US 20170013554A1

(19) United States
(12) Patent Application Publication
Jain et al.
(10) Pub. No.: US 2017/0013554 A1
(43) Pub. Date: Jan. 12, 2017

(54) **USER EQUIPMENT POWER SAVINGS FOR MACHINE TYPE COMMUNICATIONS**

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(21) Appl. No.: **15/225,483**

(22) Filed: **Aug. 1, 2016**

Related U.S. Application Data

(63) Continuation of application No. 13/718,334, filed on Dec. 18, 2012, now Pat. No. 9,407,391.

(60) Provisional application No. 61/646,223, filed on May 11, 2012.

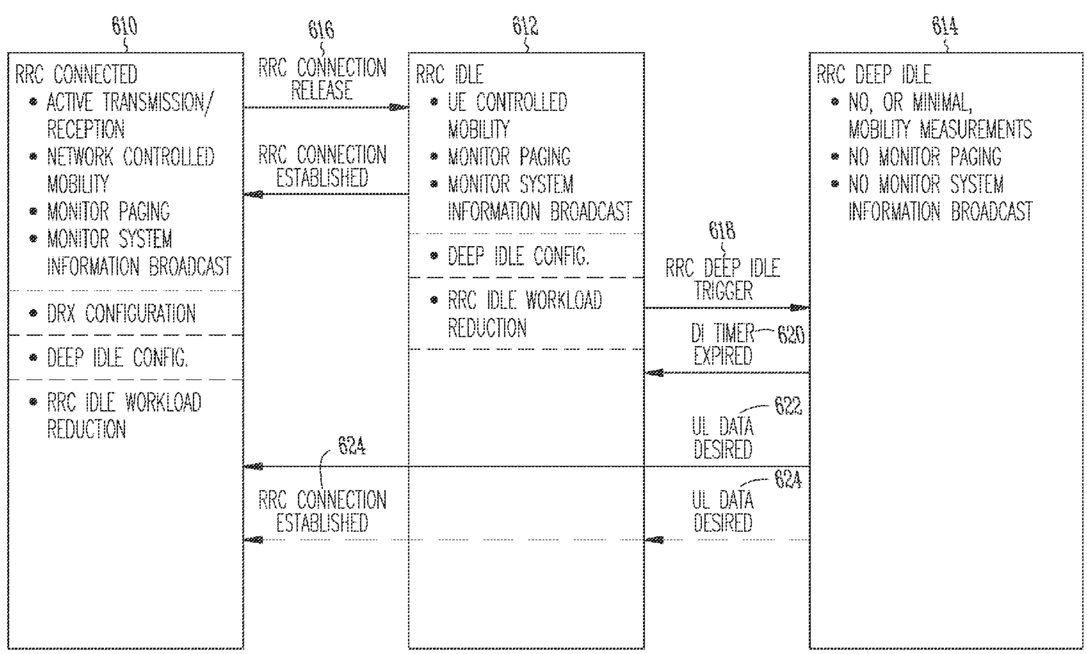
Publication Classification

(51) **Int. Cl.**
H04W 52/02 (2006.01)
H04W 76/04 (2006.01)
H04W 4/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04W 52/0209*** (2013.01); ***H04W 4/005*** (2013.01); ***H04W 76/048*** (2013.01); *H04W 4/02* (2013.01)

(57) **ABSTRACT**

Embodiments of user equipment (UE) and base stations (eNodeB) and method for reducing power consumption in UE in a wireless network are generally described herein. In some embodiments, characteristics of UE including mobility, communication data load, and communication type are used by base stations, MME or other controlling entities to configure power saving features of the UE. Power saving features can include a new Radio Resource Control (RRC) layer state where circuitry is powered off for extended periods of time, extended Discontinuous Reception (DRX) cycles, reduced workloads in existing RRC, EPC Connection Management (ECM) and/or EPS Mobility Management (EMM) states or combinations thereof.



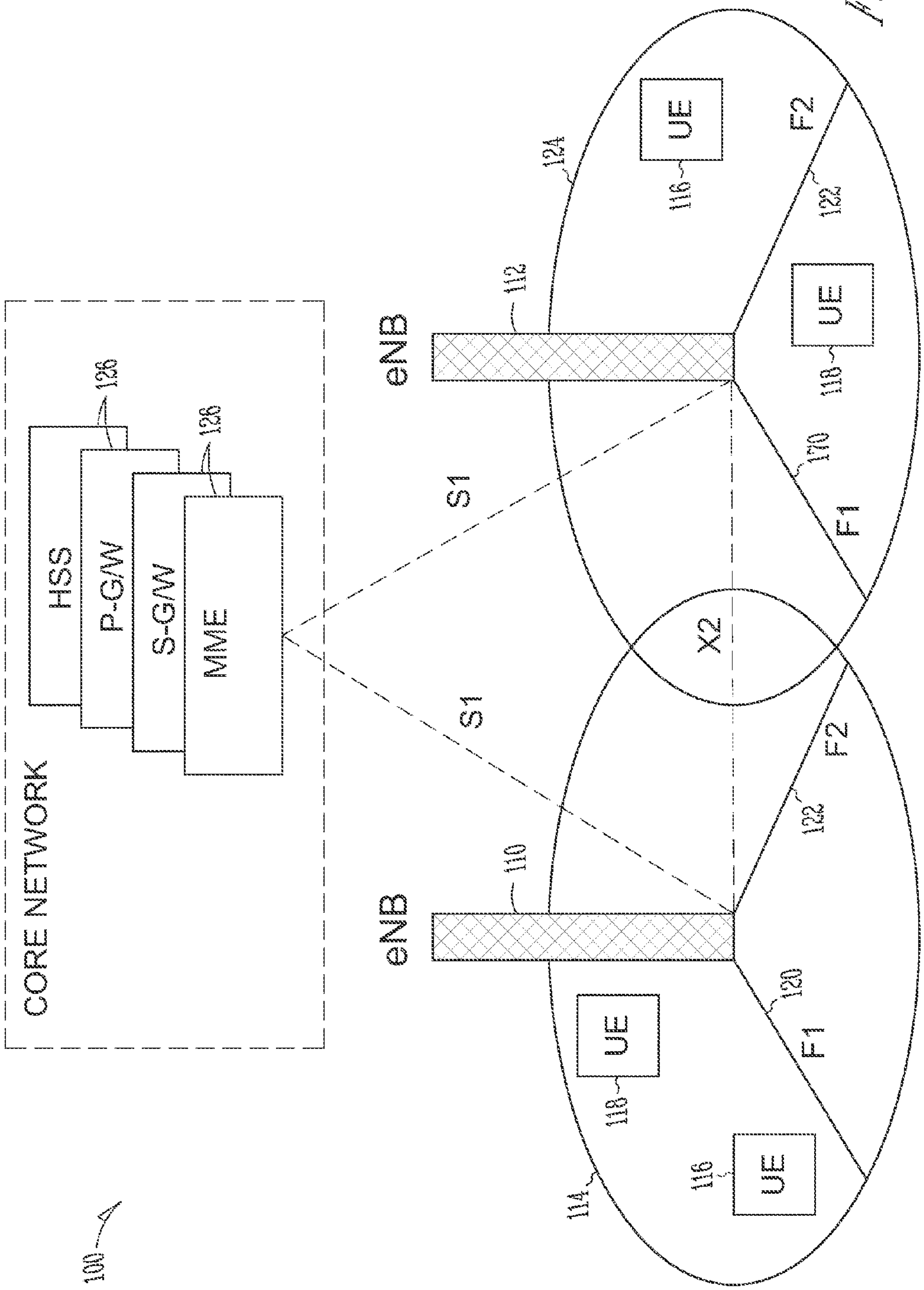

100
CORE NETWORK
HSS
P-G/W
S-G/W
MME
126
126
eNB
eNB
110
112
S1
S1
X2
UE
UE
UE
UE
116
118
116
118
114
124
120
122
122
170
F1
F2
F1
F2

Fig. 1

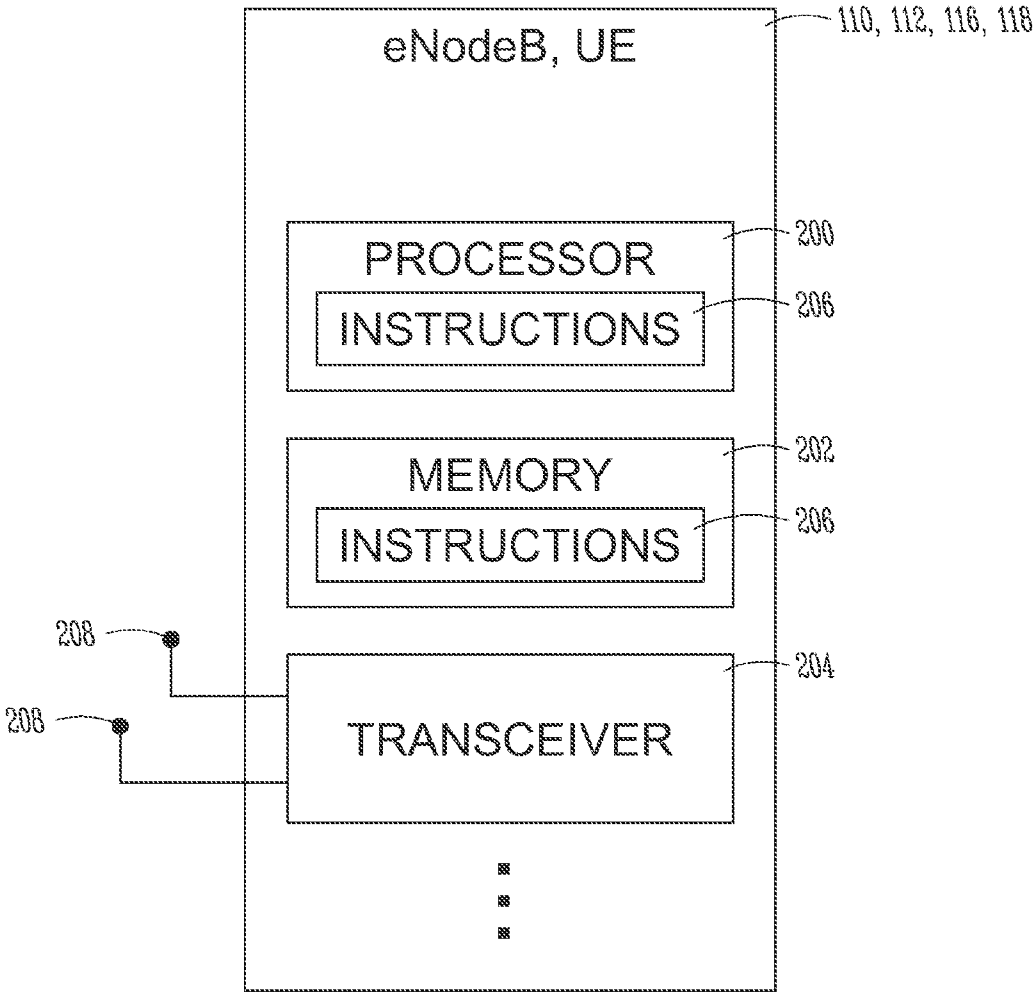
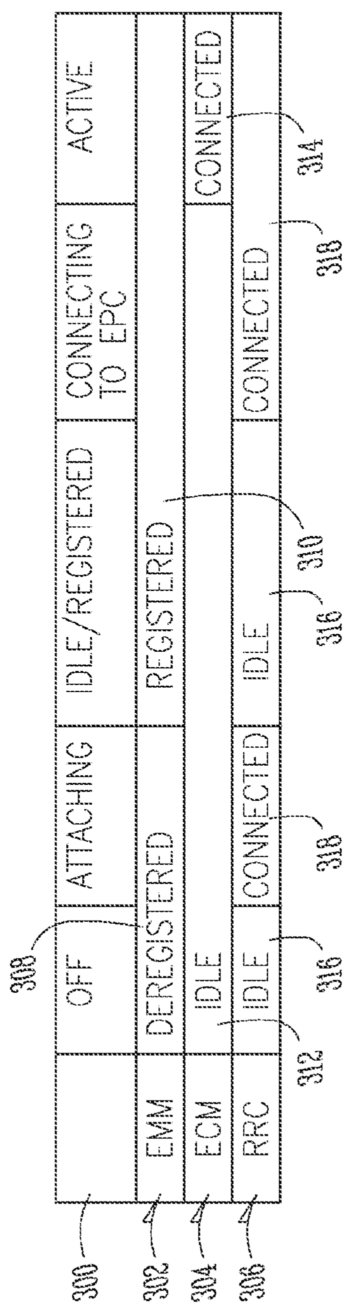
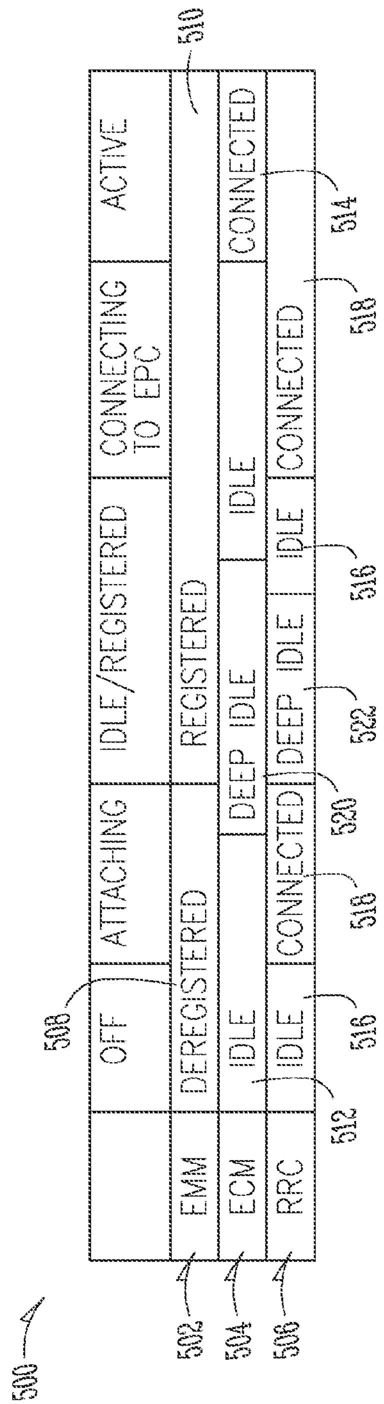

eNodeB, UE
110, 112, 116, 118
PROCESSOR
200
INSTRUCTIONS
206
MEMORY
202
INSTRUCTIONS
206
208
208
204
TRANSCEIVER

Fig.2



300
302
304
306
308
310
312
314
316
318
EMM
ECM
RRC
OFF
ATTACHING
IDLE/REGISTERED
CONNECTING TO EPC
ACTIVE
DEREGISTERED
REGISTERED
IDLE
CONNECTED
IDLE
CONNECTED
IDLE
CONNECTED

Fig. 3



500
502
504
506
508
510
512
514
516
518
520
522
EMM
ECM
RRC
OFF
ATTACHING
IDLE/REGISTERED
CONNECTING TO EPC
ACTIVE
DEREGISTERED
REGISTERED
IDLE
DEEP IDLE
IDLE
CONNECTED
IDLE
CONNECTED
DEEP IDLE
IDLE
CONNECTED

Fig. 5

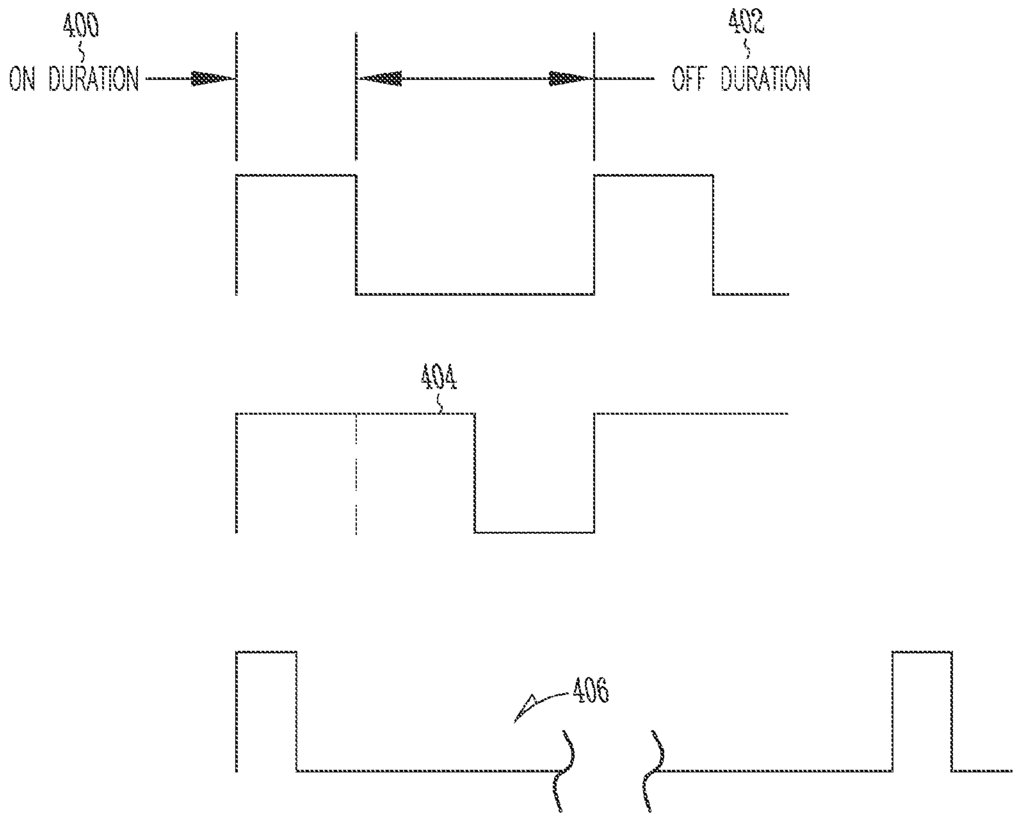


Fig. 4

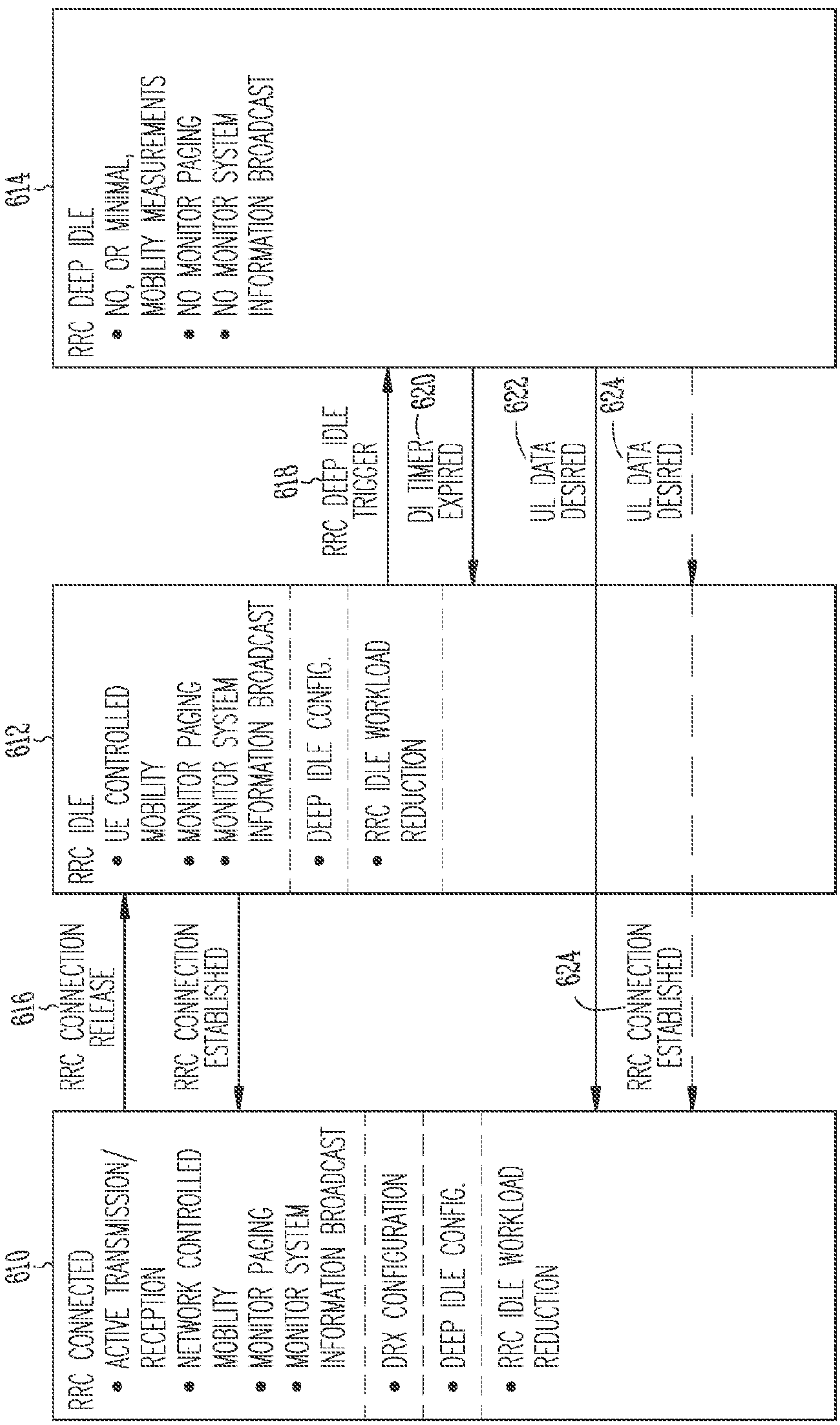

610
RRC CONNECTED
• ACTIVE TRANSMISSION/ RECEPTION
• NETWORK CONTROLLED MOBILITY
• MONITOR PAGING
• MONITOR SYSTEM INFORMATION BROADCAST
• DRX CONFIGURATION
• DEEP IDLE CONFIG.
• RRC IDLE WORKLOAD REDUCTION
616
RRC CONNECTION RELEASE
RRC CONNECTION ESTABLISHED
624
RRC CONNECTION ESTABLISHED
612
RRC IDLE
• UE CONTROLLED MOBILITY
• MONITOR PAGING
• MONITOR SYSTEM INFORMATION BROADCAST
• DEEP IDLE CONFIG.
• RRC IDLE WORKLOAD REDUCTION
618
RRC DEEP IDLE TRIGGER
DI TIMER EXPIRED
620
UL DATA DESIRED
622
UL DATA DESIRED
624
614
RRC DEEP IDLE
• NO, OR MINIMAL, MOBILITY MEASUREMENTS
• NO MONITOR PAGING
• NO MONITOR SYSTEM INFORMATION BROADCAST

Fig. 6

USER EQUIPMENT POWER SAVINGS FOR MACHINE TYPE COMMUNICATIONS

PRIORITY CLAIM

[0001] This application is a continuation of U.S. application Ser. No. 13/718,334, filed Dec. 18, 2012, which claims priority under 35 USC 119 to U.S. Provisional Patent Application Ser. No. 61/646,223, filed May 11, 2012, each of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless cellular communications. More particularly, embodiments relate to saving power in User Equipment (UE).

BACKGROUND

[0003] An ongoing problem in devices that connect to wireless networks is to reduce power consumption during operation. This is particularly true for devices that rely on batteries for their primary power source. However, there is always a tradeoff between power savings and other considerations such as data throughput or adherence to standards such as the current 3rd Generation Partnership Project (3GPP) long term evolution (LTE) standard.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1** illustrates cellular communications in accordance with some embodiments.

[0005] FIG. **2** is a block diagram of user equipment (UE) in accordance with some embodiments.

[0006] FIG. **3** illustrates UE states in accordance with some embodiments.

[0007] FIG. **4** illustrates various discontinuous reception cycles (DRX) in accordance with some embodiments.

[0008] FIG. **5** illustrates UE states in accordance with some embodiments.

[0009] FIG. **6** illustrates UE state transition in accordance with some embodiments.

DETAILED DESCRIPTION

[0010] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0011] 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.

[0012] FIG. **1** illustrates an example (portion) of a wireless communications network **100** shown in a homogeneous network deployment according to some embodiments. In one embodiment, the wireless communications network **100** comprises an evolved universal terrestrial radio access network (EUTRAN) using the 3rd Generation Partnership Project (3GPP) long-term evolution (LTE) standard. The wireless communications network **100** includes a first enhanced Node B (eNodeB or eNB or base station) **110** and a second eNodeB **112**.

[0013] The first eNodeB **110** (also referred to as eNodeB**1**, eNB**1**, a first base station, or a first macro base station) serves a certain geographic area that includes at least a first cell **114**. A plurality of UEs **116**, **118** located within the first cell **114** is served by the first eNodeB **110**. The first eNodeB **110** communicates with the UEs **116**, **118** on a first carrier frequency **120** (F**1**) and optionally, one or more secondary carrier frequencies, such as a second carrier frequency **122** (F**2**).

[0014] The second eNodeB **112** is similar to the first eNodeB **110** except it serves a different cell from that of the first eNodeB **110**. The second eNodeB **112** (also referred to as eNodeB**2**, eNB**2**, a second base station, or a second macro base station) serves another certain geographic area that includes at least a second cell **124**. The plurality of UEs **116**, **118** located within the second cell **124** is served by the second eNodeB **112**. The second eNodeB **112** communicates with the UEs **116**, **118** on the first carrier frequency **120** (F**1**) and optionally, one or more secondary carrier frequencies, such as the second carrier frequency **122** (F**2**).

[0015] The first and second cells **114**, **124** may or may not be immediately co-located next to each other. However, the first and second cells **114**, **124** may be situated close enough to be considered neighboring cells, such that the user traffic pattern and UL/DL configuration of one of the first or second cells **114**, **124** may be relevant to the other cell. For example, one of the UE **116**, **118** served by the first eNodeB **110** may move from the first cell **114** to the second cell **124**, in which case a hand-off takes places from the first eNodeB **110** to the second eNodeB **112** with respect to the particular UE **116**, **118**. Further, the inter-cell interference characteristics can be affected by the UL/DL configurations in the respective cells. As another example, the respective coverage areas of the first and second cells **114**, **124** may be distinct or isolated from each other.

[0016] The UEs **116**, **118** may comprise a variety of devices that communicate within the wireless communications 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 **116**, **118** can comprise Release 8, 9, 10, 11, and/or later releases. Furthermore, UEs **116**, **118** may comprise various characteristics pertaining to mobility, communication data load, and communication type. Mobility, for example, may be that normally associated with movable devices such as smart phones or the like (e.g. "normal" mobility), or may be more infrequent or nomadic where mobility occurs occasionally, if at all, perhaps such as a smart meter, or even stationary. Communication data load may be characterized with that typically associated with any UE device. For example, mobile phones, personal computers, etc. all have typical or "normal" data characteristics (which may, none the less, vary significantly individual device to individual device). Other devices, such as smart meters or the like, may have only infrequent periods of small amounts of data to be sent and/or received (e.g. "limited" data characteristics). Communication type may be adapted specifically, as in the case of machine type communications (MTC) or may be more general, such as that used by a phone where some may be more MTC type of communication and other may carry voice or other data (e.g. human type communications where a person initiates the call or data transfer instead of a machine).

[0017] Wireless communication network **100** may also include other elements, for example one or more Mobility Management Entities (MME), Packet Data Network (PDN) Gateway (P-GW), Serving Gateways (S-GW), Home Subscriber Servers (HSS) or other network operators or entities. These are illustrated in FIG. **1** as MME, P-GW, S-GW, HSS **126** and indicate that these, or other network operator or entities can interact with entities within wireless communication network **100**, including, without limitation, eNodeBs **110**, **112**, UEs **116**, **118** or other entities. Given their ability to control various aspects of the network or entities within the network, MMEs, P-GW, S-GW, HSS, network operators, eNodeBs or other such entities are sometimes referred to herein as a "controlling entity".

[0018] In FIG. **1**, MME and S-GW are connected to eNodeBs (e.g. eNB **110**, **112**) through S1-MME (for control) and S1-U (for user data), respectively. In FIG. **1**, these simply labeled S1, for simplicity. Similarly, other interfaces exist that are not explicitly shown. S-GW and P-GW are connected by an S5 interface. MME and HSS are connected by S6a, and UE and eNB are connected by LTE-Uu (e.g. air interface). The interface connecting eNB **110** and **112** is illustrated in FIG. **1** as X2.

[0019] It is understood that the wireless communications network **100** includes more than two eNodeBs. It is also understood that each of the first and second cells **114**, **124** can have more than one neighboring eNodeB. As an example, cell **114** may have six or more neighboring macro cells.

[0020] In one embodiment, the UEs **116**, **118** located in respective first or second cells **114**, **124** transmits data to its respective first or second eNodeB **110**, **112** (uplink transmission) and receives data from its respective first or second eNodeB **110**, **112** (downlink transmission) using radio frames comprising Orthogonal Frequency-Division Multiple Access (OFDMA) frames configured for time division duplexing (TDD) or frequency division duplexing (FDD) operations. Depending on the exact configuration, the downlink and uplink communication opportunity (subframe or slots) for an eNodeB to communicate information to a particular UE will happen at different instants.

[0021] FIG. **2** illustrates an example block diagram showing details of each of eNodeBs **110**, **112** and UE **116**, **118** according to some embodiments. In these examples, eNodeBs **110**, **112** and UE **116**, **118** include a processor **200**, a memory **202**, a transceiver **204**, one or more antennas **208**, instructions **206**, and possibly other components (not shown) which may depend on whether the devices is an eNodeB or a UE. While similar from a block diagram standpoint, it will be apparent to those of skill in the art that the configuration and details of operation of eNodeBs **110**, **112** and UE **116**, **118** are substantially different, as described herein.

[0022] The eNodeBs **110**, **112** can be similar to each other in hardware, firmware, software, configurations, and/or operating parameters. Differences can also exist, depending on exact configuration and other factors. Similarly, UE **116** and **118** can be similar to each other in hardware, firmware, software, configurations, and/or operating parameters, although differences can also exist. In one example, UE **116** and **118** are similar, while in another example, UE **116** can represent one type of UE, such as a cellular telephone, smart phone, tablet, laptop, desktop, personal computer, server, PDA, web appliance, STB, network router, switch or bridge, or the like, while UE **118** can comprise a different type of device, such as a smart meter with different characteristics in terms of mobility (e.g. nomadic), communication data load (e.g. infrequent periods of low amounts of data transfer), and/or communication type (e.g. MTC).

[0023] The processor **200** comprises one or more central processing units (CPUs), graphics processing units (GPUs), accelerated processing units (APUs), or various combinations thereof. The processor **200** provides processing and control functionalities for the eNodeB or the UE, depending on the device. Memory **202** comprises one or more transient and static memory units configured to store instructions and data for the eNodeB or UE. The transceiver **204** comprises one or more transceivers including, for an appropriate eNodeB or UE, and at least one antenna **208** such as a multiple-input and multiple-output (MIMO) antenna to support MIMO communications. For eNodeBs, the transceiver **204** receives uplink transmissions and transmits downlink transmissions, among other things, from and to the UEs respectively. For UE, the transceiver **204** receives transmissions from eNodeBs (or other UE in direct link communications) and transmits data back to eNodeBs (or other UE in direct link communications).

[0024] 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 eNodeB, or UE depending on the device. The processor **200** and memory **202** also comprise machine-readable media.

[0025] In FIG. **2**, processing and control functionalities are illustrated as being provided by processor **200** along with associated instructions **206**. However, these are only examples of processing circuitry that comprise programmable logic or circuitry (e.g., as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software or firmware to perform certain operations. In various embodiments, processing circuitry may comprise dedicated circuitry or logic that is permanently configured (e.g., within a special-purpose processor, application specific integrated circuit (ASIC), or array) to perform certain operations. It will be appreciated that a decision to implement a processing circuitry mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by, for example, cost, time, energy-usage, package size, or other considerations.

[0026] Accordingly, the term "processing circuitry" should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein.

[0027] FIG. **3** is a block diagram of UE states in accordance with some embodiments. In the example of FIG. **3**, UE (such as UE **116** or UE **118**) has overall UE state description **300** along the top row (e.g. Off, Attaching, Idle/Registered, Connecting to EPC (Evolved Packet Core), Active). Also illustrated are states for illustrated for an EPS—Mobility Management (EMM) layer **302**, an EPS—Connection Management (ECM) layer **304** and a Radio Resource Control (RRC) layer **306**.

[0028] The EMM layer **302** has two states. When a UE is switched off or uses a different radio access network technology (e.g. GPRS or UMTS) it's state is EMM Deregistered **308**. Once the UE sees an LTE network it tries to register and if successful the state is changed to EMM Registered **310**. At the same time the UE is also assigned an IP address. As a consequence UE in EMM Registered state **310** always have an IP address. However, the EMM state is only influenced by UE management procedures such as Attach, Detach and Tracking Area Updates. While the UE is in EMM Registered **310**, the network knows the location of the UE either on a cell level or a tracking area level. Which of the two depends on the connection management state machine described below.

[0029] When a UE is registered (EMM Registered state) it can be in two ECM states. While a data transfer is ongoing the UE is in ECM Connected state **314**. For the UE this means that on the radio link a RRC connection is established. For the network, ECM connected **314** means that both the Mobility Management Entity (MME) and the Serving (User Data) Gateway (SGW) have a connection to the mobile device via the S1 interface (the physical and logical link between the core network and the radio access network). In ECM connected state **314**, the cell level knows the location of the mobile and cell changes are controlled by handovers.

[0030] If there is no activity for some time, the network can decide that it is no longer worthwhile to keep a logical and physical connection in the radio network. The connection management state is then changed to ECM idle **312**. The use of the term "idle" does not mean the connection completely goes away. Logically, it is still there but the RRC connection to the UE is removed as well the S1 signaling and data link. The UE continues to be EMM registered **310** and the IP address it has been assigned remains in place. In ECM idle state **312** the location of the UE is only known down to the tracking area level and the UE performs cell changes autonomously without any signaling exchanges with the network

[0031] From the base station (eNB or the like) and UE point of view there is a lot of room for maneuvering between ECM connected **314** and ECM idle **312**. While a lot of data is exchanged, the air interface can be fully activated for the UE so it has to continuously listen for incoming data. In times of lower activity or even no activity at all, the base station can activate a discontinuous reception (DRX) mode so the UE devices can power down its transceivers for some time. The power down cycles range from milliseconds to a few seconds (2560 msec in the current standard—the longest DRX cycle defined). For some embodiments, modifications to the DRX cycle are illustrated in FIG. **4** and discussed below.

[0032] From a UE point of view the main difference between being in ECM Connected state **314** with a DRX cycle the length of a paging interval and being in ECM Idle state **312** without a radio interface connection is how it's mobility is controlled. In ECM Connected state **314**, handovers are performed. In ECM Idle state **312**, UE can change its serving cell autonomously and only has to report to the network when it leaves the current tracking area. For many UE, the base station is likely to keep the UE in ECM Connected state **314** for as long as possible by using DRX so data transfers can be resumed very quickly before cutting the link entirely and setting the state to ECM Idle **312**. Thus, power savings opportunities using DRX under the present standard are limited.

[0033] The RRC protocol is responsible for the main controlling functions between UE and eNB, for example radio bearer establishment, lower layer configuration and transfer of NAS information. This entails: 1) broadcasting system level information; and 2) maintaining connection layer bi-directional control. RRC has two states, RRC Idle **316** and RRC Connected **318**. In the RRC Connected state **318**, the RRC manages the transmission/reception of all UE and control data in the upload/download slots (UL/DL). In the RRC Idle state **316**, RRC does various tasks for radio link management such as: 1) cell selection/reselection; 2) monitoring paging channels, acquiring system information broadcast in a cell. Under the current 3GPP standard, opportunities for power savings are limited, even during the RRC Idle state **416**.

[0034] FIG. **4** illustrates an example DRX cycle, according to some embodiments of the present invention. As illustrated in FIG. **4**, the DRX cycle has an "on" time **400** and "off" time **402**. During the off time, the UE is relieved of responsibilities such as monitoring PDCCH (DL control channel), in an attempt to save power. Due to decreases in overall bandwidth produced by a longer DRX cycle time, some UE characteristics may demand a shorter DRX cycle **404**, rather than a long DRX cycle.

[0035] However, for certain UE characteristics, even the long DRX cycle may not provide sufficient power savings. Furthermore, a base station bias to keeping UE in the ECM Connected state adds to the problem. This is particularly true for UE with certain characteristics in mobility (e.g. nomadic), communication data load (e.g. infrequent periods of low amounts of data transfer), and/or communication type (e.g. MTC). Some MTC type examples are described in 3GPP TR 22.888, Study on Enhancements for MTC, and include smart grid, automotive, mobile rescue team, device-to-device type communications, cargo tracking, and other examples.

[0036] In situations where long DRX cycle do not provide sufficient power savings, a new DRX cycle **406** extends the "off" time to significant amounts of time, from the few seconds of the existing standard to multiple deci-hours or even longer in the case of appropriate UE. Such a new DRX cycle can be defined within the current DRX cycles and paging cycles or as part of a new Passive Paging message. Additionally, or alternatively, the new Passive Paging message (or changes to the current DRX cycles and paging cycles) may affect additional behavior of UEs, such as UE **116** and/or UE **118**. In one example, Passive Paging messages (or changes to the current DRX cycles and paging cycles) allow the UE to make less frequent Radio Resource Management (RRM) measurements if the UE is stationary most of the time. Additionally, or alternatively, the Passive Paging message may reduce other procedures the UE may need to do, or change the data the UE keeps stored, depending on the characteristics of the UE.

[0037] According to some embodiments, a controlling entity, such as eNodeB **110** or eNodeB **112** of FIG. **1** or a MME, can receive (or otherwise know) UE characteristic information including mobility characteristic information and/or data transmission characteristic information (e.g. communication data load and/or communication type). Based on the UE characteristic information, the controlling entity can decide on a power savings configuration for the UE, which modify UE behavior while in the RRC idle state **316** and/or the ECM Idle state **308**. Modifying the behavior of the UE while in the RRC Idle state **316** and/or ECM Idle state **312** can include modifying the DRX cycle time to be outside the parameters of the existing standard and/or modifying the work the UE performs (or data the UE keeps) during the RRC Idle state **316** and/or ECM Idle state **312**. As noted above, these modifications may be communicated to the UE through a Passive Paging message, or a message according a current standard (e.g. current paging message or other message).

[0038] FIG. **5** is a block diagram of a UE in accordance with some embodiments. The example of FIG. **5** adds additional states to those described in FIG. **3**, namely ECM Deep Idle state **520** and RRC Deep Idle state **522**. These two states, either singly or in conjunction with one another, represent additional power savings functionality that can be utilized either alone or in conjunction with other power savings functionality as described above in conjunction with FIG. **3** and/or FIG. **4**. ECM Deep Idle state **520** and/or RRC Deep Idle state **522** reduce the circuitry powered up, the data stored, the processing load (e.g. procedures performed) or some combination thereof, as described more fully below.

[0039] FIG. **6** illustrates examples of an RRC Deep Idle state (such as RRC Deep Idle state **522**) and its relationship between an RRC Idle state (such as RRC Idle state **516**) and an RRC Connected state (such as RRC Connected state **518**) according to some examples in more detail.

[0040] FIG. **6** illustrates RRC Connected state **610**. In this state, various UE activities can are performed. Examples of UE activities include active data transmission and/or reception, monitoring network paging activity, and/or monitoring system information broadcasts. In addition, the network controls mobility of the UE. Other optional activities can include DRX configuration (including an extended DRX cycle like **406** of FIG. **4**), Deep Idle state **614** configuration (discussed more fully below), and configuration for RRC Idle state **612** workload reduction (e.g. reducing the procedures performed during RRC Idle state **614**, and/or reducing the data or other information kept by UE while in the RRC Idle state **614**).

[0041] The UE enters RRC Idle state **612** in a variety of ways, such as when RRC Connection Release (illustrated by **616**) is received from an eNodeB (such as eNodeB **110** or eNodeB **112**). While in RRC Idle state **612**, the UE can perform various activities such as monitoring network paging activity, and/or monitoring system information broadcasts. The UE controls mobility in the RRC Idle state **612**. Other optional activities or characteristics can include Deep Idle state **614** configuration (discussed more fully below). Finally, depending on the configuration of RRC Idle state **612**, RRC Idle may reduce the procedures performed and/or the data or other information kept by the UE while in the RRC Idles state **614**.

[0042] As examples of workload reduction (e.g. reducing the procedures performed and/or the data or other information kept by the UE), in situations where the UE has nomadic mobility or is stationary (perhaps in the case of a smart meter, network router, or other device that moves only occasionally or not at all), the normal cell selection/reselection procedures can be modified or eliminated all together. Modification can include either eliminating things that are typically done as part of the procedure (e.g. RRM measurements), or reducing the frequency and/or changing the methodology associated with them. As an example only, if a device is nomadic or stationary, mobility related procedures may only need to be rarely performed. Even then, cell selection may simply use the stored value of the prior cell (as that is the most likely location) until additional information illustrates a need for other cell selection procedures to be performed. Finally, it may be that security or other information normally kept and/or updated as part of the RRC Idle state **612** can be reduced or eliminated.

[0043] Transition from the RRC Idle state **612** or RRC Connected **610** to RRC Deep Idle state **614** can be based on a variety of triggers (illustrated by **618**). One trigger may be information received as part of RRC Connection Release (like **616**). Other triggers may be the expiration of an inactivity timer (which happens when there is no UL/DL data detected during the "on" portion of a DRX cycle), or expiration of a length of time or some other mechanism.

[0044] In RRC Deep Idle state **614**, the intent is to reduce power consumption to a minimum. Therefore, various processing circuitry can be put in a low power or off position. During such time, no or perhaps reduced mobility measurements may be made, no paging may be monitored, and no system information broadcasts may be monitored, or combinations thereof. In one embodiment, transceiver and related processing circuitry are powered off. In another embodiment, provisions are made for paging or other information directed to the UE while in the RRC Deep Idle state **614**. Such received information can be either discarded (such as when the transceiver and related circuitry is powered off) or retained in a buffer or other storage area for later processing when the UE transitions out of RRC Deep Idle state **614**.

[0045] UE may transition out of the RRC Deep Idle state **614** in a variety of ways, depending on the particular example. In one example, transition from RRC Deep Idle **614** to RRC Idle **612** occurs upon expiration of a particular length of time (illustrated by **620**). This length of time maybe configured either by a controlling entity (such as MME or eNodeB) or may be defined at the time of manufacture. Furthermore, it may be more or less static, depending on the characteristics of the UE, or may be dynamically configured to suit the characteristics and needs of the current time. In one example, the length of time is configured by an eNodeB as part of the RRC Connection Release. In another example, the length of time is configured by an eNodeB in a paging message (Passive paging or other paging). In yet another example, the length of time can be configured as part of an of Open Mobile Alliance Device Management (OMA-DM) procedure or as part of subscriber identity module, over-the-air (SIM-OTA) procedure or as part of an HLR/HSS subscription. In still another example, the length of time can be configured as part of a broadcast by an eNodeB for a special category of devices (perhaps those with certain mobility characteristic information and/or data transmission characteristic information (e.g. communication data load and/or communication type)).

[0046] Alternatively, or additionally, UE may transition out of the RRC Deep Idle state **614** when the UE has UL data that it determines should not wait until the expiration of the length of time. In such a situation, transition may be out of RRC Deep Idle state **614** to RRC Connected state **610** (illustrated by **622**) or to RRC Idle state **612** and from there to RRC Connected state **610** (illustrated by **624**).

[0047] Although not illustrated in FIG. **6**, some embodiments may transition directly from RRC Connected **610** to RRC Deep Idle **614** or may pass through RRC Idle **612**, either as part of a defined set of circumstances or as an alternative to transitioning from RRC Connected **610** to RRC Idle **612** and then to RRC Deep Idle **614**.

[0048] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

[0049] The term "computer readable medium," "machine-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 terms 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 "computer readable medium," "machine-readable medium" shall accordingly be taken to include both "computer storage medium," "machine storage medium" and the like (tangible sources including, solid-state memories, optical and magnetic media, or other tangible devices and carriers but excluding signals per se, carrier waves and other intangible sources) and "computer communication medium," "machine communication medium" and the like (intangible sources including, signals per se, carrier wave signals and the like).

[0050] 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.

[0051] 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.

1. (canceled)

2. An apparatus for a user equipment (UE), the apparatus comprising:

memory; and

processing circuitry to:

enter a power saving mode, in which the UE is not available for paging, upon expiration of a timer after a transition from an Evolved Packet System (EPS) Connection Management (ECM) CONNECTED state to an ECM_IDLE state, while remaining in an EPS Mobility Management (EMM) REGISTERED state, wherein a mobility management entity (MME) knows a location of the UE to a cell level in the ECM CONNECTED state and wherein the MME knows the location of the UE to a tracking area level in the ECM IDLE state.

3. The apparatus of claim **2**, wherein the processing circuitry is configured to exit the power saving mode subsequent to determining to transmit uplink data.

4. The apparatus of claim **2**, wherein the processing circuitry is configured to exit the power saving mode to provide a tracking area update (TAU).

5. The apparatus of claim **2**, further including:

transceiver circuitry, and

two or more antennas coupled to the transceiver circuitry.

6. The apparatus of claim **2**, wherein the apparatus is included in a device configured to perform machine-type communications (MTC).

7. The apparatus of claim **2**, wherein the processing circuitry is further configured to control the discontinuous reception cycle (DRX).

8. The apparatus of claim **2**, wherein UE data transmission characteristics comprise either normal data characteristics associated with non-Machine Type Communications (non-MTC) or limited data characteristics associated with Machine Type Communications (MTC).

9. A non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a user equipment (UE), the instructions to configure the UE to:

enter a power saving mode, in which the UE is not available for paging, upon expiration of a timer after a transition from an Evolved Packet System (EPS) Connection Management (ECM) CONNECTED state to an ECM_IDLE state, while remaining in an EPS Mobility Management (EMM) REGISTERED state.

10. The non-transitory computer-readable medium of claim **9**, wherein a mobility management entity (MME) knows a location of the UE to a cell level in the ECM CONNECTED state and wherein the MME knows the location of the UE to a tracking area level in the ECM IDLE state.

11. The non-transitory computer-readable storage medium of claim **9**, wherein a value for the timer is configured by a Mobility Management Entity (MME).

12. The non-transitory computer-readable storage medium of claim **9**, wherein the instructions configure the UE to exit the power saving mode subsequent to determining to transmit uplink data.

13. The non-transitory computer-readable storage medium of claim **9**, wherein the instructions configure the UE to exit the power saving mode to provide a tracking area update (TAU).

14. The non-transitory computer-readable storage medium of claim **9**, wherein the UE is included in a device configured to perform machine-type communications (MTC).

15. The -transitory computer-readable storage medium of claim **9**, wherein the instructions configure the UE to control the discontinuous reception cycle (DRX).

16. The -transitory computer-readable storage medium of claim **9**, wherein UE data transmission characteristics comprise either normal data characteristics associated with non-Machine Type Communications (non-MTC) or limited data characteristics associated with Machine Type Communications (MTC).

17. A method comprising:

entering an Evolved Packet System (EPS) Connection Management (ECM) IDLE state;

enter a power saving mode, in which the UE is not available for paging, upon expiration of a timer after entering the ECM_IDLE state, while remaining in an EPS Mobility Management (EMM) REGISTERED state.

18. The method of claim **17**, wherein a mobility management entity (MME) knows a location of the UE to a cell level in an ECM CONNECTED state and wherein the MME knows the location of the UE to a tracking area level in the ECM IDLE state.

19. The method of claim **17**, further comprising:

exiting the power saving mode subsequent to determining to transmit uplink data.

20. The method of claim **19**, further comprising:

providing a tracking area update (TAU) after exiting the power saving mode.

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