a dual radio access technology (RAT) network **100** according to some embodiments. Network **100** represents an example dual-standby or dual-network architecture. In one embodiment, the network **100** comprises a 3rd Generation Partnership Project (3GPP) long term evolution (LTE)-Advanced technology network **101** and a 2nd Generation (2G) or 3rd Generation (3G) RAT network **103**. The 2G RAT network **103** comprises a network based on the Global System for Mobile (GSM) or Code Division Multiple Access (CDMA) standard. The 3G RAT network **103** comprises a network based on the Universal Mobile Telecommunications System (UMTS) or Evolved High Speed Packet Access (HSPA+) standard. The LTE RAT network **101** operates in either time division duplexing (TDD) mode or frequency division duplexing (FDD) mode. The LTE network **101** includes an evolved node B (eNodeB or eNB) **102**, an eNodeB **106**, and a core network **118**. The 2G/3G network **103** includes a base station (BS) **110**, a BS **114**, and a core network **120**.

The eNodeB **102** (also referred to as a base station) serves a certain geographic area that includes at least a cell **104**. A plurality of user equipment (UEs) **122** associated with the cell **104** communicates with the eNodeB **102** on one or more specific frequencies, the eNodeB **102** providing control and radio air interface functionalities for cell **104**. The eNodeB **106** (also referred to as a base station) is similar to eNodeB **102** except it serves a different cell from that of eNodeB **102**. The eNodeB **106** serves a certain geographic area that includes at least a cell **108**. A plurality of UEs **122** associated with the cell **108** communicates with the eNodeB **106** on one or more specific frequencies, the eNodeB **106** providing control and radio air interface functionalities for cell **108**.

Each of the eNodeBs **102**, **106** communicates with the core network **118**. Core network **118** includes, but is not limited to, a mobility management entity (MME), a home location registrar (HLR)/home subscriber server (HSS), serving gateway (SGW), and other LTE network components providing network functionalities not provided by an eNodeB.

The BS **110** serves a certain geographic area that includes at least a cell **112**. A plurality of UEs **122** associated with the cell **112** communicates with the BS **110** on one or more specific frequencies, the BS **110** providing control and radio air interface functionalities for cell **112**. The BS **114** is similar to BS **110** except it serves a different cell from that of BS **110**. The BS **114** serves a certain geographic area that includes at least a cell **116**. A plurality of UEs **122** associated with the cell **116** communicates with the BS **114** on one or more specific frequencies, the BS **114** providing control and radio air interface functionalities for cell **116**.

Each of the BSs **110**, **114** communicates with the core network **120**. Core network **120** includes, but is not limited to, base station controllers (BSCs), a mobile switching center (MSC), and other 2G/3G network components providing network functionalities not provided by a BS.

The cells **104**, **108**, **112**, **116** may or may not be immediately co-located next to each other. As another example, the respective coverage areas of the cells **104**, **108**, **112**, **116** may overlap with each other. As still another example, the respective coverage areas of the cells **104**, **108**, **112**, **116** may be distinct or isolated from each other. It is understood that the network **100** includes more than two eNodeBs and more than two BSs, each of such eNodeBs or BSs serving a cell.

The UEs **122** (also referred to as mobile devices) comprises a variety of devices that communicate within the network **100** including, but not limited to, cellular telephones, smart phones, tablets, laptops, desktops, personal computers, servers, personal digital assistants (PDAs), web appliances, set-top box (STB), a network router, switch or bridge, and the like. The UEs **122** comprise dual RAT UEs capable of switching operation between the LTE network and 2G/3G network. In one embodiment, each of the UEs **122** may access the 2G/3G network via BS **110** or **114** for voice (phone calls) and access the LTE network via eNodeB **102** or **106** for data (web browsing, emails).

When operating in LTE mode, the UEs **122** located in respective cells **104**, **108** transmits data to its respective eNodeB **102**, **106** (uplink transmission) and receives data from its respective eNodeB **102**, **106** (downlink transmission) using radio frames comprising Orthogonal Frequency-Division Multiple Access (OFDMA) frames. For Release-10 or later LTE networks **101**, carrier aggregation (CA) is supported, in which up to five frequency bands corresponding to five component carriers (CCs) can be aggregated to expand the overall bandwidth of the network (e.g., up to a bandwidth of 100 MHz). For each of the UEs **122** at a given point in time, a CC is defined as a given UE **122**'s primary cell (PCell). If more than one CC is configured for the given UE **122**, the additional CCs are referred to as secondary cells (SCells). For instance, cell **104** can be designated as the PCell for a given UE **122** while cell **108** is designated as the SCell for the same given UE **122**. In Release-10 or later LTE CA, a plurality of serving cells are served by the same eNodeB. For example, eNodeB **102** may serve cell **104** and one or more other cells not shown in FIG. **1**.

FIG. **2** illustrates an example block diagram showing details of each of eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122** according to some embodiments. Each of the eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122** includes a processor **200**, a memory **202**, a transceiver **204**, instructions **206**, and other components (not shown). The eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122** can be similar to each other in hardware, firmware, software, configurations, and/or operating parameters.

The processor **200** comprises one or more central processing units (CPUs), graphics processing units (GPUs), or both. The processor **200** provides processing and control functionalities for the eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122**. Memory **202** comprises one or more transient and static memory units configured to store instructions and data for the eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122**. The transceiver **204** comprises one or more transceivers including a multiple-input and multiple-output (MIMO) antenna to support MIMO communications. The transceiver **204** receives uplink transmissions and transmits downlink transmissions, among other things, from and to the UEs respectively.

The instructions **206** comprises one or more sets of instructions or software executed on a computing device (or machine) to cause such computing device (or machine) to perform any of the methodologies discussed herein. The instructions **206** (also referred to as computer- or machine-executable instructions) may reside, completely or at least partially, within the processor **200** and/or the memory **202** during execution thereof by the eNodeBs **102**, **106**, BSs **110**, **114**, and UEs **122**. The processor **200** and memory **202** also comprise machine-readable media.

FIG. **3** illustrates an example block diagram showing additional components included in one or more of the UEs **122** according to some embodiments. In one embodiment, a given UE **122** includes at least one RF chain **302**. When CA is supported (e.g., in Release 10 or later LTE network **101**) in the network **100**, the given UE **122** is implemented with multiple RF chains. The given UE **122** can be configured to share the RF chain **302** between LTE service and 2G/3G service if the respective frequency bands are close to each other. As shown in FIG. **3**, the RF chain **302** is selectively connectable or switchable to a LTE baseband (BB) **304** or a 2G/3G BB **306**. Each of the LTE BB **304** and 2G/3G BB **306** comprises a BB integrated circuit (IC) chip. Each of the LTE BB **304** and 2G/3G BB **306** can be provided on separate IC chips, or together on a single IC chip. The RF chain **302** includes, but is not limited to, a digital-to-analog (D/A)/analog-to-digital (D/A) converter, decoder/encoder, modulator/demodulator, filter, power amplifier (PA), and local oscillator (LO).

When the RF chain **302** is switched to the LTE BB **304**, the given UE **122** operates in the LTE network and an antenna **308** transmits or receives wireless signals configured according to the LTE standard. When the RF chain **302** is switched to the 2G/3G BB **306**, the given UE **122** operates in the 2G/3G network and the antenna transmits or receives wireless signals configured according to the 2G/3G standard. If the RE chain **302** is being used to support a LTE service, for example, then the RF chain **302** cannot simultaneously be used to support a 2G/3G service. Thus, the eNodeB associated with the given UE **122** is informed of which network the RF chain **302** is supporting.

FIGS. **4**A-**4**B illustrates example flow diagrams **400** and **420**, respectively, showing use of radio resource control (RRC) signaling to facilitate information sharing between a given UE **122** and an eNodeB (e.g., eNodeB **102** or **106**) pertaining to which network the RF chain **302** of the given UE **122** is/will be supporting according to some embodiments. FIGS. **5**A-**5**B illustrate example timing diagrams corresponding to FIG. **4**A according to some embodiments. FIGS. **5**C-**5**E illustrate example timing diagrams corresponding to FIG. **4**B according to some embodiments.

FIGS. **4**A and **5**A correspond to the given UE **122** originating a voice call (also referred to as a mobile originating (MO) call) and correspondingly, configuring its RF chain **302** to connect to the 2G/3G BB **306** to operate on the 2G/3G network. At a block **402***a* of FIG. **4**A, a given eNodeB (e.g., eNodeB **102** or **106**) associated with the given UE **122** receives UE capability signaling from the given UE **122** (communication **502** in FIG. **5**A). The UE capability signaling comprises RF sharing information (also referred to as RF chain sharing information) informing the given eNodeB whether RF chain **302** is shared between LTE and 2G/3G for each supported frequency band or frequency band combination (each frequency band of each supported frequency bandwidth provided by CA). After the UE capability signaling is received by the given eNodeB, the given UE **122** goes into connected mode (connected mode **503** in FIG. **5**A) if there is a packet switched call in LTE. Connected mode occurs upon the given UE **122** completing the initial RRC connection setup procedure with the given eNodeB.

Next at a block **404***a*, the given eNodeB transmits to the given UE **122**, RRC connection reconfiguration signaling comprising CA configuration if there is no voice call ongoing in 2G/3G (communication **504** in FIG. **5**A). When the given UE **122** starts a MO call **505** after block **404***a*, the given UE **122** transmits a circuit switched (CS) service indicator to the given eNodeB (communication **506** in FIG. **5**A). The CS service indicator is received by the given eNodeB, at a block **406***a*, the CS service indicator informing the given eNodeB of the start of a MO call by the given UE **122**.

At a block **408***a*, in response to receiving the CS service indicator, the given eNodeB determines whether to send a message for the given UE **122** to release a SCell or to handover to a new PCell. In CA, there are a number of serving cells, one cell for each CC included in the CA. The cell corresponding to a given CC operates at a specific frequency band from the other CCs within the CA. The coverage area of a cell for a CC can be different from a cell for another CC. The cells for one or more CCs can be served by the same eNodeB. When more than one CC is associated with the given UE **122** (in other words, more than one cell is associated with the given UE **122**), the cell corresponding to one of these CCs is designated as the PCell for the given UE **122**. The remaining cells corresponding to the remaining associated CCs are referred to as SCells for the given UE **122**. Only the PCell is responsible for mobility management such as providing non-access-stratum (NAS) mobility information or security keys. SCells can be added or removed, as required, for the given UE **122** with RRC connection reconfiguration, while the PCell association changes by performing handover to a new/different PCell.

The given eNodeB transmits a RRC connection reconfiguration message/signaling to the given UE **122** to release a particular SCell associated with the given UE **122**, if the particular SCell corresponds to the frequency band that is shared with 2G/3G service (communication **508** in FIG. **5**A). The eNodeB commands the given UE **122** to release the particular SCell so that there is no inadvertent use of the frequency band, which will be used for the MO call via 2G/3G service, for some other purpose. Releasing a cell refers to temporarily placing a hold on maintaining a connection with and/or use of the cell. If there is no common frequency band between the SCells and 2G/3G service and the current/source PCell corresponds to the frequency band shared for 2G/3G service, then the given eNodeB transmits a RRC connection reconfiguration message/signaling to the given UE **122** to perform inter-frequency handover (HO) of the PCell to another carrier frequency (communication **508** in FIG. **5**A). In general the RRC connection reconfiguration message with mobility control information is providing instructions to release the source/current PCell and handover to another cell in the different carrier frequency.

Once the given UE **122** has taken action in accordance with the RRC connection reconfiguration message in block **408***a*, the given UE **122** turns on 2G/3G service **509** (FIG. **5**A) and camps on a 2G/3G cell for the duration of the MO call. While camping on a 2G/3G cell, the given UE **122** maintains connection with LTE cells (the associated PCell and SCell(s) except for the cell instructed to be released in block **408***a*).

FIGS. **4**A and **5**B correspond to the given UE **122** receiving a voice call (also referred to as a mobile terminating (MT) call) and correspondingly, configuring its RF chain **302** to connect to the 2G/3G BB **306** to operate on the 2G/3G network. FIG. **5**B is similar to FIG. **5**A with the exception of communication **516** (instead of communication **506**) and involvement of the 2G/3G network **103**.

At a block **402***b* of FIG. **4**A, a given eNodeB (e.g., eNodeB **102** or **106**) associated with the given UE **122** receives UE capability signaling from the given UE **122** (communication **512** in FIG. **5**B). The UE capability signaling comprises RF sharing information informing the given eNodeB whether RF chain **302** is shared between LTE and 2G/3G for each supported frequency band or frequency band combination (each frequency band of each supported frequency bandwidth provided by CA). After the UE capability signaling is received by the given eNodeB, the given UE **122** goes into connected mode (connected mode **513** in FIG. **5**B) if there is a packet switched call in LTE. Connected mode occurs upon the given UE **122** completing the initial RRC connection setup procedure with the given eNodeB.

Next at a block **404***b*, the given eNodeB transmits to the given UE **122**, RRC connection reconfiguration signaling comprising CA configuration if there is no voice call ongoing in 2G/3G (communication **514** in FIG. **5**B), When a MT call starts **515** after block **404***b*, the 2G/3G core network **120**, e.g., the mobile switching centre server (MSC) included in the 2G/3G core network **120**, sends a paging request to the LTE core network **120**, e.g., the MME included in the LTE core network **120** (communication **516** in FIG. **5**B). The paging request includes information such as, but not limited to, UE identity and Paging cause. The MME, in turn, informs the given eNodeB that there is a MT call started using 2G/3G for the given UE **122**. Thus, the given eNodeB (indirectly) receives the paging request from the 2G/3G network **103** in response to start of a MT call **515** on the 2G/3G network **103** (block **406***b*).

At a block **408***b*, in response to receiving the paging request, the given eNodeB determines whether to send a message for the given UE **122** to release a SCell or to handover to a new PCell. The given eNodeB transmits a RRC connection reconfiguration message/signaling to the given UE **122** to release a particular SCell associated with the given

UE **122**, if the particular SCell corresponds to the frequency band that is shared with 2G/3G service (communication **518** in FIG. **5**B). The eNodeB commands the given UE **122** to release the particular SCell so that there is no inadvertent use of the frequency band, which will be used for the MT call using 2G/3G service, for some other purpose. If there is no common frequency band between the SCells and 2G/3G service and the current/source PCell corresponds to the frequency band shared for 2G/3G service, then the given eNodeB transmits a RRC connection reconfiguration message/signaling to the given UE **122** to perform inter-frequency handover (HO) of the PCell to another carrier frequency (communication **518** in FIG. **5**B). In general the RRC connection reconfiguration message with mobility control information is providing instructions to release the source/current PCell and handover to another cell in the different carrier frequency.

Once the given UE **122** has taken action in accordance with the RRC connection reconfiguration message in block **408***b*, the given UE **122** turns on 2G/3G service **519** (FIG. **5**B) and camps on a 2G/3G cell to receive paging information corresponding to the MT call. While camping on a 2G/3G cell, the given UE **122** maintains connection with LTE cells (the associated PCell and SCell(s) except for the cell instructed to be released in block **408***b*).

In some embodiments, at the block **408***b*, in order to reduce delay in starting the voice call using the 2G/3G network **103** due to page reception, the given eNodeB can send the 2G/3G paging to the given UE **122** (rather than a given BS of the 2G/3G network **103**, such as BS **110** or **114**, sending the 2G/3G paging to the given UE **122**). Such 2G/3G paging information (also referred to as 2G/3G voice call indication) can be included in the RRC connection reconfiguration message pertaining to SCell release or PCell HO (communication **518**). Then the 2G/3G network **103** can start random access for the MT call without receiving a return page in the 2G/3G cell.

FIG. **4**B illustrates an example flow diagram **420** showing an alternative use of RRC signaling to facilitate information sharing between a given UE **122** and an eNodeB (e.g., eNodeB **102** or **106**) pertaining to which network the RF chain **302** of the given UE **122** is/will be supporting according to some embodiments. FIGS. **5**C-**5**E illustrate example timing diagrams corresponding to FIG. **4**B according to some embodiments.

FIGS. **4**B and **5**C correspond to the given UE **122** originating a voice call (MO call) and the RF chain **302** included in the UE **122** connecting to the 2G/3G BB **306** to operate on the 2G/3G network. Although not shown, initial RRC connection setup signaling occurred between the given UE **122** and its associated eNodeB (e.g., eNodeB **102** or **106**) in order for the given UE **122** to be in connected mode **521** (see FIG. **5**C).

Next at a block **422***a* of FIG. **4**B, the given eNodeB transmits a RRC connection reconfiguration signaling comprising CA configuration to the given UE **122** (communication **522** at FIG. **5**C). This RRC connection reconfiguration signaling is provided if there is no voice call on-going in 2G/3G. Once the given UE **122** initiates a MO call **523**, the UE **122** sends a non-usable frequency indication to the given eNodeB (communication **524** in FIG. **5**C). The non-usable frequency indication is received by the given eNodeB (block **424***a*). The non-usable frequency indication comprises identification of one or more frequency bands or frequency band combinations (each frequency band of each supported frequency bandwidth provided by CA) that cannot be used for LTE temporarily even those it is a supported frequency band or frequency band combination. Each of the supported frequency band or frequency band combination is the same as those concerning the UE capability signaling discussed above with respect to FIGS. **4**A, **5**A, and **5**B. The identified one or more frequency bands or frequency band combinations cannot be simultaneously used with the current LTE serving cells due to RE sharing (e.g., will be used for the 2G/3G voice call) or other limitation of the dual-standby architecture.

In response to receiving the non-usable frequency indication, the given eNodeB determines and transmits RRC connection reconfiguration signaling instructing the UE **122** to release a particular SCell or to perform inter-frequency HO of PCell to another carrier frequency (block **426***a*) (communication **526**). Additional details regarding SCell release or PCell HO is discussed above with respect to blocks **408***a* and *b*. Once the given UE **122** has taken action in accordance with the RRC connection reconfiguration message in block **426***a*, the given UE **122** turns on 2G/3G **527** and camps on a 2G/3G cell for the duration of the MO call. While camping on a 2G/3G cell, the given UE **122** maintains connection with LTE cells (the associated PCell and SCell(s) except for the cell instructed to be released in block **426***a*).

In contrast to the UE capability signaling scheme discussed above with respect to FIG. **4**A, the eNodeB does not necessarily know that the given UE **122** shares the RF chain **302** between LTE and 2G/3G when non-usable frequency indication is used instead. The eNodeB is merely notified when a certain frequency band or frequency band combination among the supported frequency band(s)/frequency band combination(s) is being reserved and therefore not available for use by the LTE serving cells.

FIGS. **4**B, **5**D, and **5**E correspond to the given UE **122** receiving a voice call (MT call) and attempting to connect the RF chain **302** included in the UE **122** to the 2G/3G BB **306** to operate on the 2G/3G network **103**. Although not shown, initial RRC connection setup signaling occurred between the given UE **122** and its associated eNodeB (e.g., eNodeB **102** or **106**) in order for the given UE **122** to be in connected mode **531** (see FIG. **5**D).

Next at a block **422***b* of FIG. **4**B, the given eNodeB transmits a RRC connection reconfiguration signaling comprising CA configuration to the given UE **122** (communication **532** at FIG. **5**D). This RRC connection reconfiguration signaling is provided if there is no voice call on-going in 2G/3G. When the UE **122** anticipates receiving a 2G/3G paging, UE **122** sends a non-usable frequency indication to the given eNodeB (communication **534** in FIG. **5**D). The non-usable frequency indication is received by the given eNodeB (block **424***b*). The non-usable frequency indication comprises identification of one or more frequency bands or frequency band combinations (each frequency band of each supported frequency bandwidth provided by CA) that cannot be used for LTE temporarily even those it is a supported frequency band or frequency band combination. Each of the supported frequency band or frequency band combination is the same as those concerning the UE capability signaling discussed above with respect to FIGS. **4**A, **5**A, and **5**B. The identified one or more frequency bands or frequency band combinations cannot be simultaneously used with the current LTE serving cells due to RF sharing (e.g., will be used for a 2G/3G voice call) or other limitation of the dual-standby architecture.

The UE **122** may know that the 2G/3G paging occasion as already defined by the 2G/3G network **103** or a new 2G/3G paging occasion will be defined for this operation in the LTE network **101**. If the paging occasion is already defined, the UE **122** also provides paging related parameters and information about the difference of system frame number between LTE and 2G/3G to the given eNodeB. In some embodiments, the non-usable frequency indication or additional signaling sent by the UE **122** with the non-usable frequency indication provides additional information such as, but not limited to, the following. Such information is correspondingly received by the eNodeB at the block **426***a*.

- The purpose of the non-usable frequency indication such as whether it is for paging, voice call, or measurement.
- If the non-usable frequency indication pertains to paging or measurement, also specifying the periodicity and duration of the non-usable frequency band/frequency band combination. With this information, the eNodeB can configure a measurement gap pattern to enable the UE **122** to receive a 2G/3G paging. The measurement gap pattern may comprise an existing measurement gap pattern or a new measurement gap pattern that is introduced to align with the 2G/3G paging cycle and duration. The measurement gap pattern may apply to a subset of the serving cells to be turned off to receive 2G/3G paging. Depending on the configuration of the measurement gap pattern, the UE **122** may not need to transmit a non-usable frequency indication each paging cycle to receive a 2G/3G paging.
- Measurement information is needed when the measurement gap pattern is not configured.

In response to receiving the non-usable frequency indication (and other possible information discussed immediately above), the given eNodeB determines and transmits RRC connection reconfiguration signaling instructing the UE **122** to release a particular SCell or to perform inter-frequency HO of PCell to another carrier frequency (block **426***b*) (communication **536**). Additional details regarding SCell release or PCell HO is discussed above with respect to blocks **408***a* and *b*.

If 2G/3G operation is possible based on the RRC connection reconfiguration signaling, the UE **122** turns on 2G/3G **537** (e.g., camps on a 2G/3G cell) and attempts to receive 2G/3G paging. When a MT voice call starts **538**, the 2G/3G network **103** (e.g., a BS, such as BS **110** or **114**) sends a 2G/3G paging to the given UE **122** (communication **540** in FIG. **5**D). In response, the UE **122** initiates voice service via 2G/3G while maintaining connection with the given eNodeB for packet switch (PS) service.

FIG. **5**E illustrates the case where the 2G/3G paging (communication **540** in FIG. **5**D) is either not sent or otherwise not properly received by the given UE **122**. In this case the UE **122** turns off 2G/3G **541** and turns back on LTE **542**—in other words, switching the RF chain **302** from the 2G/3G BB **306** to LTE BB **304** (FIG. **3**). Then the UE **122** sends a usable frequency indication to the given eNodeB (communication **544**). The usable frequency indication is received by the eNodeB at a block **428***b*. The usable frequency indication comprises informing the eNodeB of the change to the previously sent non-usable frequency indication (that it is now usable again) or providing new usable frequency information, for such frequency band or frequency band combination to be available for use by the LTE serving cells. In response, at a block **430***b* and at communication **546**, the eNodeB determines and transmits RRC connection reconfiguration signaling to the UE **122** comprising instructions to release a particular SCell or to perform inter-frequency HO of PCell to another carrier frequency. Additional details regarding SCell release or PCell HO is discussed above with respect to blocks **408***a* and *b*.

Alternatively, the eNodeB can inform the UE **122** that there is a 2G/3G paging pending. In response, the UE **122** returns a non-usable frequency indication to the eNodeB to temporarily reserve frequency band/frequency band combination for use on the 2G/3G network **103** for the 2G/3G voice call. In this case the UE **122** may not require 2G/3G paging from the 2G/3G network **103** (such as communication **540**) in order to conduct the 2G/3G voice call.

In contrast to the RRC signaling approach discussed above, an alternative embodiment for informing the eNodeB whether the RF chain **302** of a given UE **122** is/will be used for 2G/3G service rather than LTE service is via enhancement of medium access control (MAC) signaling.

FIG. **6** illustrates an example flow diagram **600** for using Activation/Deactivation MAC control element (CE) signaling according to some embodiments. If a 2G/3G voice call (MO or MT call) is about to start on the given UE **122** (yes branch of block **602**), then the existence of dedicated scheduling request (SR) resource for the given UE **122** is checked at a block **604**. The UE **122** may or may not have uplink (UL) resources allocated for new transmission by the given eNodeB at the point of time of the start of the 2G/3G voice call. However, regardless of whether allocated UL resources exist, the eNodeB should be informed of the start of the 2G/3G voice call so that the frequency band/combination that will be used for that call is not used by the LTE serving cells associated with the UE **122** for the duration of the call.

If dedicated SR resource(s) are configured and exists (yes branch of block **604**), then the UE **122** transmits SR information on the physical uplink control channel (PUCCH) included in at least one subframe of a radio frame to the eNodeB (block **606**). If dedicated SR resource(s) are not allocated for the UE **122** (no branch of block **604**), then the UE **122** initiates and participates in Random Access procedure to provide the requisite 2G/3G voice call information to the eNodeB (block **608**).

In response to either the SR information or Random Access procedure, the eNodeB schedules uplink physical uplink shared channel (PUSCH) resource. The UE **122** transmits Activation/Deactivation request MAC CE signaling (block **610**). In response to such request signaling, the eNodeB sends an Activation/Deactivation MAC CE signaling instructing the UE **122** to deactivate a particular SCell or PCell operating in the LTE frequency band that cannot co-exist with the 2G/3G frequency band to be used for the 2G/3G voice call. The Activation/Deactivation MAC CE signaling is received by the UE **122**, at a block **612**. Thus, the Activation/Deactivation request MAC CE signaling is sent by the UE **122** sooner than it otherwise would be—triggered by the SR information on the PUCCH or Random Access procedure—in order to prevent delay in start of the voice call on the 2G/3G network. The UE **122** can request the deactivation of the PCell in the Activation/Deactivation request MAC CE signaling.

As another alternative embodiment, assignment of PCell and SCells and/or CCs for the PCell and SCells for the given UE **122** can be controlled by the network **100** to avoid frequency co-existence issues from occurring beforehand. As shown in an example flow diagram **700** of FIG. **7**, for example, when CA is configured, the cell that is used for RRC connection setup is a PCell. It is likely that the cell that the UE **122** is camped on for LTE service is the PCell unless HO is triggered to change the PCell, and that the LTE frequency band that cannot co-exist during the 2G/3G voice service is that associated with the PCell. Therefore, the UE **122** can proactively consider or determine a 2G/3G cell having a frequency band that cannot co-exist with LTE PCell as a barred cell or the lowest priority cell (block **702***a*). With this approach, the UE **122** can avoid camping on such 2G/3G cell which cannot co-exist with the LTE PCell (block **704***a*).

As another example, because a PCell cannot be deactivated for a given UE **122**, if the RF chain **302** is capable of supporting all LTE frequency bands (block **702***b*), the network **100** assigns a cell having the same frequency band/combination as would be used for 2G/3G service by the RF chain **302** as a SCell (rather than a PCell) (block **704***b*). Thus, that SCell may be deactivated when the RF chain **302** is switched to support 2G/3G service.

The term "machine-readable medium," "computer readable medium," and the like should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "machine-readable medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methodologies of the present disclosure. The term "machine-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, optical and magnetic media, and carrier wave signals.

It will be appreciated that, for clarity purposes, the above description describes some embodiments with reference to different functional units or processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from embodiments of the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. One skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the invention. Moreover, it will be appreciated that various modifications and alterations may be made by those skilled in the art without departing from the scope of the invention.

The Abstract of the Disclosure is provided to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

What is claimed is:

1. A mobile device, comprising:

a 3rd Generation Partnership Project (3GPP) long term evolution (LTE) baseband circuitry;

a 2nd Generation (2G) or 3rd Generation (3G) baseband circuitry; and

a radio frequency (RE) chain selectively switchable between the LTE baseband circuitry and the 2G or 3G baseband circuitry,

wherein the RE chain is arranged to transmit at least a radio frame including a scheduling request (SR) provided in a physical uplink control channel (PUCCH) or to initiate a Random Access procedure to an evolved node B (eNodeB) associated with a LTE network and the RF chain is further arranged to transmit, over a frequency band and in response to the SR in the PUCCH or the Random Access procedure, an Activation/Deactivation request medium access control (MAC) control element (CE) wherein the Activation/Deactivation MAC CE comprises an instruction to deactivate a secondary cell included in the LTE network when the frequency band is the same as a frequency band supported by a 2G or 3G network, wherein the secondary cell comprises a component carrier, configured for the mobile device, different from a primary component carrier of a primary cell configured for the mobile device and both the primary and secondary cells are part of the LTE network.

2. The mobile device of claim **1**, wherein the Activation/Deactivation request MAC CE is provided in response to a voice call to be started supported by the 2G or 3G baseband circuitry coupled to the RF chain.

3. The mobile device of claim **2**, wherein the voice call comprises a mobile originating (MO) voice call or a mobile terminating (MT) voice call.

4. The mobile device of claim **1**, wherein the RE chain is further arranged to transmit the radio frame including the SR when a dedicated SR resource has been allocated by the eNodeB for the mobile device.

5. The mobile device of claim **1**, wherein the mobile device initiates the Random Access procedure when no dedicated SR resource has been allocated by the eNodeB for the mobile device.

6. The mobile device of claim **1**, wherein the mobile device receives physical uplink shared channel (PUSCH) resource scheduled by the eNodeB.

7. The mobile device of claim **6**, wherein the mobile device sends the Activation/Deactivation request MAC CE in the PUSCH resource scheduled by the eNodeB.

8. The mobile device of claim **1**, wherein the mobile device transmits an Activation/Deactivation MAC CE signaling to the eNodeB in response to the Activation/Deactivation request MAC CE provided by the mobile device.

9. The mobile device of claim **8**, wherein the Activation/Deactivation request MAC CE comprises identification of a cell to be activated or deactivated.

10. The mobile device of claim **1**, wherein the LTE network operates in time division duplexing (TDD) mode or frequency division duplexing (FDD) mode.

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