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Taneja

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(54) **METHODS AND APPARATUS FOR PERFORMING HANDOVER BETWEEN A LONG TERM EVOLUTION (LTE) NETWORK AND ANOTHER TYPE OF RADIO ACCESS NETWORK**

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(58) **Field of Classification Search** **370/331–334, 370/465–467; 455/436–444**

See application file for complete search history.

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Primary Examiner — Ricky Ngo

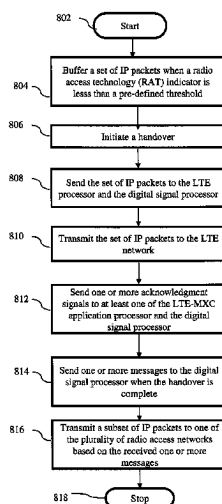
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(57) **ABSTRACT**

A method for performing handover by wireless User Equipment (UE) is provided. The UE includes a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor, a LTE processor and a Digital Signal Processor (DSP). The UE buffers a set of IP packets when a Radio Access Technology (RAT) indicator is less than a pre-defined threshold and sends the set of IP packets to the LTE processor and the DSP. The LTE processor transmits the set of IP packets to the LTE network and sends acknowledgement signals to the LTE-MXC application processor and the DSP. When the handover is complete, the LTE processor sends the transmission status of the set of IP packets to the DSP. The UE also includes multimode Radio Resource Control (RRC) and Non-Access Stratum (NAS) modules.

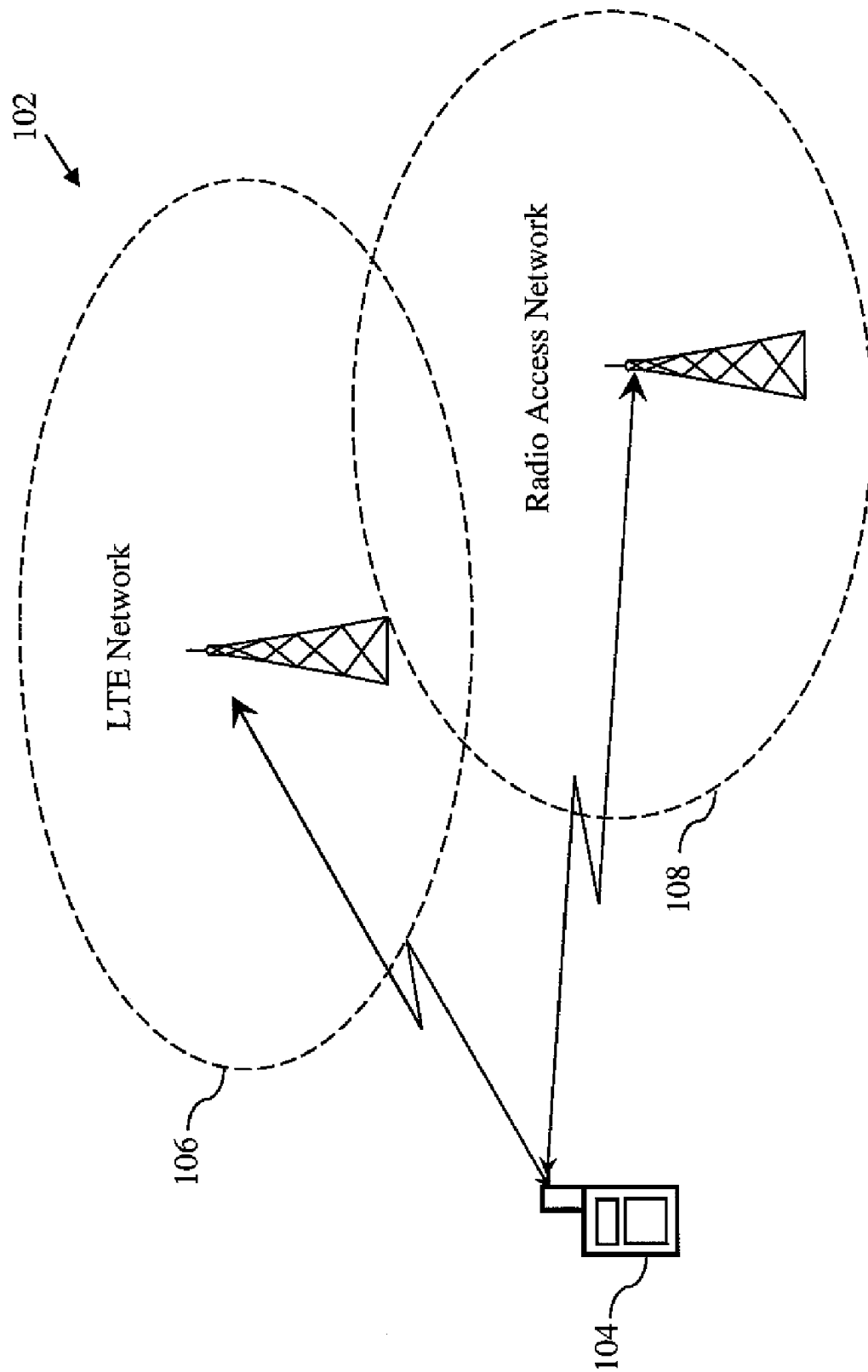
20 Claims, 11 Drawing Sheets



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**FIG. 1**

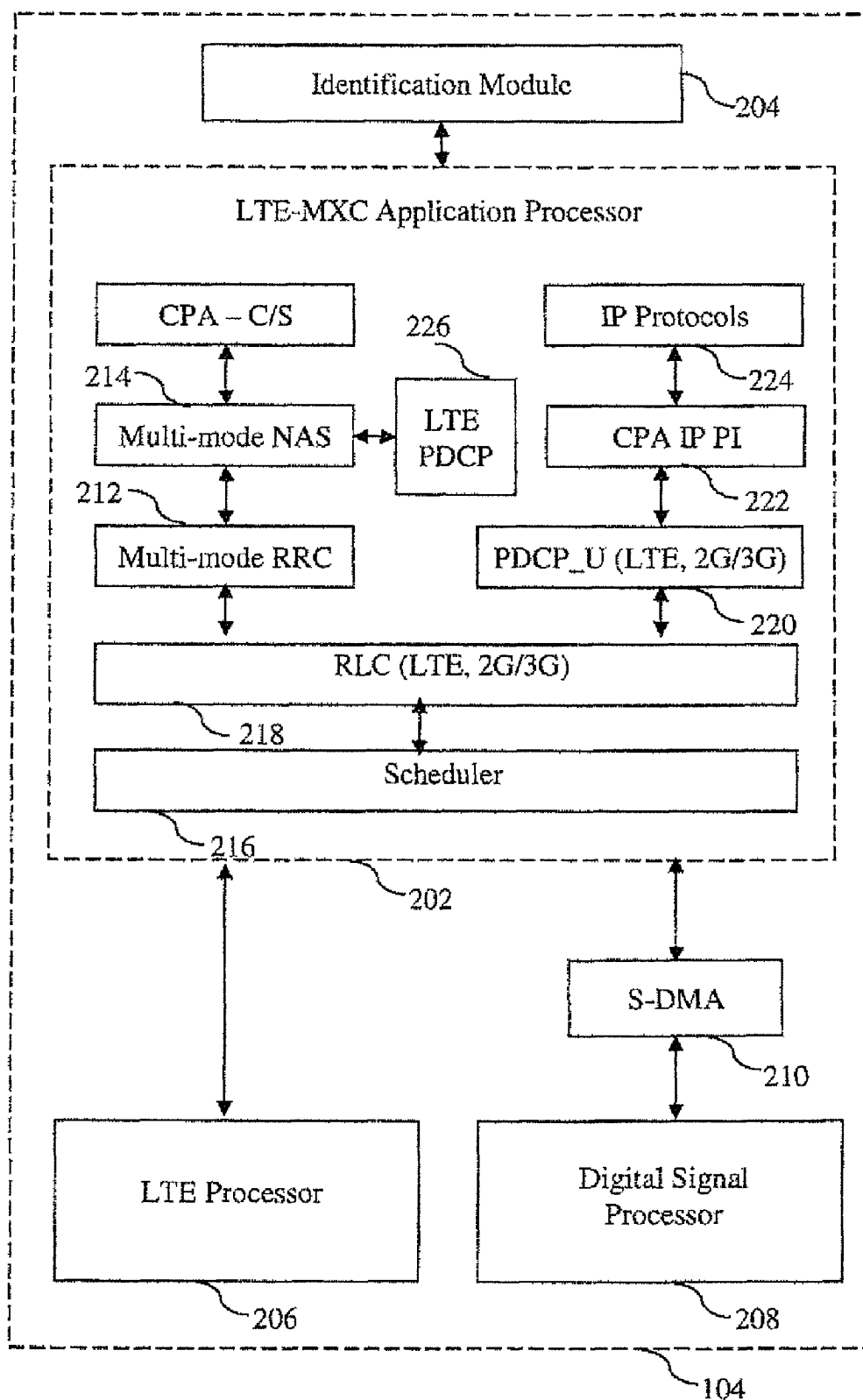
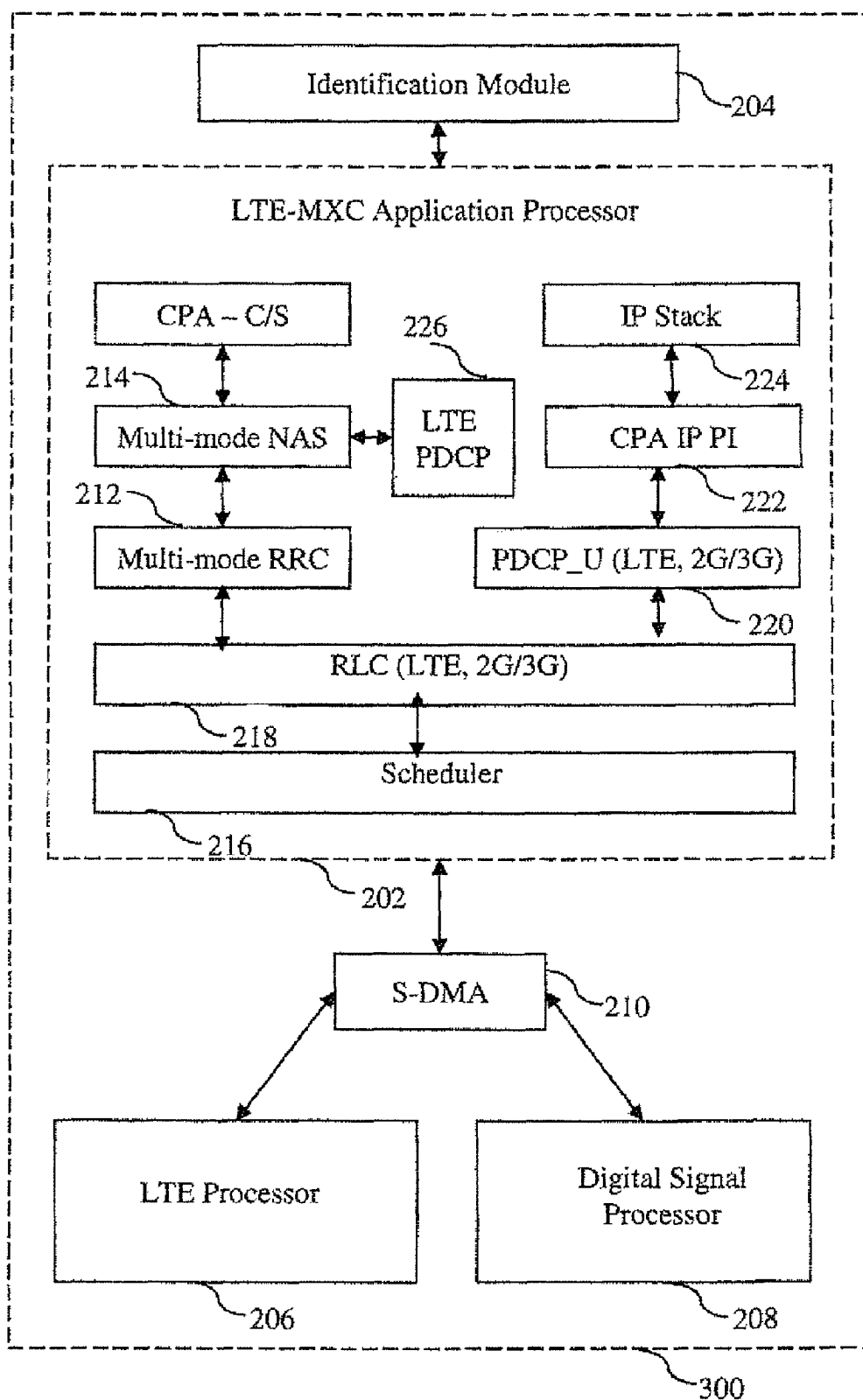
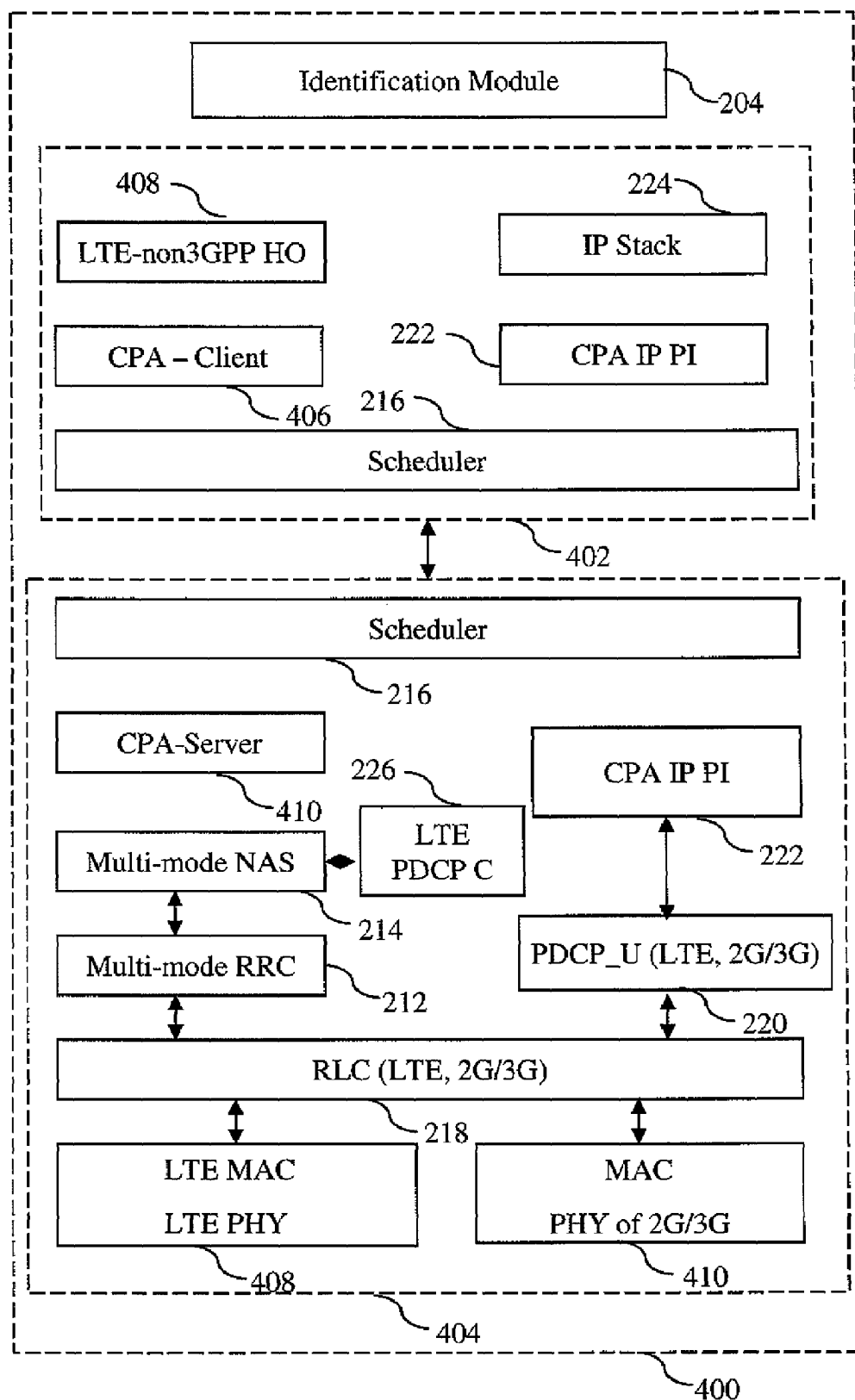


FIG. 2

**FIG. 3**

**FIG. 4**

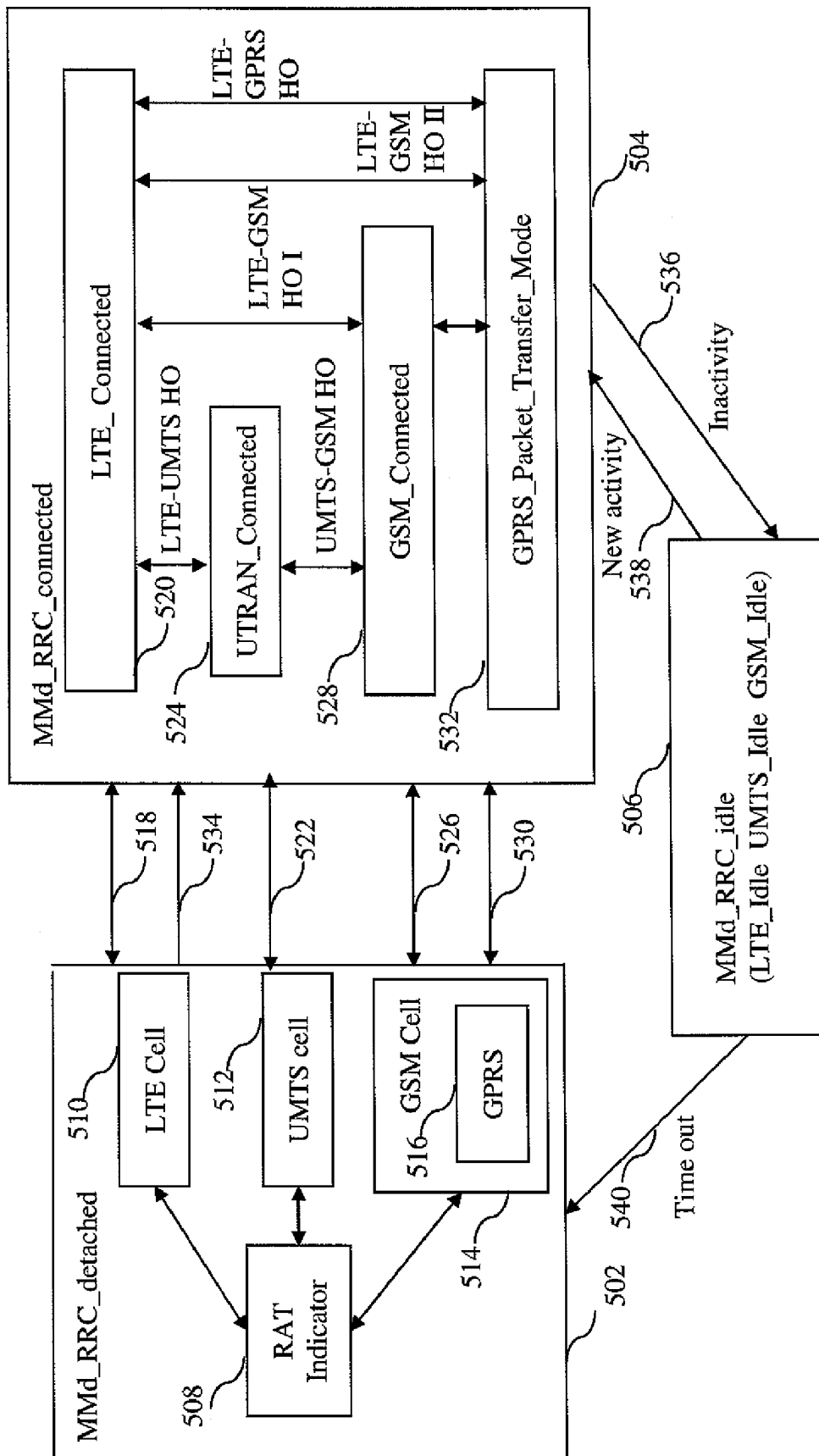


FIG. 5

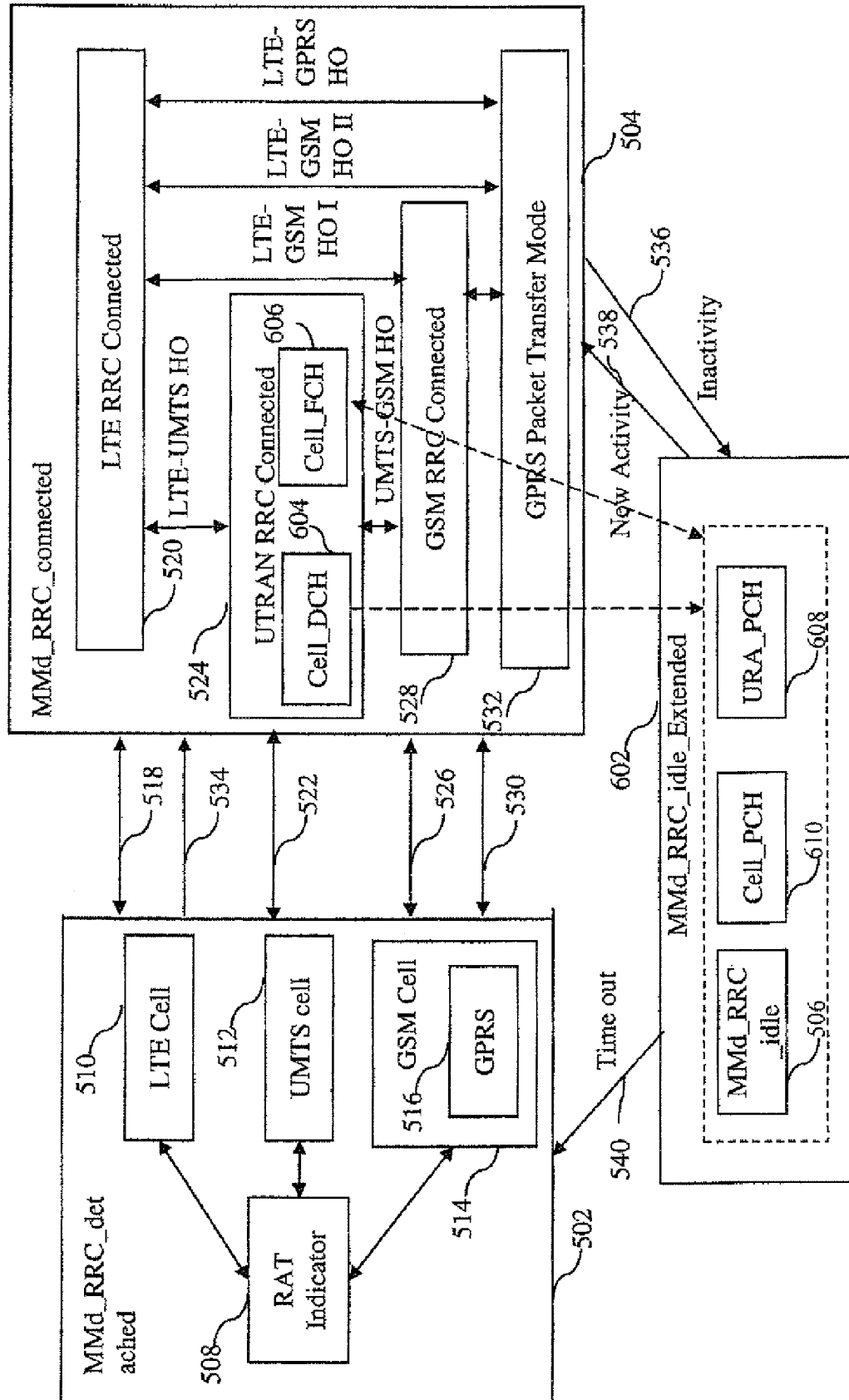
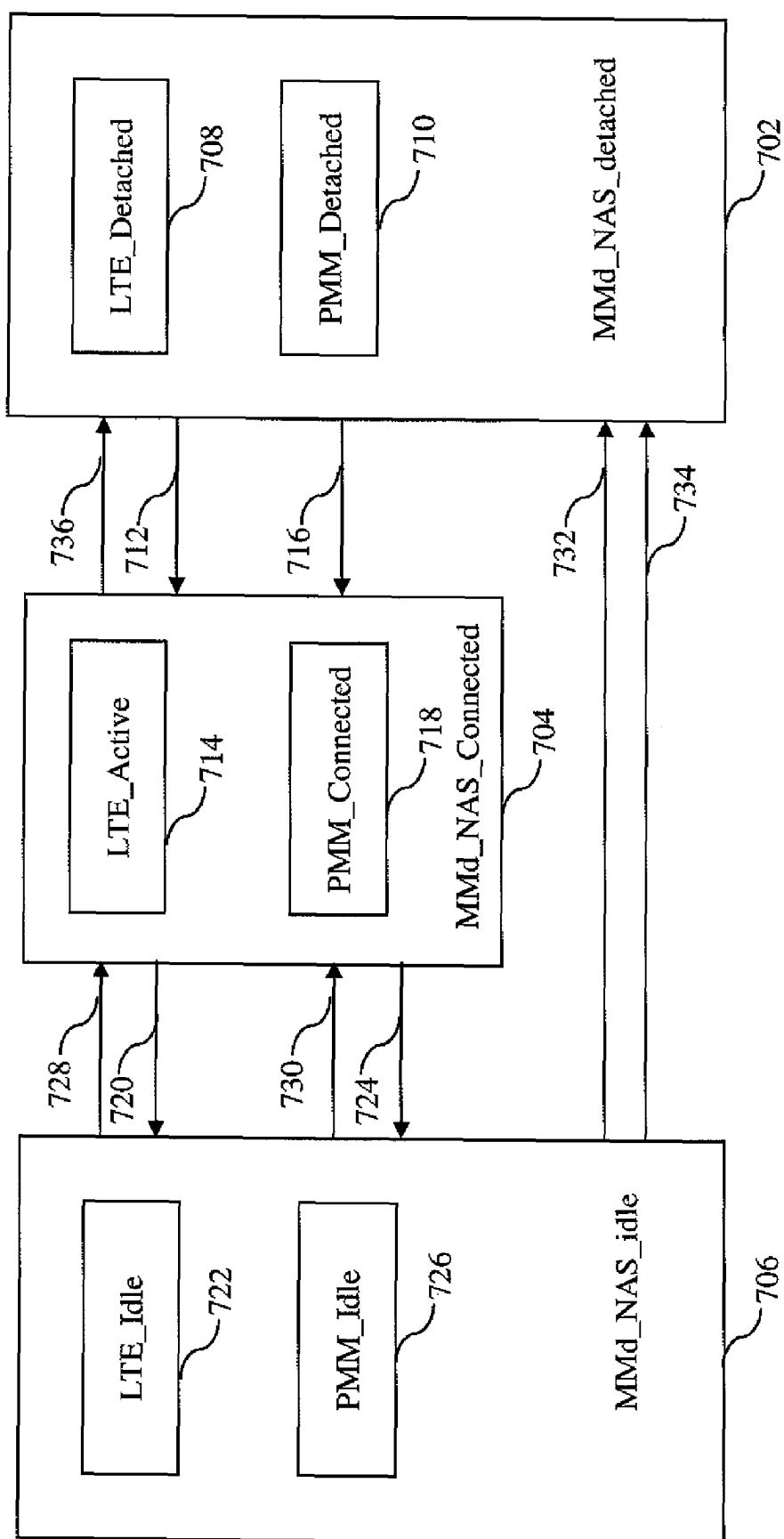


FIG. 6

**FIG. 7**

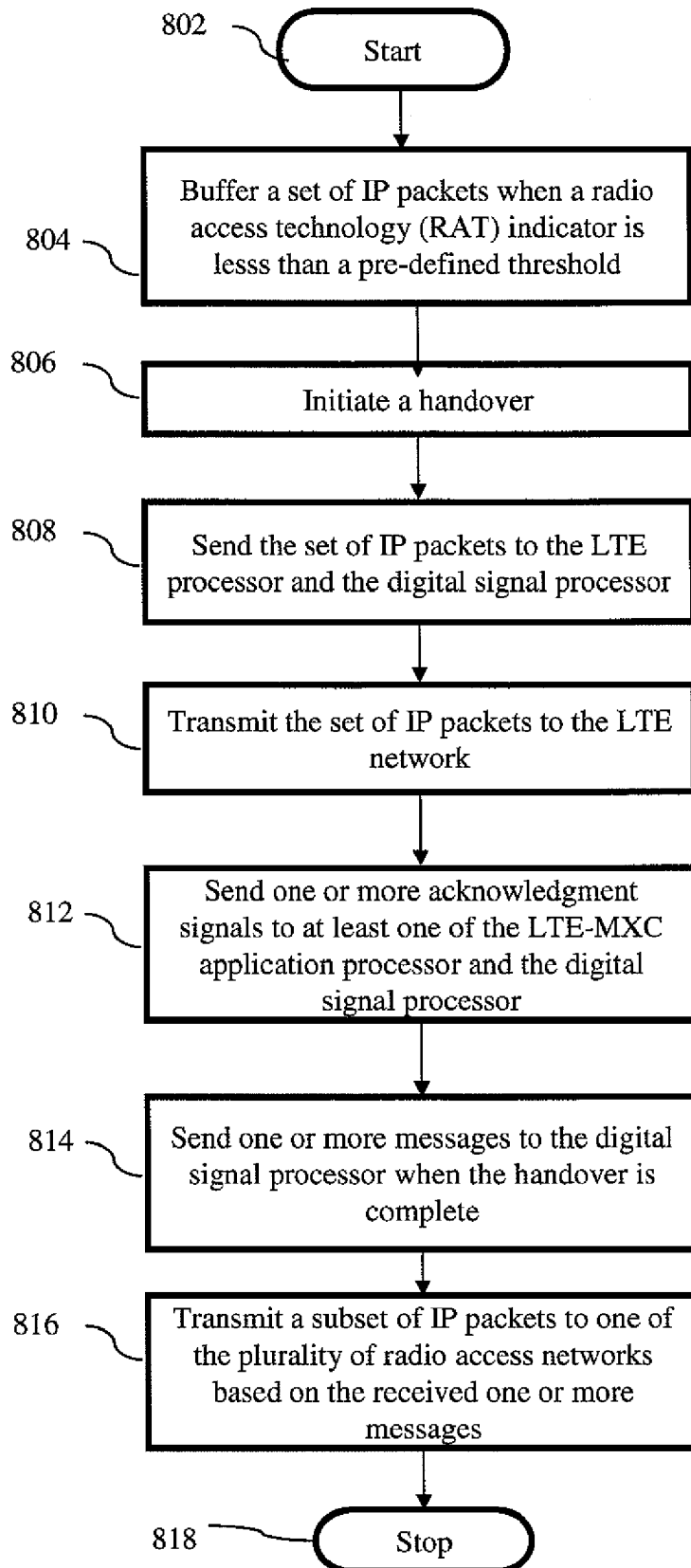
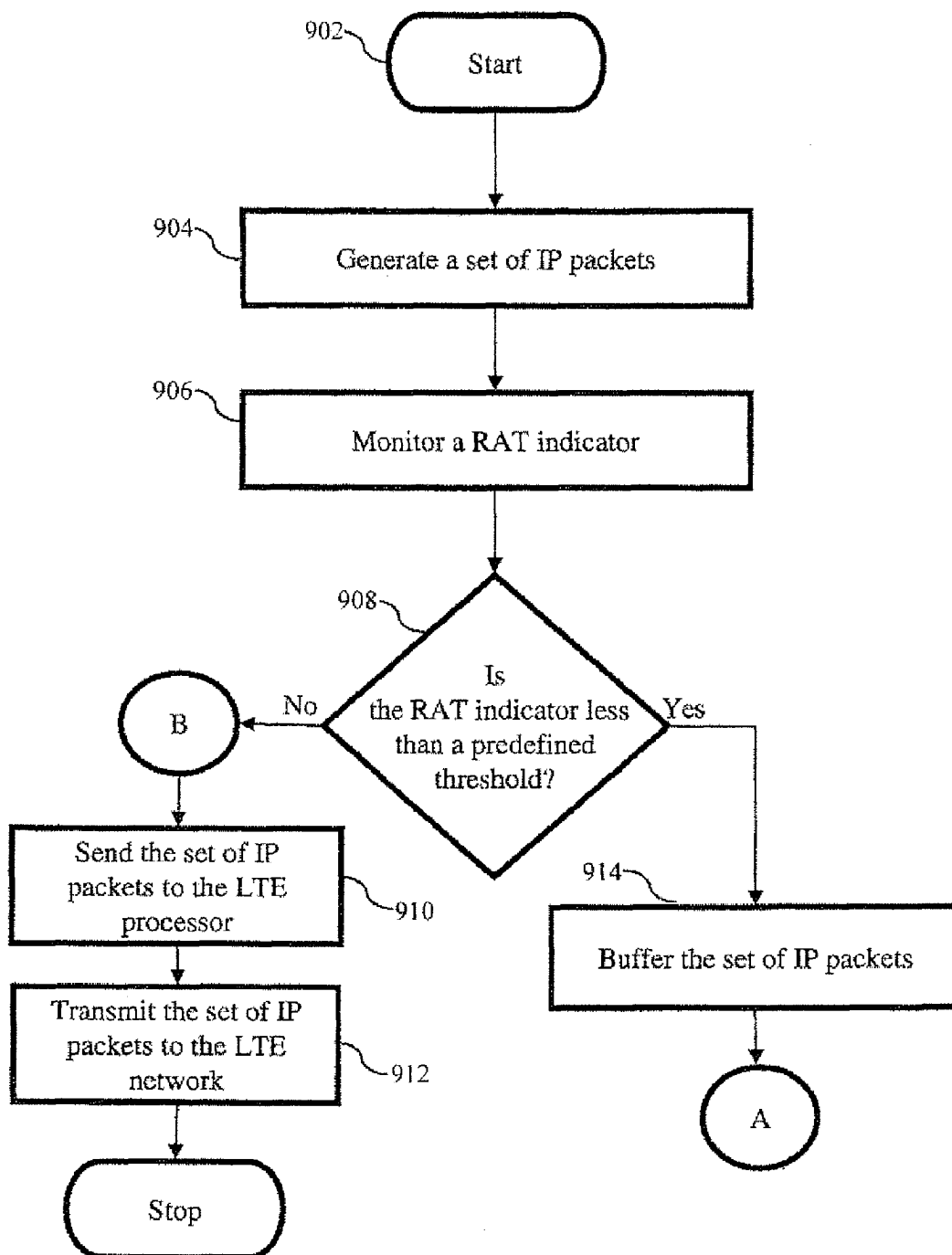


FIG. 8

**FIG. 9**

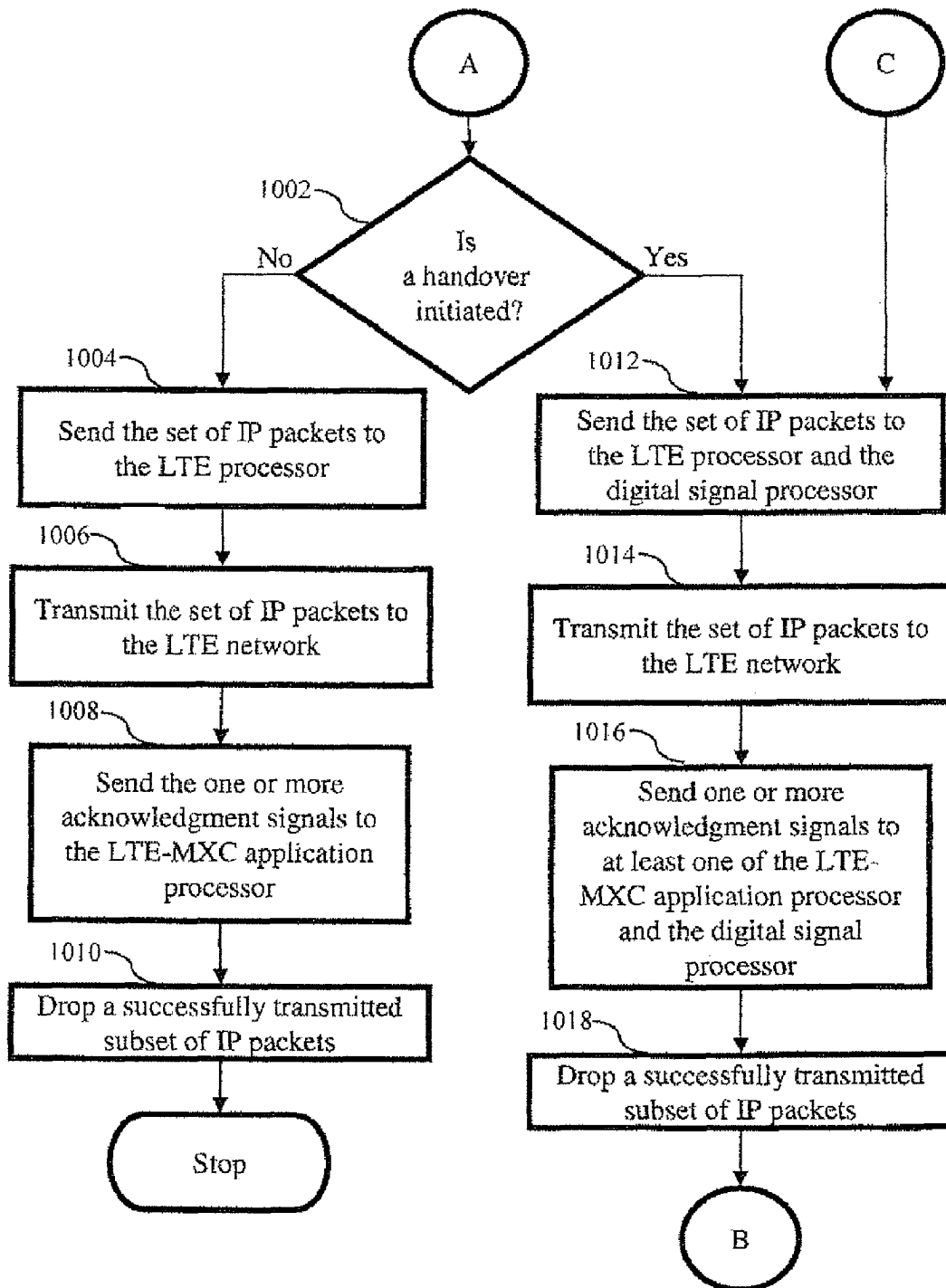
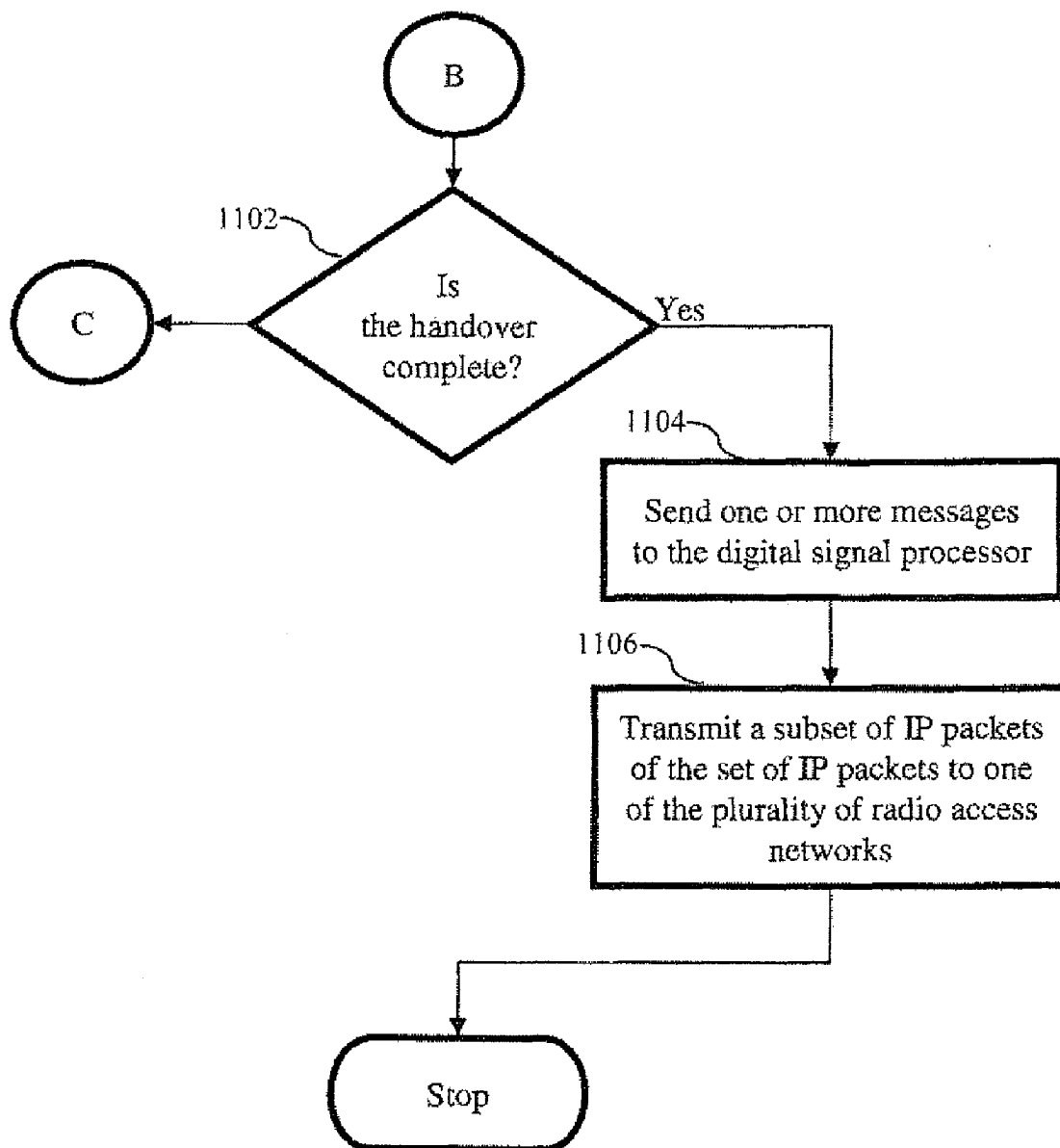


FIG. 10

**FIG. 11**

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METHODS AND APPARATUS FOR PERFORMING HANDOVER BETWEEN A LONG TERM EVOLUTION (LTE) NETWORK AND ANOTHER TYPE OF RADIO ACCESS NETWORK

BACKGROUND OF THE INVENTION

The present invention relates to wireless communication systems. In particular, the present invention relates to a method and apparatus for performing a handover between a Long Term Evolution (LTE) network and a second generation (2G)/third generation (3G) radio access network.

The advances made in wireless communication technology have resulted in the development of numerous mobile communication standards. These standards are broadly categorized into second generation (2G), third generation (3G) and the future, fourth generation (4G) technologies. Examples of 2G/3G technologies include Global System for Mobile communications (GSM), General Packet Radio Service (GPRS), Enhanced Data rates for GSM Evolution (EDGE), Universal Mobile Telecommunications System (UMTS), and the like. The UMTS standard evolved to LTE technology under the Third Generation Partnership Project (3GPP). LTE technology offers a wireless broadband system with higher data rates, lower latency, and higher spectrum efficiency. It is expected that LTE networks will be deployed in densely populated geographical areas, in the initial phases. Thus, mobile terminals may have to perform handover between the LTE networks and the 2G/3G networks so that users can seamlessly move across geographical areas covered by different networks without an interruption in communication.

Certain mobile terminals available today are capable of operating in LTE as well as 2G/3G networks. These mobile terminals employ multiple protocol stacks for wireless communication. Due to the employment of multiple protocol stacks, these mobile terminals can perform a handover between the LTE network and the 2G/3G network. However, the presence of the multiple protocol stacks increases the architectural complexity of the mobile terminals. While the handover is being performed, some of the IP packets generated by the applications running on these mobile terminals may not reach their destination. These IP packets are either lost during their transmission over the wireless connection or are not transmitted by the mobile terminals due to the absence of a free channel. Further, after the handover is complete, some of these IP packets belonging to delay sensitive applications may not be retransmitted by the mobile terminals as it may be too late to transmit those packets.

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description of the preferred embodiments of the present invention will be better understood when read in conjunction with the appended drawings. The present invention is illustrated by way of example, and not limited by the accompanying figures, in which like references indicate similar elements.

FIG. 1 is a schematic diagram illustrating an exemplary environment in which the present invention can be practiced, in accordance with an embodiment of the present invention.

FIG. 2 is a block diagram illustrating the architecture of a wireless User Equipment (UE), in accordance with an embodiment of the present invention.

FIG. 3 is a block diagram illustrating the architecture of the wireless UE, in accordance with another embodiment of the present invention.

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FIG. 4 is a block diagram illustrating the architecture of the wireless UE, in accordance with yet another embodiment of the present invention.

FIG. 5 is a block diagram illustrating the operating states of a multi-mode Radio Resource Control (MMd_RRC) module, in accordance with an embodiment of the present invention.

FIG. 6 is a block diagram illustrating the operating states of the MMd_RRC module, in accordance with another embodiment of the present invention.

FIG. 7 is a block diagram illustrating the operating states of a multi-mode Non-Access Stratum (MMd_NAS) module, in accordance with an embodiment of the present invention.

FIG. 8 is a flow diagram illustrating a method for performing a handover between a LT network and a 2G/3G network, in accordance with an embodiment of the present invention.

FIGS. 9, 10 and 11 are a flow diagram illustrating a method for performing the handover between the LTE network and the 2G/3G network, in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The detailed description of the appended drawings is intended as a description of the currently preferred embodiments of the present invention, and is not intended to represent the only form in which the present invention may be practiced. It is to be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the spirit and scope of the present invention.

In an embodiment of the present invention, a method for performing a handover by a wireless user equipment (UE) is provided. The wireless UE includes a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor, an LTE processor and a Digital Signal Processor (DSP) supporting MXC modem (UMTS/GSM) functionality. The MXC platform is a mobile phone architecture that separates the domain of application processing from the domain of communication (modem). This separation helps the developers to develop and continuously update applications without modifying the modem. The wireless UE communicates with a wireless communication system that includes a plurality of Radio Access Networks (RANs). One of the RANs is a LTE network. The wireless UE buffers a set of IP packets when a Radio Access Technology (RAT) indicator is less than a pre-defined threshold. When the handover is initiated, the set of IP packets is sent to the LTE processor and the DSP. The LTE processor transmits the set of IP packets to the LTE network via a wireless connection between the wireless UE and the LTE network. Further, the LTE processor sends acknowledgement signals to the LTE-MXC application processor and the DSP. The acknowledgement signals indicate a successfully transmitted subset of IP packets. The successfully transmitted subset of IP packets includes IP packets that are received by the LTE network without getting lost during their transmission over the wireless connection. The successfully transmitted subset of IP packets are positively acknowledged of being received, by the LTE network to the wireless UE. When the handover is complete, the LTE processor sends messages to the DSP and LTE-MXC application processor. At least one of the messages indicates the transmission status of the set of IP packets. The transmission status indicates a subset of IP packets that has not been successfully transmitted by the LTE processor to the LTE network. The subset of IP packets includes IP packets that were not positively acknowledged of being received, by the LTE network to the wireless UE. The subset of IP packets also includes IP packets that

were buffered at the LTE processor but could not be transmitted by the LTE processor over the wireless connection due to the handover. Once the handover is complete, the DSP transmits the subset of IP packets to one of the plurality of RANs based on the transmission status received from the LTE processor.

In another embodiment of the present invention, a wireless UE is provided. The wireless UE communicates with a wireless communication system that includes a plurality of RANs. One of the RANs is a LTE network. The wireless UE includes a multi-mode Radio Resource Control (MMd_RRC) module, a multi-mode Non-access Stratum (MMd_NAS) module, a LTE-MXC application processor, an LTE processor and a DSP. The MMd_RRC module establishes a wireless connection between the wireless UE and at least one of the plurality of RANs. The MMd_NAS module establishes a wireless connection between the wireless UE and at least one of a core network providing circuit-switched services and a core network providing packet-switched services. The LTE-MXC application processor facilitates the generation, buffering and sending of IP packets. The LTE processor is operatively coupled to the LTE-MXC application processor and receives IP packets from the LTE-MXC application processor, sends messages to the LTE-MXC application processor and transmits IP packets to the LTE network. The DSP is operatively coupled to the LTE-MXC application processor and the LTE processor. The DSP receives IP packets from the LTE-MXC application processor, receives messages from the LTE processor and LTE-MXC application processor, and transmits IP packets to one of the plurality of RANs based on the received messages.

In yet another embodiment of the present invention, a wireless UE is provided. The wireless UE includes a LTE-MXC application processor, an LTE processor and a DSP supporting MXC modem (UMTS/GSM) functionality. The wireless UE also includes a multi-mode RRC (MMd_RRC) module and a multi-mode NAS (MMd_NAS) module. The MMd_RRC module operates in an MMd_RRC_detached state, an MMd_RRC_connected state and an MMd_RRC_idle state. In the MMd_RRC_detached state, the MMd_RRC module monitors a Radio Access Technology (RAT) indicator and establishes a wireless connection between the wireless UE and at least one of the wireless networks (an LTE cell, a UMTS cell and a GSM cell) in the vicinity of the wireless UE based on the RAT indicator. By establishing the wireless connection for data communication the MMd_RRC module performs a state transition to the MMd_RRC_connected state.

In the MMd_RRC_connected state, the MMd_RRC module performs a handover from an LTE_connected state to a UTRAN_connected state and vice-versa, performs a handover from the LTE_connected state to a GSM_connected state and vice-versa, and performs a handover from the LTE_connected state to the GSM_connected state via a GPRS_Packet_Transfer_Mode state and vice versa. Further, the MMd_RRC module performs a handover from the LTE_connected state to the GPRS_Packet_Transfer_Mode state and vice-versa, and performs a handover from the UTRAN_connected state to the GSM_connected state and vice-versa.

The MMd_RRC module performs a state transition to the MMd_RRC_idle state when there is no activity on the connected wireless network (i.e., one of the LTE cell, the UMTS cell and the GSM cell) for the wireless UE for a time period greater than a first predefined time threshold. The MMd_RRC module performs a state transition to the MMd_RRC_detached state when the wireless connection between the wireless UE and connected wireless network is released.

In the MMd_RRC_idle state, the MMd_RRC module performs a state transition to the MMd_RRC_detached state and performs a state transition to the MMd_RRC_connected state when there is new activity on at least one of the wireless networks.

The MMd_NAS module operates in an MMd_NAS_detached state, an MMd_NAS_connected state, and an MMd_NAS_idle state.

In the MMd_NAS_detached state the MMd_NAS module establishes a wireless connection between the wireless UE and at least one of a core network providing circuit-switched services and a core network providing packet-switched services.

In the MMd_NAS_connected state, when the wireless UE is connected to the core network providing packet/circuit switched services, the MMd_NAS module performs a state transition to the MMd_NAS_idle state when the wireless connection between the wireless UE and one of the core networks is released. Further, the MMd_NAS module, when connected to the LTE network, performs a state transition to the MMd_NAS_idle state when an LTE network is inactive for a time period greater than a third predefined time threshold and performs a state transition to the MMd_NAS_detached state when the wireless connection between the wireless UE and the LTE network is released.

In the MMd_NAS_idle state, when wireless UE is in an LTE_Idle state, the MMd_NAS module performs a state transition to the MMd_NAS_connected state when there is new activity on the wireless connection between the wireless UE and the LTE network. Further, the MMd_NAS module performs a state transition to the MMd_NAS_connected state when the wireless connection between the wireless UE and at least one of the core network providing circuit-switched services and the core network providing packet-switched services is established, and performs a state transition to the MMd_NAS_detached state.

Referring now to FIG. 1, a schematic diagram illustrating an exemplary wireless communication system 102 with a wireless UE 104 is shown, in accordance with an embodiment of the present invention. Examples of the wireless UE 104 include a cellular phone, a smart phone, a Personnel Digital Assistant (PDA), a pager, a handheld computer and so forth. The wireless UE 104 is capable of operating within various RANs. The wireless communication system 102 includes an LTE network 106 and a RAN 108. Examples of the RAN 108 include, but are not limited to a 2G/3G radio access network like a GSM radio access network (GRAN), Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (UTRAN), an Enhanced Data Rates for GSM Evolution (EDGE) Radio Access Network (GERAN), High Speed Packet Access (HSPA) Network. The wireless UE 104 establishes a wireless connection with either the LTE network 106 or the RAN 108. The wireless UE 104 also performs a handover between the LTE network 106 and the RAN 108.

Referring now to FIG. 2, a block diagram illustrating the architecture of the wireless UE 104 is shown, in accordance with an embodiment of the present invention. The wireless UE 104 includes a LTE-MXC application processor 202, an Identification Module (IM) 204, an LTE processor 206 and a Digital Signal Processor (DSP) 208. The LTE-MXC application processor 202 is used for developing and executing applications. These applications can be multimedia applications that require very high data rates for providing multimedia data to the users in real-time. Examples of the multimedia applications include video conferencing, image processing applications, video playback, push-to-talk applications and

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the like. The LTE-MXC application processor **202** facilitates the generation, buffering and sending of IP packets to the LTE processor **206** and the DSP **208**. The LTE-MXC application processor **202** sends IP packets to the LTE processor **206** or the DSP **208**, when the wireless UE **104** is operating in the LTE network **106** or the RAN **108** respectively. The LTE-MXC application processor **202** stores IP packets in a buffer and sends IP packets to both the LTE processor **206** and the DSP **208** when the handover of the wireless UE **104** is initiated between the LTE network **106** and the RAN **108**. In this embodiment, the LTE-MXC application processor **202** further receives messages from the LTE processor **206**. Based on the received messages, the LTE-MXC application processor **202** drops IP packets. Dropping IP packets refers to deleting IP packets from the buffer. In one embodiment, the LTE-MXC application processor **202** is an Advanced RISC Machine (ARM™) application processor.

The Identification Module (IM) **204** contains data pertaining to the wireless UE **104** so that the wireless UE **104** can be authenticated by the LTE network **106** and the RAN **108**. Based on the authentication, the wireless UE **104** connects to the LTE network **106** and the RAN **108**. In an embodiment of the present invention, the wireless UE **104** is capable of operating in the LTE network **106** and the RAN **108**. In this embodiment, the IM **204** includes a Subscriber Identification Module (SIM), a Universal Subscriber Identity Module (USIM), an IP Multimedia Services Identity Module (ISIM), and an LTE Subscriber Identity Module (LSIM). The SIM module and the USIM module are used for the authentication of the wireless UE **104** in the GERAN and the UTRAN respectively. The USIM module can also be used for the authentication of the wireless UE **104** in the LTE network **106**. The ISIM module and the LSIM module contain data for the authentication of the wireless UE **104** in the IMS and the LTE network **106** respectively.

In one embodiment, the LTE processor **206** receives IP packets from the LTE-MXC application processor **202** and transmits IP packets to the LTE network **106** over a wireless connection. There is the possibility that some of the IP packets will not reach the LTE network **106**, as they are lost during the transmission over the wireless connection. The reasons for this loss can be signal degradation over the wireless connection, an oversaturated wireless connection, IP packets that get corrupted and the like. These lost IP packets are not positively acknowledged of being received, by the LTE network **106** to the wireless UE **104**. Further, in this embodiment, the LTE processor **206** sends messages to the LTE-MXC application processor **202** and the DSP **208**. For example, these messages are acknowledgement signals that indicate successfully transmitted IP packets. The successfully transmitted IP packets are IP packets that were transmitted by the LTE processor **206** and were positively acknowledged of being received, by the LTE network **106** to wireless UE **104**. The messages also include the transmission status of IP packets received by the LTE processor **206**. The transmission status indicates IP packets that were not successfully transmitted by the LTE processor **206** to the LTE network **106**, i.e., the IP packets that were not positively acknowledged of being received, by the LTE network **106** to wireless UE **104**. The transmission status also indicates IP packets that were buffered by the LTE processor **206** but could not be transmitted by the LTE processor **206** over the wireless connection due to the handover from LTE network **106** to the RAN **108**.

In one embodiment, the DSP **208** receives IP packets from the LTE-MXC application processor **202** and transmits IP packets to the RAN **108** via a wireless connection. Further, in the one embodiment, the DSP **208** stores IP packets received

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from the LTE-MXC application processor **202** in a local buffer. In this embodiment, the DSP **208** receives messages from the LTE processor **206**. In one example, the messages are acknowledgement signals that indicate successfully transmitted IP packets that were positively acknowledged of being received, by the LTE network **106** to the wireless UE **104**. Based on the received acknowledgement signals, the DSP **208** drops the successfully transmitted IP packets. Dropping of IP packets refers to deleting the successfully transmitted IP packets from the local buffer in the DSP **208**. After the handover is complete, the DSP **208** receives the transmission status of the IP packets from the LTE processor **206**. Based on the transmission status, the DSP **208** transmits the IP packets that were either transmitted by LTE processor **206** but not positively acknowledged of being received, by the LTE network **106** to the wireless UE **104** or could not be transmitted by the LTE processor **206** due to the handover. In one embodiment, the DSP **208** is a Starcore™ DSP such as the MSC8144 available from Freescale Semiconductor, Inc.

The LTE-MXC application processor **202** includes a multi-mode Radio Resource Control (MMd_RRC) module **212** and a multi-mode Non-access Stratum (MMd_NAS) module **214**. The MMd_RRC module **212** and the MMd_NAS module **214** operate using a multi-mode control protocol. The multi-mode control protocol is a single stack protocol that enables the wireless UE **104** to operate in the LTE network **106** and the RAN **108**. The multi-mode control protocol also facilitates the handover of the wireless UE **104** between the LTE network **106** and the RAN **108**.

When the wireless UE **104** is switched on, the MMd_RRC module **212** selects a wireless network for establishing a wireless connection between the wireless UE **104** and the selected wireless network. The selected wireless network can either be the RAN **108** or the LTE network **106**. The selection is made based on the signal strength the wireless UE **104** receives from wireless networks (**106**, **108**) in the vicinity of the wireless UE **104**. In one embodiment, the selection can also be based on the policies defined by the user of the wireless UE **104** or the operators of the wireless networks (**106**, **108**). The MMd_RRC module **212** also facilitates performing the handover of the wireless UE **104** between the LTE network **106** and the RAN **108**. Further, in this embodiment, the MMd_RRC module **212** configures a scheduler **216**, a radio link control (RLC) module **218** and the Packet Data Convergence Protocol (PDCP) modules (**220** and **226**) to send IP packets generated by the applications running on the LTE-MXC application processor **202** to the LTE processor **206** and the DSP **208**. The MMd_RRC module **212** also facilitates performing policy related functions such as measurement control, mobility management, radio resource management, and setting up of channels. Setting up of channels includes the selection of a specific radio frequency over which the wireless connection is established.

In one embodiment, the MMd_NAS module **214** establishes a wireless connection between the wireless UE **104** and a core network that provides packet-switched services. The core network providing packet-switched services routes the IP packets originating from the wireless UE **104** to a destination UE via a channel that is shared with traffic originating from other user equipments (UEs). In this embodiment, the MMd_NAS module **214** also establishes a wireless connection between the wireless UE **104** and another core network that provides circuit-switched services. The core network providing circuit-switched services routes the IP packets originating from the wireless UE **104** to the destination UE via a fixed bandwidth channel that cannot be shared with traffic originating from other UEs. A core network also sup-

ports other functionalities such as authentication the wireless UE **104** that requests for a service from the core network, routing and billing calls made by the wireless UE **104**, call waiting and call transfer.

The LTE-MXC application processor **202** also includes a Packet Data Convergence Protocol_User Plane (PDCP_U) module **220**, a Common Platform Access Packet Interface (CPA_PI) module **222** and an IP Stack **224**. The IP Stack **224** generates IP packets. The IP packets are sent to the PDCP_U module **220** via the CPA_PI module **222**. The CPA_PI module **222** is used to adapt the architecture of the wireless UE **104** to applications developed using any Operating System (OS). The PDCP_U module **220** performs header compression on the IP packets and sends the compressed IP packets to the RLC module **218**. The RLC module **218** sends the IP packets to the LTE processor **206** or the DSP **208** via the Scheduler **216**.

In one embodiment, the LTE-MXC application processor **202** and the LTE processor **206** communicate via a High Speed Universal Serial Bus (USB). The LTE-MXC application processor **202** and the DSP **208** communicate via a Serial Direct Memory Access (S-DMA) link **210**.

Referring now to FIG. 3, a block diagram illustrating the architecture of a wireless UE **300** is shown, in accordance with another embodiment of the present invention. The architecture is an example of the Mobile Extreme Convergence (MXC) platform architecture. The LTE-MXC application processor **202** and the LTE processor **206** communicate via the Serial Direct Memory Access (S-DMA) link **210**. The S-DMA link **210** blocks the LTE processor **206** as a peripheral device and controls the movement of IP packets from LTE-MXC application processor **202** to the LTE processor **206** and vice-versa. Also, the S-DMA link **210** controls the movement of IP packets from LTE-MXC application processor **202** to the DSP **208** and vice-versa.

Referring now to FIG. 4, a block diagram illustrating the architecture of a wireless UE **400** is shown, in accordance with yet another embodiment of the present invention. The wireless UE **400** includes an application processor **402**, a LTE-MXC baseband processor **404** and the identification module **204**. The LTE-MXC baseband processor **404** includes the MMd_RRC module **212** and the MMd_NAS module **214**. The architecture shown in FIG. 4 is an example of the MXC platform architecture. The underlying concept of this architecture is the separation of the two main domains of a wireless communication device: the communication domain (i.e., the modem) and the applications domain. The components of the communication domain (modem) are represented by the LTE-MXC baseband processor **404** that facilitates communication between the wireless UE **400** and the selected wireless network, whereas the components in the applications domain are represented by the application processor **402** that facilitates development and execution of applications. The LTE-MXC baseband processor **404** facilitates buffering and sending IP packets to the LTE network **106** and the RAN **108**.

The wireless UE **400** further includes a CPA_Client module **406**, an LTE-3GPP Handover (HO) module **408** and a CPA_Server **410**. The CPA_Client module **406** is operatively coupled to the CPA_Server **410**. The CPA_Client **406** receives IP packets from the IP Stack **224** and sends the received IP packets to the CPA_Server **410**. The CPA_Server **410** translates the IP packets to a format that can be used by the MMd_NAS module **214**. These IP packets are transmitted to the LTE network **106** via an LTE Media Access Control (MAC) module and an LTE Physical (PHY) module collectively represented by **412**. These IP packets can also be trans-

mitted to the RAN **108** via a MAC of 2G/3G networks module and a PHY of 2G/3G networks module collectively represented by **414**.

Referring now to FIG. 5, a block diagram illustrating the operating states of the MMd_RRC module **212** is shown, in accordance with an embodiment of the present invention. The MMd_RRC module **212** operates in three states an MMd_RRC_detached state **502**, an MMd_RRC_connected state **504** and an MMd_RRC_idle state **506**. When the wireless UE **104** (**300**, **400**) is switched on, it is in the MMd_RRC_detached state **502**. In the MMd_RRC_detached state **502**, the wireless UE **104** is not connected to any of the wireless networks in the vicinity of the wireless UE **104**. In one example, the wireless networks include an LTE cell **510**, an UMTS cell **512** and a GSM cell **514**. The MMd_RRC module **212** selects one of the wireless networks **510**, **512**, **514** for establishing a wireless connection between the wireless UE **104** and the selected wireless network. The selection is made based on the monitoring of a RAT indicator **508**. The RAT indicator **508** indicates the signal strength the wireless UE receives from the wireless networks **510**, **512**, **514**. In one embodiment, the RAT indicator **508** indicates the policies made by the user of the wireless UE **104** or the operators of the wireless networks **510**, **512**, **514**. On establishing the wireless connection, the MMd_RRC module **212** makes a state transition to the MMd_RRC_connected state **504**. In the MMd_RRC_connected state **504**, IP packets can be actively transmitted over the wireless connection between the wireless UE **104** and the selected wireless network.

In one embodiment, the MMd_RRC module **212** establishes the wireless connection between the wireless UE **104** and the LTE cell **512** by an LTE Registration as indicated by **518**. On establishing the wireless connection the MMd_RRC module **212** performs a state transition to an LTE_connected state **520**.

In this embodiment, the MMd_RRC module **212** establishes the wireless connection between the wireless UE **104** and the UMTS cell **512** via an UMTS_RRC_Connection as indicated by **522** and performs a state transition to an UTRAN_connected state **524**.

In this embodiment, the MMd_RRC module **212** establishes the wireless connection between the wireless UE **104** and the GSM cell **514** via a GSM_RRC_Connection as indicated by **526** and performs a state transition to a GSM_connected state **528**. The GSM cell **514** also supports GPRS **516** that enables data transfer over the wireless connection between the wireless UE **104** and the GSM cell **514**. On the initiation of a data session as indicated by **530**, the MMd_RRC module **212** performs a state transition to a GPRS_Packet_Transfer_Mode **532**.

In one embodiment, the MMd_RRC module **212** performs a state transition to the MMd_RRC_connected state **504** by Cell Reselection as indicated by **534** to select one of the wireless networks **510**, **512** and **514** for the wireless connection.

The wireless UE **104** can also perform a handover (LTE-UMTS HO) from the LTE cell **510** to the UMTS cell **512** when the MMd_RRC module **212** performs a state transition from the LTE_connected state **520** to the UTRAN_connected state **524**, and vice versa.

In this embodiment, the wireless UE **104** performs a handover (LTE-GSM HO I) from the LTE cell **510** to the GSM cell **514** when the MMd_RRC module **212** performs a state transition from the LTE_connected state **520** to the GSM_connected state **528**, and vice versa.

The wireless UE **104** performs a handover (LTE-GSM HO II) from the LTE cell **510** to the GSM cell **514** when the

MMd_RRC module 212 performs a state transition from the LTE_connected state 520 to the GSM_connected state 528 via the GPRS_Packet_Transfer_Mode 532, and vice versa.

The wireless UE 104 performs a handover (LTE-GPRS HO) from the LTE cell 510 to the GSM cell 514 when the MMd_RRC module 212 performs a state transition from the LTE_connected state 520 to the GPRS_Packet_Transfer_Mode 532, and vice versa.

The wireless UE 104 performs a handover (UMTS-GSM HO) from the UMTS cell 512 to the GSM cell 514 when the MMd_RRC module 212 performs a state transition from the UTRAN_connected state 524 to the GSM_connected state 528, and vice versa.

The MMd_RRC module 212 also performs a state transition from the MMd_RRC_connected state 504 to the MMd_RRC_detached state 502 by a LTE Deregistration as indicated by 518, release of the UMTS_RRC_Connection as indicated by 522, release of the GSM_RRC_Connection as indicated by 526 or end of the data session as indicated by 530.

In the MMd_RRC_idle state 506, only the control signals can be transmitted over the wireless connection between the wireless UE 104 and the selected wireless network.

In one embodiment, the MMd_RRC module 212 performs a state transition from MMd_RRC_connected state 504 to the MMd_RRC_idle state 506 when there is inactivity as indicated by 536 in the selected wireless network for a time period that is greater than a first pre-defined time threshold. Inactivity in the selected wireless network refers to the absence of IP packets for the wireless UE 104 over the wireless connection between the wireless UE 104 and the selected wireless network. The MMd_RRC_idle state 506 includes the LTE_idle state, an UMTS_idle state and a GSM_idle state. In an example, when the selected wireless network is the LTE cell 510, the MMd_RRC module 212 performs a state transition from LTE_connected state 520 to the LTE_idle state when there is inactivity as indicated by 536 in the LTE cell 510 or a time period that is greater than the first pre-defined time threshold.

The MMd_RRC module 212 performs a state transition from MMd_RRC_idle state 506 to the LTE_connected state 520 when there is a new activity as indicated by 538 over the wireless connection between the wireless UE 104 and the selected wireless network 510. The new activity is determined by an attempt to transmit IP packets between the wireless UE 104 and the selected wireless network. In an example, when the selected wireless network is the LTE cell 510, the MMd_RRC module 212 performs a state transition from the MMd_LTE_idle state to the LTE_connected state 520 when there is new activity as indicated by 538 over the wireless connection between the wireless UE 104 and the LTE cell 510. The MMd_RRC module 212 performs a state transition from the MMd_RRC_idle state 506 to the MMd_RRC_detached state 502 when there is a time-out as indicated by 540. The time-out 540 occurs when there is no new activity over the wireless connection between the wireless UE 104 and the selected wireless network for a time period that is greater than a second pre-defined time threshold.

In this embodiment, the UTRAN_connected state 524 includes four substates. The four states are the URA_PCH state, the Cell_PCH state, the Cell_DCH state and the Cell_FACH state. In the Cell_DCH state and the Cell_FACH state, the wireless UE 104 continuously monitors the wireless connection between the wireless UE 104 and the UMTS cell 512 for IP packets. Further, although IP packets are not transmitted between the wireless UE 104 and the UMTS cell 512 in the URA_PCH state and the Cell_PCH state, the wireless UE

104 monitors the wireless connection for paging signals transmitted by the UMTS cell 512.

Referring now to FIG. 6, a block diagram illustrating the operating states of the MMd_RRC module 212 is shown, in accordance with another embodiment of the present invention. In this embodiment, the MMd_RRC module 212 operates in three states the MMd_RRC_detached state 502, the MMd_RRC_connected state 504 and an MMd_RRC_idle_Extended state 602. The UTRAN_connected state 524 of the MMd_RRC_connected state 504 includes two substates, the Cell_DCH state 604 and the Cell_FACH state 606. The MMd_RRC_idle_Extended state 602 includes the MMd_RRC_idle state 506, the URA_PCH state 608 and the Cell_PCH state 610. This embodiment provides for an efficient implementation of the architecture of the wireless UE 104. Also, the specifications required for this architecture are simpler.

Referring now to FIG. 7, a block diagram illustrating the operating states of the MMd_NAS module 214 is shown, in accordance with an embodiment of the present invention. The MMd_NAS module 214 operates in an MMd_NAS_detached state 702, an MMd_NAS_connected state 704, and an MMd_NAS_idle state 706. When the wireless UE 104 is switched on, the MMd_NAS module 214 is in the MMd_NAS_detached state 702. In the MMd_NAS_detached state 702, the wireless UE 104 is not connected to the LTE network 106, a core network providing circuit-switched services or a core network providing packet-switched services. The core network providing packet-switched services can be any 2G/3G packet-switched core network. The MMd_NAS_detached state 702 includes an LTE_Detached state 708 and a Packet Mobility Management (PMM)_Detached state 710. The wireless UE 104 is not connected to the LTE network 106 in the LTE_Detached state 708. The wireless UE 104 is not connected to the core network providing packet-switched services in the PMM_Detached state 710. The MMd_NAS module 214 establishes a wireless connection between the wireless UE 104 and the LTE network 106 by performing an LTE registration as indicated by 712. On establishing the wireless connection, the MMd_NAS module 214 performs a state transition to an LTE_Active state 714 of the MMd_NAS_connected state 704. In this embodiment, the MMd_NAS module 214 establishes a wireless connection between the wireless UE 104 and the core network providing packet-switched services by performing a Packet Switch (PS) Attach as indicated by 716. On establishing the wireless connection, the MMd_NAS module 214 performs a state transition to a PMM_Connected state 718 of the MMd_NAS_connected state 704. In the PMM_Connected 718, data packets and control signals can be transmitted over the wireless connection between the wireless UE 104 and the core network providing packet-switched services.

In the LTE_Active state 714, the MMd_NAS module 214 performs a state transition 720 to an LTE_idle state 722 of the MMd_NAS_idle state 706 when the LTE network 106 is inactive for a time period that is greater than a third predefined time threshold. In one embodiment, the MMd_NAS module 214 performs a state transition from the PMM_Connected state 718 to a PMM_Idle state 726 of the MMd_NAS_idle state 706 when a Packet Switched (PS) Signaling Connection is released as indicated by 724. In the PMM_Idle state 726, only control signals can be transmitted over the wireless connection between the wireless UE 104 and the core network providing packet-switched services.

In one embodiment, the MMd_NAS module 214 performs a state transition from the LTE_idle state 722 to the LTE_Active state 714 when there is a new activity as indicated by 728

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over the wireless connection between the wireless UE 104 and the LTE network 106. Further, the MMd_NAS module 214 performs a state transition from the PMM_Idle state 726 to the PMM_Connected state 718 when a PS Signaling Connection is established as indicated by 730. Furthermore, the MMd_NAS module 214 performs a state transition from the LTE_idle state 722 to the LTE_Detached 708 when there is a timeout as indicated by 732. The timeout 732 occurs when there is no new activity on the LTE network 106 for a time period that is greater than a fourth pre-defined time threshold. The MMd_NAS module 214 performs a state transition from the PMM_Idle state 726 to the PMM_Detached 710 by performing a PS Detach as indicated by 734.

In one embodiment, the MMd_NAS module 214 performs a state transition from the LTE_Active state 714 to the LTE_Detached state 708 by performing a LTE De-registration as indicated by 736. Further, the MMd_NAS module 214 performs a state transition from the LTE_Active state 714 to the LTE_Detached 708 when there is a change in the Public Land Mobile Network (PLMN) to which the wireless UE 104 belongs as indicated by 736.

Referring now to FIG. 8, a flow diagram illustrating a method for performing handover between the LTE network 106 and the 2G/3G RAN 108 is shown, in accordance with an embodiment of the present invention. The method starts at step 802, where the wireless UE 104 is connected via a wireless connection with the LTE network 106.

At step 804, the LTE-MXC application processor 202 buffers a set of IP packets by storing the set of IP packets in the buffer when the RAT indicator 508 is less than a pre-defined threshold. In one embodiment, the LTE-MXC application processor 202 buffers the set of IP packets when the signal strength the wireless UE 104 received from the LTE network 106 is below the pre-defined threshold of signal strength.

At step 806, the handover is initiated by the LTE network 106 or by the wireless UE 104.

At step 808, the LTE-MXC application processor 202 sends the set of IP packets to the LTE processor 206 and the DSP 208. In one embodiment, the set of IP packets is sent to the LTE processor 206 via a USB. In another embodiment, the set of IP packets is sent to the LTE processor 206 and the DSP 208 via the S-DMA link 210.

At step 810, the LTE processor 206 transmits the set of IP packets to the LTE network 106 via the wireless connection between the wireless UE 104 and the LTE network 106.

At step 812, the LTE processor 206 sends acknowledgement signals to the LTE-MXC application processor 202 and the DSP 208. These acknowledgement signals indicate a successfully transmitted subset of IP packets. The successfully transmitted subset of IP packets includes IP packets that have been positively acknowledged of being received, by LTE network 106 to wireless UE 104.

At step 814, the LTE processor 206 sends messages to the DSP 208 when the handover is complete after a wireless connection is established between the wireless UE 104 and the RAN 108. The messages include the transmission status of the set of IP packets received by the LTE processor 206. In one example, the transmission status indicates a subset of IP packets that was not successfully transmitted by the LTE processor 206 to the LTE network 106, i.e., the subset of IP packets includes IP packets that have been transmitted by the wireless UE 104 but were not positively acknowledged of being received, by LTE network 106 to wireless UE 104. The subset of IP packets also includes IP packets that were buffered by the LTE processor but could not be transmitted by the LTE processor 206 to the LTE network 106 due to the handover.

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At step 816, the DSP 208 transmits the subset of IP packets to the RAN 108 via the wireless connection between the wireless UE 104 and the RAN 108. The subset of IP packets is determined by the transmission status the DSP 208 receives from the LTE processor 206. The method for performing the handover between the LTE network 106 and the RAN 108 then is complete at a step 818.

Referring to FIGS. 9, 10 and 11, a flow diagram illustrating a method for performing handover between the LTE network 106 and the 2G/3G RAN 108 is shown, in accordance with another embodiment of the present invention. The method is initiated at step 902. At step 904, the LTE-MXC application processor 202 generates a set of IP packets. The set of IP packets is generated by the applications running on the LTE-MXC application processor 202.

At step 906, the MMd_RRC module 212 of the LTE-MXC application processor 202 monitors the RAT indicator 508 to determine the present value of the RAT indicator 508. In one embodiment, the MMd_RRC module 212 monitors the signal strength the wireless UE 104 receives from the LTE network 106. The RAT indicator 508 is continuously monitored. In another embodiment, the RAT indicator 508 is periodically monitored at fixed time of intervals.

At step 908, the MMd_RRC module 212 compares the present value of the RAT indicator 508 with the pre-defined threshold. In one embodiment, the MMd_RRC module 212 compares the signal strength the wireless UE 104 receives from the LTE network 106 with the pre-defined threshold of the signal strength.

At step 910, the LTE-MXC application processor 202 sends the set of IP packets to the LTE processor 206 when the present value of the RAT indicator 508 is greater than the pre-defined threshold.

At step 912, the LTE processor 206 transmits the set of IP packets to the LTE network 106 via the wireless connection between the wireless UE 104 and the LTE network 106. The method is completed after step 1012.

At step 914, the LTE-MXC application processor 202 buffers the set of IP packets by storing the set of IP packets in the buffer when the present value of the RAT indicator 508 is less than the pre-defined threshold.

At step 1002, the wireless UE 104 determines whether a handover has been initiated from the LTE network 106 to the RAN 108.

At step 1004, the LTE-MXC application processor 202 sends the set of IP packets to the LTE processor 106 via the USB when the handover has not been initiated. In another embodiment, the LTE-MXC application processor 202 sends the set of IP packets to the LTE processor 106 via the S-DMA link 210.

At step 1006, the LTE processor 206 transmits the set of IP packets to the LTE network 106 via the wireless connection between the wireless UE 104 and the LTE network 106.

At step 1008, the LTE processor 206 sends acknowledgement signals to the LTE-MXC application processor 202. These acknowledgement signals indicate a successfully transmitted subset of IP packets. The successfully transmitted subset of IP packets are IP packets that were positively acknowledged of being received, by the LTE network 106 to the wireless UE 104.

At step 1010, the LTE-MXC application processor 202 drops the successfully transmitted subset of IP packets by deleting the successfully transmitted subset of IP packets from the buffer. After step 1110, the method is completed.

At step 1012, the LTE-MXC application processor 202 sends the set of IP packets to the LTE processor 206 and the DSP 208 when the handover is initiated.

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At step **1014**, the LTE processor **206** transmits the set of IP packets to the LTE network **106** via the wireless connection between the wireless UE **104** and the LTE network **106**.

At step **1016**, the LTE processor **206** sends acknowledgement signals to the LTE-MXC application processor **202** and the DSP **208**. In one embodiment, the acknowledgement signals are sent only to the LTE-MXC application processor **202**. These acknowledgement signals indicate a successfully transmitted subset of IP packets. The successfully transmitted subset of IP packets are IP packets that have been positively acknowledged of being received, by the LTE network **106** to the wireless UE **104**.

At step **1018**, the LTE-MXC application processor **202** and the DSP **208** drop the successfully transmitted subset of IP packets based on the received acknowledgement signals. The LTE-MXC application processor **202** drops the successfully transmitted subset of IP packets by deleting the successfully transmitted subset of IP packets from the buffer. The DSP **208** drops the successfully transmitted subset IP packets by deleting the successfully transmitted subset IP packets from the local buffer present in the DSP **208**.

At step **1102**, the wireless UE **104** determines whether the handover of the wireless UE **104** from the LTE network **106** to the RAN **108** is complete. The handover is complete when the MMd_RRC module **214** establishes a wireless connection between the wireless UE **104** and the RAN **108**.

At step **1104**, the LTE processor **206** sends messages to the DSP **208** and the LTE-MXC application processor **202** when the handover is complete. The messages include the transmission status of the set of IP packets received by the LTE processor **206**. In one example, the transmission status indicates a subset of IP packets that were not successfully transmitted to the LTE network **106**, i.e., the subset of IP packets includes IP packets that have not been positively acknowledged of being received, by LTE network **106** to the wireless UE **104**. The subset of IP packets also includes IP packets buffered by the LTE processor **206** but could not be transmitted by the LTE processor **206** due to the handover.

At step **1106**, the DSP **208** transmits the subset of IP packets to the RAN **108** via the wireless connection between the wireless UE **104** and the RAN **106**. The subset of IP packets is determined by the transmission status the DSP **208** received from the LTE processor **206**. The method is completed after step **1106**.

In an example, the wireless UE **104** is used by a user in a car. The wireless UE **104** is connected to the LTE network **106** via a wireless connection. The wireless UE **104** transmits IP packets to the LTE network **106** via the wireless connection. As the car moves away from the LTE network **106** towards the RAN **108**, the signal strength the wireless UE **104** receives from the LTE network **106** weakens. Due to the weak signal strength some of the IP packets transmitted over the wireless connection may get lost. Thus the wireless UE **104** starts buffering the IP packets when the signal strength is lower than the pre-defined threshold. Further, as the car continues moving towards the RAN **108**, a handover is initiated to connect the wireless UE **104** to the RAN **108** so that the user does not experience an interruption in the communication process. On establishing a wireless connection between the wireless UE **104** and the RAN **108**, the wireless UE **104** retransmits those IP packets that were either not transmitted to the LTE network **106** or were lost during their transmission to the LTE network **106**.

While various embodiments of the present invention have been illustrated and described, it will be clear that the present invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions, and

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equivalents will be apparent to those skilled in the art, without departing from the spirit and scope of the present invention, as described in the claims.

I claim:

1. A wireless user equipment (UE) comprising a Long Term, Evolution-Mobile Extreme Convergence (LTE-MXC) application processor, a LTE processor and a digital signal processor supporting MXC modem (UMTS/GSM) functionality, the wireless UE further comprising:

a multi-mode radio resource control (MMd_RRC) module configured to operate in a MMd_RRC_detached state, a MMd_RRC_connected state and a MMd_RRC_idle state, wherein in the MMd_RRC_detached state the multimode RRC module is configured to:

monitor a radio access technology (RAT) indicator, establish a wireless connection between the wireless UE and at least one of a LTE cell, a UMTS cell and a GSM cell based on the RAT indicator, and perform a state transition to the MMd_RRC_connected state by cell reselection,

wherein in the MMd_RRC_connected state the MMd_RRC module is configured to:

perform a handover from an LTE_connected state to an UTRAN_connected state and vice-versa, perform a handover from the LTE_connected state to a GSM_connected state and vice-versa,

perform a handover from the LTE_connected state to the GSM_connected state via a GPRS_Packet_Transfer_Mode state and vice-versa,

perform a handover from the LTE_connected state to the GPRS_Packet_Transfer_Mode state and vice-versa, perform a handover from the UTRAN_connected state to the GSM_connected state and vice-versa,

perform a state transition to the MMd_RRC_idle state when at least one of the LTE cell, the GSM cell and the UMTS cell is inactive for a time period greater than a first predefined time threshold, and

perform a state transition to the MMd_RRC_detached state when the wireless connection between the wireless UE and at least one of the LTE cell, the GSM cell and the UMTS cell is released,

wherein in the MMd_RRC_idle state the MMd_RRC module is configured to:

perform a state transition to the MMd_RRC_detached state, and

perform a state transition to the MMd_RRC_connected state when there is new activity on the wireless connection between the wireless UE and at least one of the LTE cell, the GSM cell and the UMTS cell; and

a multi-mode non-access stratum (MMd_NAS) module, wherein the MMd_NAS module is configured to operate in a MMd_NAS_detached state, a MMd_NAS_connected state, and a MMd_NAS_idle state, wherein the MMd_NAS module is further configured to:

establish a wireless connection between the wireless UE and at least one of a core network providing circuit-switched services and a core network providing packet-switched services in the MMd_NAS_detached state,

wherein in the MMd_NAS_connected state, the MMd_NAS module is configured to:

perform a state transition to the MMd_NAS_idle state when the wireless connection between the wireless UE and at least one of the core network providing packet-switched services and the core network providing circuit-switched services is released,

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perform a state transition to the MMd_NAS_idle state when the LTE network is inactive for a time period greater than a third predefined time threshold, and perform a state transition to the MMd_NAS_detached state when the wireless connection between the wireless UE and the LTE network is released, wherein in the MMd_NAS_idle state, the MMd_NAS module is configured to:

- perform a state transition to the MMd_NAS_connected state when there is new activity on the wireless connection between the wireless UE and the LTE network,
- perform a state transition to the MMd_NAS_connected state when the wireless connection between the wireless UE and at least one of the core network providing packet-switched services and the core network providing circuit-switched services is established, and
- perform a state transition to the MMd_NAS_detached state.

2. A method for performing handover by a wireless user equipment (UE), the wireless UE being in communication with a wireless communication system, the wireless communication system comprising a plurality of radio access networks (RANs), at least one of the plurality of radio access networks being a long term evolution (LTE) network, the wireless UE comprising a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor, a LTE processor and a digital signal processor supporting MXC modem (UMTS/GSM) functionality, the method comprising:

- buffering a set of IP packets when a radio access technology (RAT) indicator is less than a pre-defined threshold;
- initiating a handover by at least one of the wireless UE and the LTE network;
- sending the set of IP packets to the LTE processor and the digital signal processor when the handover is initiated;
- transmitting the set of IP packets to the LTE network by the LTE processor;
- sending one or more acknowledgment signals to at least one of the LTE-MXC application processor and the digital signal processor, wherein the one or more acknowledgment signals indicate a successfully transmitted subset of the set of IP packets sent to the LTE processor;
- sending one or more messages to the digital signal processor and the LTE-MXC application processor when the handover is complete, wherein at least one of the one or more messages indicates transmission status of the set of IP packets sent to the LTE processor;
- transmitting a subset of the set of IP packets to one of the plurality of RANs based on the received one or more messages, wherein the subset of IP packets is transmitted by the digital signal processor; and
- dropping the successfully transmitted subset of IP packets when the LTE-MXC application processor receives the one or more acknowledgement signals from the LTE processor.

3. The method for performing handover of claim 2, wherein the handover performed by the wireless UE is between the LTE network and one of the plurality of RANs, wherein the one of the plurality of RANs is one of a UMTS radio access network (UTRAN) and a GSM radio access network (GRAN).

4. The method for performing handover of claim 2, further comprising generating the set of IP packets prior to buffering the set of IP packets, wherein the set of IP packets is generated by the LTE-MXC application processor.

5. The method for performing handover of claim 2, further comprising monitoring the RAT indicator.

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6. The method for performing handover of claim 2, further comprising sending the set of IP packets to the LTE processor prior to the initiating of the handover.

7. The method for performing handover of claim 2, further comprising sending the one or more acknowledgment signals to the LTE-MXC application processor prior to the initiating of the handover.

8. A method for performing handover by a wireless user equipment (UE), the wireless UE being in communication with a wireless communication system, the wireless communication system comprising a plurality of radio access networks (RANs), at least one of the plurality of radio access networks being a long term evolution (LTE) network, the wireless UE comprising a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor, a LTE processor and a digital signal processor supporting MXC modem (UMTS/GSM) functionality, the method comprising:

- buffering a set of IP packets when a radio access technology (RAT) indicator is less than a pre-defined threshold;
- initiating a handover by at least one of the wireless UE and the LTE network;
- sending the set of IP packets to the LTE processor and the digital signal processor when the handover is initiated;
- transmitting the set of IP packets to the LTE network by the LTE processor;
- sending one or more acknowledgment signals to at least one of the LTE-MXC application processor and the digital signal processor, wherein the one or more acknowledgment signals indicate a successfully transmitted subset of the set of IP packets sent to the LTE processor;
- sending one or more messages to the digital signal processor and the LTE-MXC application processor when the handover is complete, wherein at least one of the one or more messages indicates transmission status of the set of IP packets sent to the LTE processor; and
- transmitting a subset of the set of IP packets to one of the plurality of RANs based on the received one or more messages, wherein the subset of IP packets is transmitted by the digital signal processor;

wherein the transmission status of the set of IP packets includes information about the subset of IP packets, wherein the subset of IP packets includes IP packets not successfully transmitted to the LTE network by the LTE processor.

9. The method for performing handover of claim 8, wherein the handover performed by the wireless UE is between the LTE network and one of the plurality of RANs, wherein the one of the plurality of RANs is one of a UMTS radio access network (UTRAN) and a GSM radio access network (GRAN).

10. The method for performing handover of claim 8, further comprising generating the set of IP packets prior to buffering the set of IP packets, wherein the set of IP packets is generated by the LTE-MXC application processor.

11. The method for performing handover of claim 8, further comprising monitoring the RAT indicator.

12. The method for performing handover of claim 8, further comprising sending the set of IP packets to the LTE processor prior to the initiating of the handover.

13. The method for performing handover of claim 8, further comprising sending the one or more acknowledgment signals to the LTE-MXC application processor prior to the initiating of the handover.

14. A wireless user equipment (UE) for communication via a wireless communication system, the wireless communication system comprising a plurality of radio access networks

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(RANs), at least one of the plurality of radio access networks being a Long Term Evolution (LTE) network, the wireless UE comprising:

- a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor configured to generate, buffer and send IP packets;
- a multi-mode radio resource control (MMd_RRC) module located within the LTE-MXC application processor configured to establish a first wireless connection between the wireless UE and at least one of the plurality of RANs;
- a multi-mode non-access stratum (MMd_NAS) module located within the LTE-MXC application processor configured to establish a second wireless connection between the wireless UE and at least one of a first core network configured to provide circuit-switched services and a second core network configured to provide packet-switched services;
- a LTE processor, operatively coupled to the LTE-MXC application processor, configured to receive IP packets from the LTE-MXC application processor, configured to send messages to the LTE-MXC application processor and configured to transmit IP packets to the LTE network, wherein at least one of the messages indicates transmission status of the IP packets received by the LTE processor; and
- a digital signal processor operatively coupled to the LTE processor and the LTE-MXC application processor, wherein the digital signal processor is configured to receive IP packets from the LTE-MXC application processor, receive messages from the LTE processor, and transmit IP packets to one of the plurality of RANs based on the received messages;

wherein the messages include acknowledgement signals, wherein the acknowledgement signals indicate successfully transmitted IP packets; and wherein the LTE-MXC application processor is further configured to drop IP packets based on the acknowledgement signals received from the LTE processor.

15. The wireless UE of claim **14**, wherein the MMd_RRC module is configured to establish a third wireless connection between the wireless UE and at least one of the plurality of RANs based on a Radio Access Technology (RAT) indicator.

16. The wireless UE of claim **14**, wherein the transmission status of IP packets includes information about IP packets not successfully transmitted to the LTE network by the LTE processor.

17. A wireless user equipment (UE) for communication via a wireless communication system, the wireless communication system comprising a plurality of radio access networks (RANs), at least one of the plurality of radio access networks being a Long Term Evolution (LTE) network, the wireless UE comprising:

- a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor configured to generate, buffer and send IP packets;
- a multi-mode radio resource control (MMd_RRC) module located within the LTE-MXC application processor configured to establish a first wireless connection between the wireless UE and at least one of the plurality of RANs;
- a multi-mode non-access stratum (MMd_NAS) module located within the LTE-MXC application processor configured to establish a second wireless connection between the wireless UE and at least one of a first core network configured to provide circuit-switched services and a second core network configured to provide packet-switched services;
- a LTE processor, operatively coupled to the LTE-MXC application processor, configured to receive IP packets

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from the LTE-MXC application processor, configured to send messages to the LTE-MXC application processor and configured to transmit IP packets to the LTE network, wherein at least one of the messages indicates transmission status of the IP packets received by the LTE processor; and

- a digital signal processor operatively coupled to the LTE processor and the LTE-MXC application processor, wherein the digital signal processor is configured to receive IP packets from the LTE-MXC application processor, receive messages from the LTE processor, and transmit IP packets to one of the plurality of RANs based on the received messages;
- wherein the messages include acknowledgement signals, wherein the acknowledgement signals indicate successfully transmitted IP packets; and wherein the digital signal processor is further configured to drop IP packets based on the acknowledgement signals received from the LTE processor.

18. The wireless UE of claim **17**, wherein the MMd_RRC module is configured to establish a third wireless connection between the wireless UE and at least one of the plurality of RANs based on a Radio Access Technology (RAT) indicator.

19. The wireless UE of claim **17**, wherein the transmission status of IP packets includes information about IP packets not successfully transmitted to the LTE network by the LTE processor.

20. A wireless user equipment (UE) for communication via a wireless communication system, the wireless communication system comprising a plurality of radio access networks (RANs), at least one of the plurality of radio access networks being a Long Term Evolution (LTE) network, the wireless UE comprising:

- a Long Term Evolution-Mobile Extreme Convergence (LTE-MXC) application processor configured to generate, buffer and send IP packets;
 - a multi-mode radio resource control (MMd_RRC) module located within the LTE-MXC application processor configured to establish a first wireless connection between the wireless UE and at least one of the plurality of RANs;
 - a multi-mode non-access stratum (MMd_NAS) module located within the LTE-MXC application processor configured to establish a second wireless connection between the wireless UE and at least one of a first core network configured to provide circuit-switched services and a second core network configured to provide packet-switched services;
 - a LTE processor, operatively coupled to the LTE-MXC application processor, configured to receive IP packets from the LTE-MXC application processor, configured to send messages to the LTE-MXC application processor and configured to transmit IP packets to the LTE network, wherein at least one of the messages indicates transmission status of the IP packets received by the LTE processor; and
 - a digital signal processor operatively coupled to the LTE processor and the LTE-MXC application processor, wherein the digital signal processor is configured to receive IP packets from the LTE-MXC application processor, receive messages from the LTE processor, and transmit IP packets to one of the plurality of RANs based on the received messages;
- wherein the transmission status of IP packets includes information about IP packets not successfully transmitted to the LTE network by the LTE processor.

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