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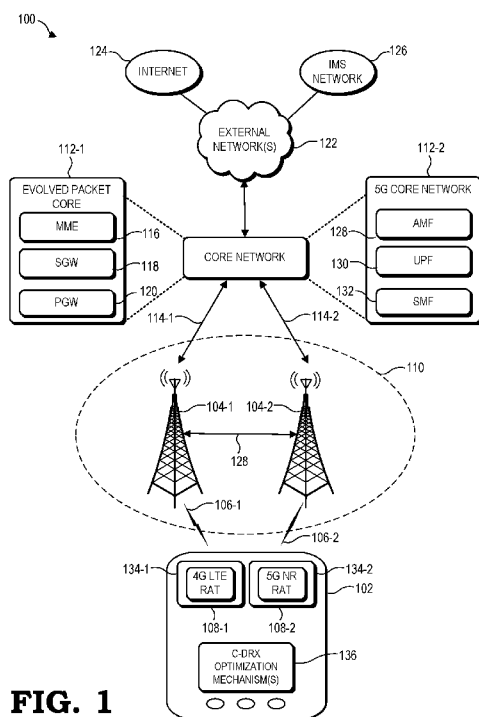


FIG. 1

(57) Abstract: A user equipment (UE) device (102) in a mobile cellular network (100) implements one or more techniques to adapt Connected Mode Discontinuous Reception (C-DRX) timers for optimizing energy consumption at the UE device. For example, the UE device suspends a C-DRX retransmission timer (430) in response to completing a last Physical Uplink Shared Channel (PUSCH) transmission (310) in a set of scheduled PUSCH transmissions. The UE device enters into a low-power state in response to suspending the C-DRX retransmission timer. The UE device resumes the C-DRX retransmission timer according to one or more parameters indicated in a legacy C-DRX configuration (428). The UE device enters into an active state in response to resuming the C-DRX retransmission timer.

USER EQUIPMENT SELF-ADAPTIVE CONNECTED MODE DISCONTINUOUS RECEPTION TIMERS

BACKGROUND

[0001] The evolution of wireless communication systems has paved the way for numerous advancements in technology, enabling faster and more reliable connections between user equipment (UE) devices and the network. However, this evolution has also led to complexities in maintaining compatibility between legacy and newer devices, ensuring that all UEs can effectively communicate within the network. Legacy UEs, often operating under older standards, have certain limitations in terms of their capabilities and functionalities. A significant portion of these legacy UEs supports Physical Uplink Shared Channel (PUSCH) repetitions, a feature that enables the UE to send multiple repetitions of a packet to increase the probability of successful transmission in challenging channel conditions. While PUSCH repetitions have proven beneficial in enhancing uplink reliability, they pose challenges when integrated with certain network configurations.

SUMMARY OF EMBODIMENTS

[0002] In one aspect a method for configuring Connected Mode Discontinuous Reception (C-DRX) timers at a user equipment (UE) device in a cellular network includes suspending a C-DRX retransmission timer responsive to completing a last Physical Uplink Shared Channel (PUSCH) transmission in a set of scheduled PUSCH transmissions, and entering into a low-power state in response to suspending the C-DRX retransmission timer.

[0003] In at least some embodiments, the method further includes resuming the C-DRX retransmission timer according to one or more parameters indicated in a legacy C-DRX configuration, and entering into an active state in response to resuming the C-DRX retransmission timer.

[0004] In at least some embodiments, the method further includes stopping a C-DRX inactivity timer responsive to completing the last Physical Uplink Shared Channel (PUSCH) transmission in a set of scheduled PUSCH transmission.

[0005] In at least some embodiments, the method further includes initially configuring the C-DRX retransmission timer according to one or more parameters indicated in a relaxed C-DRX configuration.

[0006] In at least some embodiments, wherein initially configuring the C-DRX retransmission timer includes configuring the C-DRX retransmission timer to maintain the UE device in an active state for at least a duration of a maximum number of PUSCH repetitions set by the cellular network.

[0007] In at least some embodiments, wherein entering into the low-power state includes entering into the low-power state for any remaining PUSCH repetitions of the maximum number of PUSCH repetitions.

[0008] In at least some embodiments, wherein suspending the C-DRX retransmission timer includes, responsive to receiving an uplink (UL) grant, determining if a number of scheduled PUSCH repetitions indicated in the UL grant is lower than a maximum number of PUSCH repetitions, and, responsive to the number of scheduled PUSCH repetitions being lower than the maximum number of PUSCH repetitions, suspending the C-DRX retransmission timer when the last Physical Uplink Shared Channel (PUSCH) transmission has been completed.

[0009] In at least some embodiments, the method further includes receiving a legacy C-DRX configuration from the cellular network responsive to sending a set of legacy capabilities for the UE device to the cellular network.

[0010] In at least some embodiments, wherein sending the set of legacy capabilities includes determining that an up-to-date legacy C-DRX configuration is not available at the UE device, and sending the set of legacy capabilities to the cellular network in response to the legacy C-DRX configuration being unavailable at the UE device.

[0011] In at least some embodiments, wherein the set of legacy capabilities includes at least one indication that the UE device does not support a feature despite the UE device actually supporting the feature.

[0012] In at least some embodiments, the method further includes receiving a relaxed C-DRX configuration from the cellular network responsive to sending a set of actual capabilities for the UE device to the cellular network.

[0013] In at least some embodiments, wherein sending the set of actual capabilities includes sending the set of actual capabilities in response to receiving the legacy C-DRX configuration from the cellular network.

[0014] In at least some embodiments, the method further includes adjusting, based on one or more parameters of the legacy C-DRX configuration, one or more parameters of the C-DRX retransmission timer initially set based on the relaxed C-DRX configuration.

[0015] In accordance with another aspect, a user equipment device includes one or more radio frequency (RF) modems configured to wirelessly communicate with at least one network; one or more processors coupled to the one or more RF modems; and at least one memory storing executable instructions, the executable instructions configured to manipulate at least one of the one or more processors or the one or more RF modems to perform the methods described above and herein.

[0016] In accordance with a further aspect, a computer-readable storage medium embodies a set of executable instructions, the set of executable instructions to manipulate a user equipment device to perform the methods described above and herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art, by referencing the

accompanying drawings. The use of the same reference symbols in different drawings indicates similar or identical items.

[0018] FIG. 1 is a diagram illustrating an example wireless system employing a UE device configured to adapt Connected Mode Discontinuous Reception (C-DRX) timers for optimizing energy consumption at a UE device in accordance with some embodiments.

[0019] FIG. 2 is a block diagram illustrating example modes of a C-DRX configuration optimization mechanism employed by the UE device of FIG. 1 in accordance with some embodiments.

[0020] FIG. 3 is a diagram illustrating adapted C-DRX timers and related energy savings in accordance with some embodiments.

[0021] FIG. 4 is a diagram illustrating an example hardware configuration of a UE device of the wireless system of FIG. 1 in accordance with some embodiments.

[0022] FIG. 5 and FIG. 6 together are a flow diagram illustrating an example method illustrates a diagram of an example method of adapting C-DRX timers for optimizing energy consumption at a UE device in accordance with some embodiments.

DETAILED DESCRIPTION

[0023] The fifth-generation (5G) new radio (NR) technology has significantly advanced wireless communication, providing higher data rates, improved reliability, and better user experiences. However, one of the persistent challenges in 5G NR systems is the limitation imposed by the User Equipment (UE) uplink (UL) power, which can notably degrade the quality of communication services, leading to issues such as call drops. To mitigate the challenges associated with limited UE UL power, 5G NR systems implement the concept of UE Physical Uplink Shared Channel (PUSCH) repetition, specifically denoted as PUSCH-RepetitionTypeA-rel16 in Third (3rd) Generation Partnership Project (3GPP) Release 16. This mechanism enhances the reliability of UL transmissions by effectively increasing the UL coverage, ensuring

that signals are transmitted with sufficient strength and clarity even under suboptimal radio conditions.

[0024] PUSCH-RepetitionTypeA-rel16 enables the repetition of PUSCH transmissions, adapting the number of repetitions based on current radio conditions for a balance between energy efficiency and transmission latency. The integration of this feature with Connected Mode Discontinuous Reception (C-DRX) in 5G NR allows UE devices to enter a low-power state when inactive, conserving energy while reducing latency associated with starting transmissions. This creates an environment for energy and latency-efficient transmission.

[0025] Nonetheless, the combination of PUSCH-RepetitionTypeA-rel16 and C-DRX introduces complexity, particularly in timer configurations. Misalignments can occur when UL grants are scheduled during UE device inactivity, causing missed transmission opportunities. The introduction of lastTransmissionUL-r17 in 3GPP Release 17 addresses this issue by ensuring that the retransmission UL timer (specifically the drx-HARQ-RTT-TimerUL) aligns with the last transmission in a bundle, preventing the UE device from entering DRX sleep state during potential retransmission opportunities and enhancing UL communication reliability.

[0026] The standard C-DRX timers, when not optimally configured, can lead to scenarios where the UE device is inactive during scheduled UL grants, resulting in missed opportunities and performance degradation. To mitigate this, a relaxed C-DRX timer configuration is implemented by 5G NR systems, ensuring proper alignment between UE device inactivity and network scheduling, and enhancing overall system performance. For example, relaxed C-DRX configurations configure one or more C-DRX timers (such as drx-InactivityTimer or drx-RetransmissionTimerUL) with more lenient settings to ensure the UE device remains active for a sufficient duration to accommodate potential retransmissions.

[0027] A 5G NR network, with these enhancements, offers various C-DRX configuration profiles, accommodating a diverse range of UE devices and ensuring interoperability and optimal performance. For example, these C-DRX configuration

profiles include legacy C-DRX configurations for legacy UE devices that do not support PUSCH-RepetitionTypeA-rel16 or lastTransmissionUL-r17, optimized C-DRX configurations for UE devices that support lastTransmissionUL-r17, relaxed C-DRX configurations for legacy UE devices that support semi-static PUSCH repetitions (i.e., based 3GPP Release 15), and relaxed C-DRX UL timer configurations for Legacy UE devices that support pusch-RepetitionTypeA-rel16 but not support lastTransmissionUL-r17.

[0028] However, there is a notable challenge with legacy UEs that support pusch-RepetitionTypeA-rel16 but do not support lastTransmissionUL-r17. When configured with relaxed C-DRX timers, these legacy UEs tend to consume more energy, particularly in scenarios where the maximum number of PUSCH repetitions is not required. This energy inefficiency underscores the need for innovative solutions and configurations to ensure optimal performance and user experience across different UE generations and capabilities.

[0029] As such, the following describes embodiments of systems and methods for a UE device to implement self-adaptive C-DRX timers for optimizing the energy consumption at the UE device. In more detail, a UE device that is capable of enhancing its uplink transmission reliability through repeated transmissions (e.g., PUSCH-RepetitionTypeA-rel16) based on the radio conditions but does not support the optimized timing adjustment (e.g., lastTransmissionUL-r17) introduced in later iterations, adapts the relaxed C-DRX configuration based on the dynamic UL PUSCH repetitions to optimize its power consumption. In at least some embodiments, when a UE device registers with the cellular network, the UE device reports its actual radio capabilities. For example, the UE device reports that the device supports PUSCH-RepetitionTypeA-rel16 and does not support lastTransmissionUL-r17. After completing the registration with the cellular network, the UE device receives a C-DRX configuration from the cellular network via a Radio Resource Control (RRC) reconfiguration message based on the reported UE capabilities. For example, based on the UE device supporting PUSCH-RepetitionTypeA-rel16 but not supporting lastTransmissionUL-r17, the network sends the UE device a relaxed C-DRX

configuration, which adjusts the timing parameters of the C-DRX to accommodate certain transmission characteristics or limitations of the UE device.

[0030] The UE device determines if an up-to-date legacy C-DRX configuration is locally available. A legacy C-DRX configuration refers to a C-DRX configuration that includes settings and parameters used in older generations or earlier releases of cellular network standards for managing the UE device sleep and active cycles, and lacks support for features such as PUSCH-RepetitionTypeA-rel16 and lastTransmissionUL-r17. In at least some embodiments, the UE device maintains a database or other data structure that stores up-to-date C-DRX configurations, such as legacy configurations, relaxed C-DRX configurations, a combination thereof, or the like. The UE device updates/refreshes the stored C-DRX configurations in response to the expiration of a timer or any other criteria related to the cellular network. In at least some embodiments, the network periodically sends the UE device updated C-DRX configurations.

[0031] If the UE device determines that an up-to-date legacy C-DRX configuration is locally available, the UE device implements an energy-optimized C-DRX configuration, as described below. However, if the UE device determines that a legacy C-DRX configuration is not locally available or is out-of-date, the device triggers a Tracking Area Update (TAU) procedure (or similar procedure) and provides a reason, such as UE Capabilities Update, to the network. During this procedure, the UE device reports its capabilities to the cellular network. However, in this instance, the UE device identifies itself as a legacy UE device that does not support PUSCH repetitions type A or lastTransmissionUL-r17. The network responds with a legacy C-DRX configuration via an RRC reconfiguration message. The UE device locally stores the legacy C-DRX configuration received from the network.

[0032] The UE device then reports its actual radio capabilities, such as supporting PUSCH-RepetitionTypeA-rel16 but not supporting lastTransmissionUL-r17, to receive an updated relaxed C-DRX configuration. The network responds by sending a relaxed C-DRX configuration via an RRC reconfiguration message. The UE device

locally stores the relaxed C-DRX configuration received from the network. In at least some embodiments, instead of initially reporting actual capabilities when registering with the network, the UE device reports that it is a legacy UE device not supporting PUSCH repetitions type A or lastTransmissionUL-r17. This allows the UE device to initially receive a legacy C-DRX configuration if one is not currently stored at the UE device instead of initially receiving the relaxed C-DRX configuration and then having to obtain another relaxed C-DRX configuration if an up-to-date legacy C-DRX configuration is not available (unavailable) at the UE device.

[0033] After the UE device obtains the legacy C-DRX configuration and relaxed C-DRX configuration, the UE device implements an energy-optimized C-DRX configuration. When the UE device is operating in an RRC Connected mode with C-DRX activated and receives a UL grant from the network, the UE device determines if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions specified by the 3GPP release (e.g., Release 16) supported by the UE device. If the number of scheduled/configured PUSCH repetitions indicated in the UL grant equals (or is greater than) the maximum number of PUSCH repetitions, the UE device operates according to a default (regular) C-DRX configuration. However, if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions, the UE device adapts the C-DRX timers, such as the drx-InactivityTimer and drx-RetransmissionTimerUL, by, for example, decreasing/shortening one or more of the start or duration of these timers based on the number of configured PUSCH repetitions to optimize the energy consumption of the device.

[0034] For example, the UE device accesses the stored legacy C-DRX configuration to determine the legacy drx-RetransmissionTimerUL. This timer is used by the network to ensure that the UE device wakes up in time to receive a retransmission grant. The timer is started when the UE device transmits data and expires after a certain period of time. The UE device also accesses the stored relaxed C-DRX configuration to determine the relaxed drx-RetransmissionTimerUL. This timer is used by the network to keep the UE device awake during the duration of

the maximum number of PUSCH repetitions plus the legacy drx-RetransmissionTimerUL, which is inefficient in terms of energy consumption. Therefore, after the expiration of the last PUSCH transmission, the UE device suspends the drx-RetransmissionTimerUL and resumes the drx-RetransmissionTimerUL aligned to the expected legacy behavior. The UE device also stops any inactivity timer if this timer is still running. As such, after the expiration of the last PUSCH transmission, the UE device is able to enter into a sleep state for the remaining PUSCH repetitions and only transition into an active state based on the legacy RetransmissionTimerUL parameters, which saves energy at the UE device.

[0035] For ease of illustration, the following techniques are described in an example context in which one or more UE devices and one or more RANs implement at least a Fifth Generation (5G) New Radio (NR) standard (e.g., 3GPP Release 15, 3GPP Release 16, 3GPP Release 17, etc.) (hereinafter, "5G NR" or "5G NR standard"). However, it should be understood that the present disclosure is not limited to networks employing a 5G NR RAT configuration, but rather, the techniques described herein can be applied to any combination of different RATs employed at the UE devices and the RANs. It should also be understood that the present disclosure is not limited to any specific network configurations or architectures described herein for implementing self-adaptive C-DRX timers for optimizing energy consumption at UE devices. Instead, techniques described herein can be applied to any configuration of RANs. Also, the present disclosure is not limited to the examples and context described herein, but rather, the techniques described herein can be applied to any network environment where a UE device implements self-adaptive C-DRX timers for optimizing energy consumption at the device.

[0036] FIG. 1 illustrates a mobile cellular network (system) 100 in accordance with at least some embodiments. As shown, the mobile cellular network 100 includes a user equipment (UE) device 102 that is configured to communicate with one or more base stations (BSs) 104 (illustrated as BS 104-1 and BS 104-2) through one or more wireless communication links 106 (illustrated as wireless links 106-1 and 106-2). The UE device 102, in at least some embodiments, includes any of a variety of wireless

communication devices, such as a cellular phone, a cellular-enabled tablet computer or cellular-enabled notebook computer, a cellular-enabled wearable device, an automobile, or other vehicle employing cellular services (e.g., for navigation, provision of entertainment services, in-vehicle mobile hotspots, etc.), and so on. In at least some embodiments, the UE device 102 employs a single RAT 108. In other embodiments, the UE device 102 is a multi-mode UE device that employs multiple RATs 108 (illustrated as RAT 108-1 and RAT 108-2). Examples of multiple RATs include cellular-based RATs, such as a 3GPP Long-Term Evolution (3GPP LTE) RAT and a 3GPP Fifth Generation New Radio (5G NR) RAT, a Wi-Fi RAT, and the like. It should be understood that although FIG. 1 only shows the UE device 102 implementing two different RATs 108, the UE device 102, in at least some embodiments, implements three or more different RATs 108. In at least some embodiments, one or more RAT modules 134 (illustrated as RAT module 134-1 and RAT module 134-2) manage the RATs 108 and enable communication between the UE device 102 and the radio access technology of the network 100. The one or more RAT modules 134, in at least some embodiments, include one or more of a modem chipset(s) of the UE device 102, a protocol stack(s), driver software, or the like.

[0037] In at least some embodiments, the BSs 104 are implemented in a macrocell, microcell, small cell, picocell, and the like, or any combination thereof. Examples of base stations 104 include an Evolved Universal Terrestrial Radio Access Network Node B (E-UTRAN Node B), Evolved Node B (eNodeB or eNB), Next Generation (NG or NGEN) Node B (gNode B or gNB), and so on. The BSs 104 communicate with the UE device 102 via the wireless links 106, which are implemented using any suitable type of wireless link. The wireless links 106, in at least some embodiments, include a downlink of data and control information communicated from the base stations 104 to the UE device 102, an uplink of data and control information communicated from the UE device 102 to the BSs 104, or both. In at least some embodiments, the wireless links 106 (or bearers), such as data radio bearers (DRBs) and signal radio bearers (SRBs), are implemented using any suitable communication protocol or standard, or combination of communication protocols or standards, such

as 3GPP 4G LTE, 5G NR, and so on. In at least some embodiments, multiple wireless links 106 are aggregated in a carrier aggregation to provide a higher data rate for the UE device 102. Also, multiple wireless links 106 from multiple base stations 104 are configured, in at least some embodiments, for coordinated multipoint (CoMP) communication with the UE device 102, as well as dual connectivity, such as single-RAT LTE-LTE or NR-NR dual connectivity, or multi-radio access technology (Multi-RAT) dual connectivity (MR-DC) including E-UTRA-NR dual connectivity (EN-DC), NGEN radio access network (RAN) E-UTRA-NR dual connectivity (NGEN-DC), and NR E-UTRA dual connectivity (NE-DC).

[0038] The BSs 104 collectively form a Radio Access Network (RAN) 110, such as an E-UTRAN or 5G NR RAN. The base stations 104 are connected to a core network (CN) 112 (illustrated as CN 112-1 and CN 112-2) via control-plane and user-plane interfaces through one or more links 114 (illustrated as link 114-1 and link 114-2). Depending on the configuration of the mobile cellular network 100, the core network 112 is either an Evolved Packet Core (EPC) network 112-1 or a 5G Core Network (5GC) 112-2. For example, in an E-UTRAN configuration or a 5G non-standalone (NSA) EN-DC configuration, the core network 112 is an EPC network 112-1 that includes, for example, a Mobility Management Entity (MME) 116, a Serving Gateway (SGW) 118, and a Packet Data Network Gateway (PGW) 120. The MME 116 provides control-plane functions, such as registration and authentication of multiple UE devices 102, authorization, mobility management, and so on. The SGW 118 transfers user-plane packets related to audio calls, video calls, Internet traffic, and the like. The PGW 120 provides connectivity from the UE device 102 to external packet data networks 122, such as the Internet 124 and an IMS network 126, by being the point of exit and entry of traffic for the UE device 102. In a 5G standalone (SA) configuration or an NSA NE-DC or NGEN-DC configuration, the core network 112 is a 5GC network 112-2. The 5GC 112-2 includes, for example, an Access and Mobility Management function (AMF) 128 and a User Plane Function (UPF) 130, and a Session Management Function (SMF) 132. The AMF 128 provides control-plane functions such as registration and authentication of multiple UE devices 102, authorization, mobility management, and so on. The UPF 130 transfers user-plane

packets related to audio calls, video calls, Internet traffic, and the like. The SMF 132 manages protocol data unit (PDU) sessions.

[0039] In at least some embodiments, the core network 112 communicatively couples the UE device 102 to an IMS network 126 via the RAN 110. The IMS network 126 provides various IMS services to the UE device 102, such as IMS short messages, IMS unstructured supplementary service data (USSD), IMS value-added service data, IMS supplementary service data, IMS voice calls, and IMS video calls. To this end, an entity (e.g., a server or a group of servers) operating in the IMS network 126 supports packet exchange with the UE device 102. The packets convey signaling (such as session initiation protocol (SIP) messages, IP messages, or other suitable messages) as well as data (or media), such as voice or video. In at least some embodiments, the IMS network includes entities (not shown) such as a Proxy Call Session Control Function (P-CSCF), an Interrogating Call Session Control Function (I-CSCF), a Serving Call Session Control Function (S-CSCF), a Home Subscriber Server (HSS), a Media Gateway Control Function (MGCF), and the like.

[0040] As described above, one of the persistent challenges in 5G NR systems is the limitation imposed by the UE device UL power, which can notably degrade the quality of communication services, leading to issues such as call drops. To mitigate the challenges associated with limited UE UL power, 5G NR incorporates the UE Physical Uplink Shared Channel (PUSCH) repetition, specifically the PUSCH-RepetitionTypeA-rel16 as standardized in the 3GPP Release 16. This feature allows for the repetition of PUSCH transmissions, dynamically adjusting the number of repetitions in response to the existing radio conditions. Additionally, the 5G NR leverages the connected mode-discontinuous reception (C-DRX), a mechanism that permits the UE device to transition to a low-power state during inactivity, thereby preserving battery life.

[0041] However, in the initial configuration specified by 3GPP Release 16, the UE device triggers the drx-HARQ-RTT-TimerUL right after the first transmission in a bundle is completed. The drx-HARQ-RTT-TimerUL, which stands for Discontinuous

Reception Hybrid Automatic Repeat Request Round Trip Time Timer for Uplink, is a timer that defines the period the UE device waits for an acknowledgment or a negative acknowledgment after transmitting data on the uplink. If the acknowledgment is not received within this period, this indicates a potential need for retransmission. Following the expiration of this timer, the UE device initiates the drx-RetransmissionTimerUL, marking the time window available for retransmissions. This setup, however, creates complexities when interfacing with PUSCH repetition, introducing the potential of the UE device prematurely re-entering sleep state during periods when retransmission could be necessary. To mitigate pre-mature sleep reentry, 5G NR systems employ relaxed DRX timers for UE devices utilizing PUSCH repetition. While this approach effectively prevents early transitions to sleep state, it inadvertently leads to increased UE battery consumption.

[0042] The subsequent 3GPP Release 17 introduces the lastTransmissionUL-r17 feature, refining the process by initiating the drx-HARQ-RTT-TimerUL after the last transmission within a bundle. The lastTransmissionUL-r17 feature aligns the active periods of the UE devices more closely with potential retransmission opportunities and ensures that the UE device remains ready for potential retransmissions, minimizing the need for excessively relaxed DRX timers and contributing to an overall more efficient power consumption profile. This shift in DRX operation to starting the retransmission UL timer at the end of the last transmission ensures the UE device stays active during retransmission opportunities, preventing unnecessary transitions to DRX sleep and promoting a more seamless communication experience.

[0043] However, many UE devices, such as UE device 102 of FIG. 1, are legacy devices that operate under older standards or possess certain limitations in terms of their capabilities and functionalities. For example, a legacy UE device, in some instances, supports PUSCH-RepetitionTypeA-rel16 but does not support lastTransmissionUL-r17. Therefore, the network 100 configures these UE devices 102 with a relaxed C-DRX configuration, which is inefficient in terms of energy consumption, as described above.

[0044] As such, the UE device 102 of one or more embodiments employs at least one C-DRX configuration optimization mechanism 136 for optimizing the energy consumption at the UE device 102. In at least some embodiments, when the UE device 102 is operating in an RRC Connected mode with C-DRX activated and receives a UL grant from the network 100, the C-DRX configuration optimization mechanism 136 determines if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions specified by the 3GPP release (e.g., Release 16) supported by the UE device 102. If the number of PUSCH repetitions indicated in the UL grant equals (or is higher than) the maximum number of PUSCH repetitions, the UE device 102 operates according to a default (regular) C-DRX configuration as defined in one or more specifications or standards.

[0045] However, if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions, the C-DRX configuration optimization mechanism 136 adapts the C-DRX timers, such as the drx-InactivityTimer and drx-RetransmissionTimerUL. For example, after the expiration of the last PUSCH transmission, the C-DRX configuration optimization mechanism 136 suspends the drx-RetransmissionTimerUL, which is initially set based on parameters included in a relaxed C-DRX configuration 426 (FIG. 4) received from the network 100. The C-DRX configuration optimization mechanism 136 then resumes the drx-RetransmissionTimerUL based on the expected legacy behavior, as indicated in a legacy C-DRX configuration 428 (FIG. 4) received from the network 100. In at least some embodiments, the C-DRX configuration optimization mechanism 136 also stops any inactivity timer that is still running. As such, after the expiration of the last PUSCH transmission, the UE device 102 is able to enter into a sleep state for the remaining PUSCH repetitions and only transition into an active state based on the legacy RetransmissionTimerUL parameters, which saves energy at the UE device 102.

[0046] For example, FIG. 2 illustrates various example modes employed singularly or in various combinations by the UE device 102 as part of the C-DRX configuration optimization mechanism 136 in accordance with at least some embodiments. In at

least some embodiments, these modes include a C-DRX configuration identification mode 202 and an energy-optimized C-DRX configuration mode 204. During the C-DRX configuration identification mode 202, the C-DRX configuration optimization mechanism 136 identifies the relaxed C-DRX configuration 426 and the legacy C-DRX configuration 428 available from the network 100. For example, after the UE device 102 registers with the network 100, the UE device 102 sends an RRC message, such as a UE capability information message 206, to the network 100 reporting the actual capabilities of the UE device 102. In at least some embodiments, the UE capability information message 206 reports that the UE device supports PUSCH-RepetitionTypeA-rel16 and does not support lastTransmissionUL-r17.

[0047] In response to sending the UE capability information message 206, the UE device 102 receives a relaxed C-DRX configuration 426 from the network 100 via an RRC Reconfiguration message 208 based on the actual capabilities of the UE device 102. In at least some embodiments, the UE device 102 locally stores the relaxed C-DRX configuration 426 in a storage mechanism 420 (FIG. 4), such as a database. The relaxed C-DRX configuration 426 adjusts the C-DRX timing parameters to accommodate certain transmission characteristics or limitations of the UE device 102. In the context of a UE device 102, which supports PUSCH repetitions but does not support the lastTransmissionUL-r17 feature, a relaxed C-DRX configuration 426 includes, for example, one or more of an extended inactivity timer, a prolonged retransmission UL timer(s), an adjusted HARQ timer(s), a modification(s) to DRX cycle length, an increased on-duration timer(s), or the like. The inactivity timer is the period after which the UE device 102 transitions from a state of high activity to low activity (e.g., a sleep state). Extending this timer ensures that the UE device 102 stays awake longer, anticipating possible retransmissions and, hence, avoiding missing them. The retransmission UL timer is a timer that determines when the UE device 102 should be ready to receive a retransmission and is extended so that the UE device 102 is awake and ready, even though this may lead to increased energy consumption. The adjusted HARQ timer is used for error correction through retransmissions and is adjusted so that the UE device 102 is ready to receive retransmissions, particularly when PUSCH repetitions are being used. The DRX

cycle length is the periodicity with which the UE device 102 wakes up from sleep to check for incoming transmissions. The DRX cycle length is adjusted to ensure alignment with the timing of possible retransmissions. The on-duration timer is the duration for which the UE device 102 stays active after waking up from a DRX sleep cycle. The on-duration timer is increased so that the UE device 102 does not miss retransmissions.

[0048] In response to (or independent of) receiving the relaxed C-DRX configuration 426, the C-DRX configuration optimization mechanism 136 determines if an up-to-date legacy C-DRX configuration 428 is locally available at, for example, the storage mechanism 420. In at least some embodiments, “up-to-date” refers to a legacy C-DRX configuration 428 that was obtained or refreshed within a specified threshold period of time. A legacy C-DRX configuration 428 refers to a C-DRX configuration having settings and parameters used in older generations or earlier releases of cellular network standards for managing UE device sleep and active cycles. Therefore, although a legacy C-DRX configuration 428 includes one or more of an inactivity timer, a prolonged retransmission UL timer(s), a HARQ timer(s), a DRX cycle length, an on-duration timer(s), or the like, these settings and parameters are not optimized based on newer releases of cellular network standards (e.g., 3GPP Release 16 or Release 17).

[0049] If an up-to-date legacy C-DRX configuration 428 is locally available, the C-DRX configuration optimization mechanism 136 implements the second mode 204 described below. However, if a legacy C-DRX configuration 428 is not locally available or is out-of-date, the C-DRX configuration optimization mechanism 136 triggers a Tracking Area Update (TAU) with the network 100 providing a reason, such as UE Capabilities Update. For example, the C-DRX configuration optimization mechanism 136 triggers the UE device 102 to once again report its capabilities to the network 100. However, in this instance, the UE device 102 identifies itself as a legacy UE device that does not support PUSCH repetitions type A or lastTransmissionUL-r17. In at least some embodiments, the UE device 102 sends an RRC message, such as a UE capability information message 206, to the network

100, reporting that the UE device 102 does not support PUSCH-RepetitionTypeA-rel16 or lastTransmissionUL-r17. In response to sending the UE capability information message 206, the UE device 102 receives a legacy C-DRX configuration 428 from the network 100 via an RRC Reconfiguration message 208 based on the reported legacy capabilities of the UE device 102. In at least some embodiments, the UE device 102 locally stores the legacy C-DRX configuration 428 in the storage mechanism 420.

[0050] The C-DRX configuration optimization mechanism 136 then triggers the UE device 102 to report its actual radio capabilities once again to the network 100. For example, the UE device 102 sends an RRC message, such as a UE capability information message 206, to the network 100, reporting that the UE device supports PUSCH-RepetitionTypeA-rel16 and does not support lastTransmissionUL-r17. In response to sending the UE capability information message 206, the UE device 102 receives an updated relaxed C-DRX configuration 426 from the network 100 via an RRC Reconfiguration message 208 based on the actual capabilities of the UE device 102. In at least some embodiments, the UE device 102 locally stores the updated relaxed C-DRX configuration 426 in the storage mechanism 420.

[0051] In at least some embodiments, the number of operations performed by the UE device 102 to obtain the relaxed C-DRX configuration 426 and the legacy C-DRX configuration 428 is reduced. Instead of initially reporting actual capabilities when registering with the network 100, the UE device 102 initially reports that it is a legacy UE device that does not support PUSCH repetitions type A or lastTransmissionUL-r17. For example, when the UE device 102 is registering (or has registered) with the network 100, the C-DRX configuration optimization mechanism 136 determines if an up-to-date legacy C-DRX configuration 428 is locally available at, for example, the storage mechanism 420. If an up-to-date legacy C-DRX configuration 428 is not locally available, the C-DRX configuration optimization mechanism 136 triggers the UE device 102 to send a UE capability information message 206 to the network 100 indicating that the UE device 102 does not support PUSCH-RepetitionTypeA-rel16 or lastTransmissionUL-r17. This enables the UE device 102 to initially receive the

legacy C-DRX configuration 428 from network 100 and then proceed to obtain the relaxed C-DRX configuration 426 from the network 100 based on the actual capabilities of the UE device 102, as described above.

[0052] After the UE device 102 has identified or obtained the relaxed C-DRX configuration 426 and the legacy C-DRX configuration 428, the C-DRX configuration optimization mechanism 136 implements the energy-optimized C-DRX configuration mode 204. During this mode 204, when the UE device 102 is operating in an RRC Connected mode with C-DRX activated and receives a UL grant from the network 100, the C-DRX configuration optimization mechanism 136 determines if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions specified by the 3GPP release (e.g., Release 16) supported by the UE device 102. If the number of PUSCH repetitions indicated in the UL grant equals (or is higher than) the maximum number of PUSCH repetitions, the UE device 102 operates according to the relaxed C-DRX configuration 426. However, if the number of PUSCH repetitions indicated in the UL grant is lower than the maximum number of PUSCH repetitions, the C-DRX configuration optimization mechanism 136 adapts the C-DRX timers 210, such as the drx-InactivityTimer and drx-RetransmissionTimerUL to optimize the energy consumption of the device 102.

[0053] For example, the C-DRX configuration optimization mechanism 136 accesses the stored legacy C-DRX configuration 428 to determine the legacy drx-RetransmissionTimerUL parameters. The C-DRX configuration optimization mechanism 136 also accesses the stored relaxed C-DRX configuration 426 to determine the relaxed drx-RetransmissionTimerUL parameters. When the UE device 102 transmits data in DRX mode, the UE device 102 initiates the drx-RetransmissionTimerUL according to the relaxed drx-RetransmissionTimerUL parameters. After the expiration of the last PUSCH transmission, the C-DRX configuration optimization mechanism 136 suspends the drx-RetransmissionTimerUL and resumes the drx-RetransmissionTimerUL according to the legacy drx-RetransmissionTimerUL parameters. For example, when the C-DRX configuration optimization mechanism 136 suspends the drx-RetransmissionTimerUL, the UE

device 102 enters an inactive or low-power state (e.g., a sleep state) until the drx-RetransmissionTimerUL is resumed based on the legacy parameters, during which the UE device 102 enters an active state. Stated differently, the UE device 102 resumes the drx-RetransmissionTimerUL when aligned with the legacy C-DRX retransmission UL timer. In at least some embodiments, the C-DRX configuration optimization mechanism 136 also stops any inactivity timer still running after the expiration of the last PUSCH transmission or at another point in time.

[0054] In at least some embodiments, the network 100 uses may use a combination of an extended drx-inactivityTimer and the drx-RetransmissionTimerUL to ensure that UE device 102 is active for potential UL retransmissions. The combination of these two timers offers the network scheduler more flexibility to keep the UE device 102 awake for the next Physical Downlink Control Channel (PDCCH) monitoring opportunities. There is a discrete set of values for the timers based on C-DRX RRC configuration, so the combination of both times offers more options to the BS 104.

[0055] As such, instead of the UE device 102 being awake for the duration of the maximum number of PUSCH repetitions plus the legacy drx-RetransmissionTimerUL, as required by conventional relaxed C-DRX configurations, the UE device 102 is only awake for the scheduled PUSCH repetition(s) and sleeps until the drx-RetransmissionTimerUL is resumed according to the legacy C-DRX timer parameters, which optimizes energy consumption at the UE device 102. This energy optimization is illustrated in FIG. 3. For example, FIG. 3 shows a plurality of frames 302 (illustrated as frame 302-1 to 302-3), each including a plurality of slots 304, a drx-HARQ-RTT-TimerUL 306, a C-DRX retransmission UL timer 308 (illustrated as a legacy drx-RetransmissionTimerUL 308-1 and a relaxed drx-RetransmissionTimerUL 308-2 for illustration purposes), scheduled PUSCH transmissions 310, a maximum number of PUSCH repetitions 312, sleep opportunities 314 according to conventional relaxed C-DRX timers, sleep opportunities 316 according to the self-adaptive C-DRX timers of one or more embodiments, and energy savings 318 resulting from the self-adaptive C-DRX timers of one or more embodiments. It should be understood

[0056] In the example shown in FIG. 3, the maximum number of PUSCH repetitions specified by the 3GPP release (e.g., Release 16) supported by the UE device 102 is four, with each PUSCH repetition 312 (data transmission opportunity) being scheduled every five slots 304 across multiple frames 302. The UL grant received by the UE device 102, in this example, has scheduled a single PUSCH transmission 310 in the first frame 302-1. After the UE device 102 completes the last PUSCH transmission, which occurs at slot 4 of the first frame 302-1 in this example, the UE device 102 initiates the drx-HARQ-RTT-TimerUL 306. In this example, the duration of the drx-HARQ-RTT-TimerUL 306 is three slots. In conventional configurations, after expiration of the drx-HARQ-RTT-TimerUL 306, the UE device 102 starts the relaxed drx-RetransmissionTimerUL 308-2 and stays in an active state (e.g., stays awake) for the duration of this timer 308-2 plus the duration of the legacy drx-RetransmissionTimerUL 308-1. In the example shown in FIG. 3, when implementing a conventional relaxed C-DRX configuration 426, the UE device 102 stays away for a total of sixteen slots and only has three slots of sleep opportunity 314 during the drx-HARQ-RTT-TimerUL 306.

[0057] However, the C-DRX configuration optimization mechanism 136 described herein suspends the drx-RetransmissionTimerUL 308 after transmission of the last PUSCH transmission 310, which occurs at slot 4 of the first frame 302-1 in this example, and resumes the drx-RetransmissionTimerUL 308 according to the legacy drx-RetransmissionTimerUL parameters in the legacy C-DRX configuration 428. For example, the DRX configuration optimization mechanism 136 resumes the drx-RetransmissionTimerUL 308 at slot 0 of the third frame 302-3. Stated differently, the UE device 102 enters an inactive or low-power state (e.g., a sleep state) during the remaining PUSCH repetitions 312 and only enters into an active state (e.g., an awake state) when the drx-RetransmissionTimerUL 308 is resumed according to the legacy drx-RetransmissionTimerUL parameters. Therefore, in the example shown in FIG. 3, the UE device 102 has fifteen slots of sleep opportunity 316 when implementing the energy-optimized C-DRX configuration of one or more embodiments compared to the three slots of sleep opportunity 316 when

implementing a conventional relaxed C-DRX configuration, which results in at least twelve extra slots of energy savings 318.

[0058] The C-DRX configuration optimization mechanism 136, in at least some embodiments, provides additional energy savings by adapting the extended drx-inactivityTimer. For example, the C-DRX configuration optimization mechanism 136 limits the drx-inactivityTimer to the legacy drx-InactivityTimer value, as indicated in the legacy C-DRX configuration 428, without waiting for the completion of the last PUSCH repetition. In at least some embodiments, this further power-saving enhancement is activated during regular UE device operation after having sensed the network scheduler behavior. If the C-DRX configuration optimization mechanism 136 determines that the extended drx-inactivityTimer has not been used for a certain number of cycles, the C-DRX configuration optimization mechanism 136 limits the drx-inactivityTimer to the legacy drx-InactivityTimer value, as described above, to save additional power at the UE device 102.

[0059] FIG. 4 illustrates an example device diagram 400 of a UE device 102. In at least some embodiments, the device diagram 400 describes a UE device that implements the self-adaptive C-DRX timers and C-DRX configuration optimization techniques described herein. The UE device 102 may include additional functions and interfaces that are omitted from FIG. 4 for the sake of clarity. The UE device 102, in at least some embodiments, includes antennas 402, a radio frequency (RF) front end 404, and one or more RF transceivers 406 (e.g., a 3GPP 4G LTE transceiver 406-1 and a 5G NR transceiver 406-2) for communicating with one or more base stations 104 in a RAN 110, such as a 5G RAN, an E-UTRAN, a combination thereof, and so on. The RF front-end 404, in at least some embodiments, includes a transmitting (Tx) front end 404-1 and a receiving (Rx) front end 404-2. The Tx front end 404-1 includes components such as one or more power amplifiers (PA), drivers, mixers, filters, and so on. The Rx front end 404-2 includes components such as low-noise amplifiers (LNAs), mixers, filters, and so on. The RF front end 404, in at least some embodiments, couples or connects the one or more

transceivers 406, such as the LTE transceiver 406-1 and the 5G NR transceiver 406-2, to the antennas 402 to facilitate various types of wireless communication.

[0060] In at least some embodiments, the antennas 402 of the UE device 102 include an array of multiple antennas configured similarly to or different from each other. The antennas 402 and the RF front end 404, in at least some embodiments, are tuned to or are tunable to one or more frequency bands, such as those defined by the 3GPP LTE, 3GPP 5G NR, IEEE wireless local area network (WLAN), IEEE wireless metropolitan area network (WMAN), or other communication standards. In at least some embodiments, the antennas 402, the RF front end 404, the LTE transceiver 406-1, and the 5G NR transceiver 406-2 are configured to support beamforming (e.g., analog, digital, or hybrid) or in-phase and quadrature (I/Q) operations (e.g., I/Q modulation or demodulation operations) for the transmission and reception of communications with one or more base stations 104. By way of example, the antennas 402 and the RF front end 404 operate in sub-gigahertz bands, sub-6 GHz bands, above 6 GHz bands, or a combination of these bands defined by the 3GPP LTE, 3GPP 5G NR, or other communication standards.

[0061] In at least some embodiments, the antennas 402 include one or more receiving antennas positioned in a one-dimensional shape (e.g., a line) or a two-dimensional shape (e.g., a triangle, a rectangle, or an L-shape) for implementations that include three or more receiving antenna elements. While the one-dimensional shape enables the measurement of one angular dimension (e.g., an azimuth or an elevation), the two-dimensional shape enables two angular dimensions to be measured (e.g., both azimuth and elevation). Using at least a portion of the antennas 402, the UE device 102 can form beams that are steered or un-steered, wide or narrow, or shaped (e.g., as a hemisphere, cube, fan, cone, or cylinder). The one or more transmitting antennas may have an un-steered omnidirectional radiation pattern or may produce a wide steerable beam. Either of these techniques enables the UE device 102 to transmit a radio signal to illuminate a large volume of space. In some embodiments, the receiving antennas generate thousands of narrow steered beams

(e.g., 2000 beams, 4000 beams, or 6000 beams) with digital beamforming to achieve desired levels of angular accuracy and angular resolution.

[0062] The UE device 102, in at least some embodiments, includes one or more sensors 408 implemented to detect various properties such as one or more of temperature, supplied power, power usage, battery state, or the like. Examples of sensors include a thermal sensor, a battery sensor, a power usage sensor, and so on.

[0063] The UE device 102 also includes at least one processor 410. The processor 410, in at least some embodiments, is a single-core processor or a multiple-core processor composed of a variety of materials, such as silicon, polysilicon, high-K dielectric, copper, and so on. In at least some embodiments, the processor 410 is implemented at least partially in hardware, including, for example, components of an integrated circuit or a system-on-a-chip (SoC), a digital-signal-processor (DSP), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a complex programmable logic device (CPLD), other implementations in silicon or other hardware, or a combination thereof.

[0064] Examples of the processor(s) 410 include a communication processor, an application processor, microprocessors, DSPs, controllers, and so on. A communication processor, in at least some embodiments, is implemented as a modem baseband processor, software-defined radio module, configurable modem (e.g., multi-mode, multi-band modem), wireless data interface, wireless modem, or so on. In at least some embodiments, a communication processor supports one or more of data access, messaging, or data-based services of a wireless network, as well as various audio-based communication (e.g., voice calls). An application processor, in at least some embodiments, provides computing resources to applications executing on the UE device 102. For example, an application provides a self-contained operating environment that delivers system capabilities (e.g., graphics processing, memory management, and multimedia processing) to support applications executing on the UE device 102.

[0065] The UE device 102 further includes a non-transitory computer-readable storage media 412 (CRM 412). The computer-readable storage media described herein excludes propagating signals. The CRM 412, in at least some embodiments, includes any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), or Flash memory useable to store device data 414 of the UE device 102. In at least some embodiments, the device data 414 includes user data, multimedia data, beamforming codebooks, applications 416, a user interface(s) 418, an operating system of the UE device 102, and so on, which are executable by the processor(s) 410 to enable user-plane communication, control-plane signaling, and user interaction with the UE device 102. The user interface 418, in at least one embodiment, is configured to receive inputs from a user of the UE device 102, such as to receive input from a user that defines and or facilitates the self-adaptive C-DRX timers and C-DRX configuration optimizations described herein. In at least some embodiments, the user interface 418 includes a graphical user interface (GUI) that receives the input information via a touch input. In other instances, the user interface 418 includes an intelligent assistant that receives the input information via an audible input or speech. Alternatively, or additionally, the operating system of the UE device 102 is maintained as firmware or an application on the CRM 412 and executed by the processor(s) 410.

[0066] The CRM 412, in at least some embodiments, further includes a storage mechanism 420, such as a database or other data structure, and either or both of a communication manager 422 and a C-DRX configuration optimization module 424. The storage mechanism 420 stores one or more C-DRX configurations, such as a relaxed C-DRX configuration 426, a legacy C-DRX configuration 428, or a combination thereof. In at least some embodiments, the C-DRX configuration optimization mechanism 136 or another component of the UE device 102 updates/refreshes the stored C-DRX configurations in response to the expiration of a timer or any other criteria related to the cellular network 100. The network 100, in at least some embodiments, periodically sends the UE device 102 updated C-DRX configurations.

[0067] Alternatively, or additionally, either or both of the communication manager 422 and the C-DRX configuration optimization module 424, in at least some embodiments, are implemented in whole or part as hardware logic or circuitry integrated with or separate from other components of the UE device 102. In at least some embodiments, the communication manager 422 configures the RF front end 404, the LTE transceiver (modem) 406-1, the 5G NR transceiver (modem) 406-2, or a combination thereof to perform one or more wireless communication operations. The C-DRX configuration optimization module 424, in at least some embodiments, implements the C-DRX configuration optimization mechanism 136 described above.

[0068] The UE device 102 further includes one or more C-DRX timers 210, such as a C-DRX retransmission UL timer 430, a C-DRX inactivity timer 432, a combination thereof, or the like. One example of a C-DRX retransmission UL timer 430 is the drx-RetransmissionTimerUL, which is a timer mechanism that defines a specific duration the UE device 102 is to remain in an active state after the expiration of the drx-HARQ-RTT-TimerUL. One example of the C-DRX inactivity timer 432 is the drx-InactivityTimer, which is a timer mechanism that defines a duration of UE device inactivity, after which the UE device 102 transitions to an inactive or low-power state.

[0069] FIG. 5 and FIG. 6 are diagrams together illustrating an example method 500 of a UE device 102 adapting C-DRX timers 210 for optimizing energy consumption at the UE device 102 in accordance with at least some embodiments. The processes described below with respect to method 500 have been described above in greater detail with reference to FIG. 1 to FIG. 4. It should be understood that method 500 is not limited to the sequence of operations shown in FIG. 5, as at least some of the operations can be performed in parallel or in a different sequence. Moreover, in at least some embodiments, method 500 can include one or more different operations than those shown in FIG. 5 and FIG. 6.

[0070] At block 502, the UE device 102 registers with the cellular network 100. At block 504, the C-DRX configuration optimization module 424 determines if an up-to-date legacy C-DRX configuration 428 is locally available. If an up-to-date legacy C-

DRX configuration 428 is locally available, the method 500 proceeds to block 510. At block 506, if an up-to-date legacy C-DRX configuration 428 is not locally available, the C-DRX configuration optimization module 424 triggers the UE device 102 to send a UE capability information message 206 to the network 100 indicating that the UE device 102 is a legacy device, e.g., does not support either PUSCH Repetitions Type A or lastTransmissionUL-r17. Therefore, even though the UE device 102 does support PUSCH Repetitions Type A, the UE capabilities sent to the network 100 indicates that the UE device 102 does not support PUSCH Repetitions Type A so that the network 100 sends a legacy C-DRX configuration 428 to the UE device 102 instead of a relaxed C-DRX configuration 426. This set of UE capabilities that includes an indication that the UE device 102 does not support a specified feature despite the UE device 102 actually supporting this feature is referred to herein as a “legacy UE capability set” or a “set of legacy UE capabilities”.

[0071] At block 508, the UE device 102 receives and stores a legacy C-DRX configuration 428 from the network 100 based on the reported UE capabilities. At block 510, the C-DRX configuration optimization module 424 triggers the UE device 102 to send another UE capability information message 206 to the network 100 reporting the actual capabilities of the UE device 102, such as supporting PUSCH Repetitions Type A but not supporting lastTransmissionUL-r17. At block 512, the UE device 102 receives and stores a relaxed C-DRX configuration 428 from the network 100 based on the reported UE capabilities (e.g., supporting PUSCH Repetitions Type A but not supporting lastTransmissionUL-r17). The method 500 then proceeds to block 514 of FIG. 6.

[0072] At block 514, the UE device 102 enters into an RRC_Connected mode with C-DRX activated. At block 516, the UE device 102 receives a UL grant specifying a number of scheduled/configured PUSCH Repetitions that have been configured. At block 518, the C-DRX configuration optimization module 424 determines if the specified number of PUSCH repetitions is lower than the maximum number of PUSCH repetitions set by the network 100 or allowed by the standard supported by the UE device 102. At block 520, if the specified number of PUSCH repetitions is

equal to (or greater than) the maximum number of PUSCH repetitions, the UE device 102 proceeds to operate according to a default (regular) C-DRX configuration. At block 522, if the specified number of PUSCH repetitions is lower than the maximum number of PUSCH repetitions, the C-DRX configuration optimization module 424 adapts the C-DRX timers 210, such as the drx-RetransmissionTimerUL, the drx-InactivityTimer, a combination thereof, or the like. For example, at block 524, after the UE device 102 has completed the last PUSCH transmission of a set of scheduled PUSCH transmissions, the C-DRX configuration optimization module 424 suspends the C-DRX retransmission UL timer 430, such as the drx-RetransmissionTimerUL. In at least some embodiments, the C-DRX configuration optimization module 424 also stops any running C-DRX inactivity timers 432, such as the drx-InactivityTimer.

[0073] At block 526, the UE device 102 enters into an inactive or low-power state (e.g., a sleep state) instead of staying in an active state (e.g., an awake state) for the remaining PUSCH repetitions. At block 528, the C-DRX configuration optimization module 424 determines if the C-DRX retransmission UL timer 430 should be resumed. For example, the C-DRX configuration optimization module 424 determines if the legacy C-DRX configuration 428 indicates that the current time or slot (or subsequent slot) is where the C-DRX retransmission UL timer starts. If the C-DRX configuration optimization module 424 determines that the C-DRX retransmission UL timer 430 should not be resumed, the C-DRX configuration optimization module 424 continues to monitor when the C-DRX retransmission UL timer 430 should be resumed. At block 530, if the C-DRX configuration optimization module 424 determines that the C-DRX retransmission UL timer 430 should be resumed, the C-DRX configuration optimization module 424 resumes the C-DRX retransmission UL timer 430 according to the parameters/settings in legacy C-DRX configuration 428. Stated differently, the UE device 102 resumes the C-DRX retransmission UL timer 430 when aligned with the legacy C-DRX retransmission UL timer.

[0074] At block 532, the UE device 102 determines if any activities or operations are to be performed, such as network scheduled operations, radio resource management

(RRM) measurements, a combination thereof, or the like. At block 534, if the UE device 102 determines that no activities or operations are to be performed for at least a specified period of time, the UE enters into an inactive state. The method 500 then ends or returns to block 502 (or another block) to be repeated. At block 536, if the UE device 102 determines one or more activities or operations are to be performed for at least a specified period of time, the UE device 102 enters into an active state. The method 500 then ends or returns to block 502 (or another block) to be repeated. In some embodiments, certain aspects of the techniques described above may be implemented by one or more processors of a processing system executing software. The software comprises one or more sets of executable instructions stored or otherwise tangibly embodied on a non-transitory computer readable storage medium. The software can include the instructions and certain data that, when executed by the one or more processors, manipulate the one or more processors to perform one or more aspects of the techniques described above. The non-transitory computer readable storage medium can include, for example, a magnetic or optical disk storage device, solid state storage devices such as Flash memory, a cache, random access memory (RAM) or other non-volatile memory device or devices, and the like. The executable instructions stored on the non-transitory computer readable storage medium may be in source code, assembly language code, object code, or other instruction format that is interpreted or otherwise executable by one or more processors.

[0075] A computer readable storage medium may include any storage medium, or combination of storage media, accessible by a computer system during use to provide instructions and/or data to the computer system. Such storage media can include, but is not limited to, optical media (e.g., compact disc (CD), digital versatile disc (DVD), Blu-Ray disc), magnetic media (e.g., floppy disc, magnetic tape, or magnetic hard drive), volatile memory (e.g., random access memory (RAM) or cache), non-volatile memory (e.g., read-only memory (ROM) or Flash memory), or microelectromechanical systems (MEMS)-based storage media. The computer readable storage medium may be embedded in the computing system (e.g., system RAM or ROM), fixedly attached to the computing system (e.g., a magnetic hard

drive), removably attached to the computing system (e.g., an optical disc or Universal Serial Bus (USB)-based Flash memory), or coupled to the computer system via a wired or wireless network (e.g., network accessible storage (NAS)).

[0076] Note that not all of the activities or elements described above in the general description are required, that a portion of a specific activity or device may not be required, and that one or more further activities may be performed, or elements included, in addition to those described. Still further, the order in which activities are listed are not necessarily the order in which they are performed. Also, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present disclosure as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present disclosure.

[0077] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims. Moreover, the particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. No limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope of the disclosed subject matter. Accordingly, the protection sought herein is as set forth in the claims below.

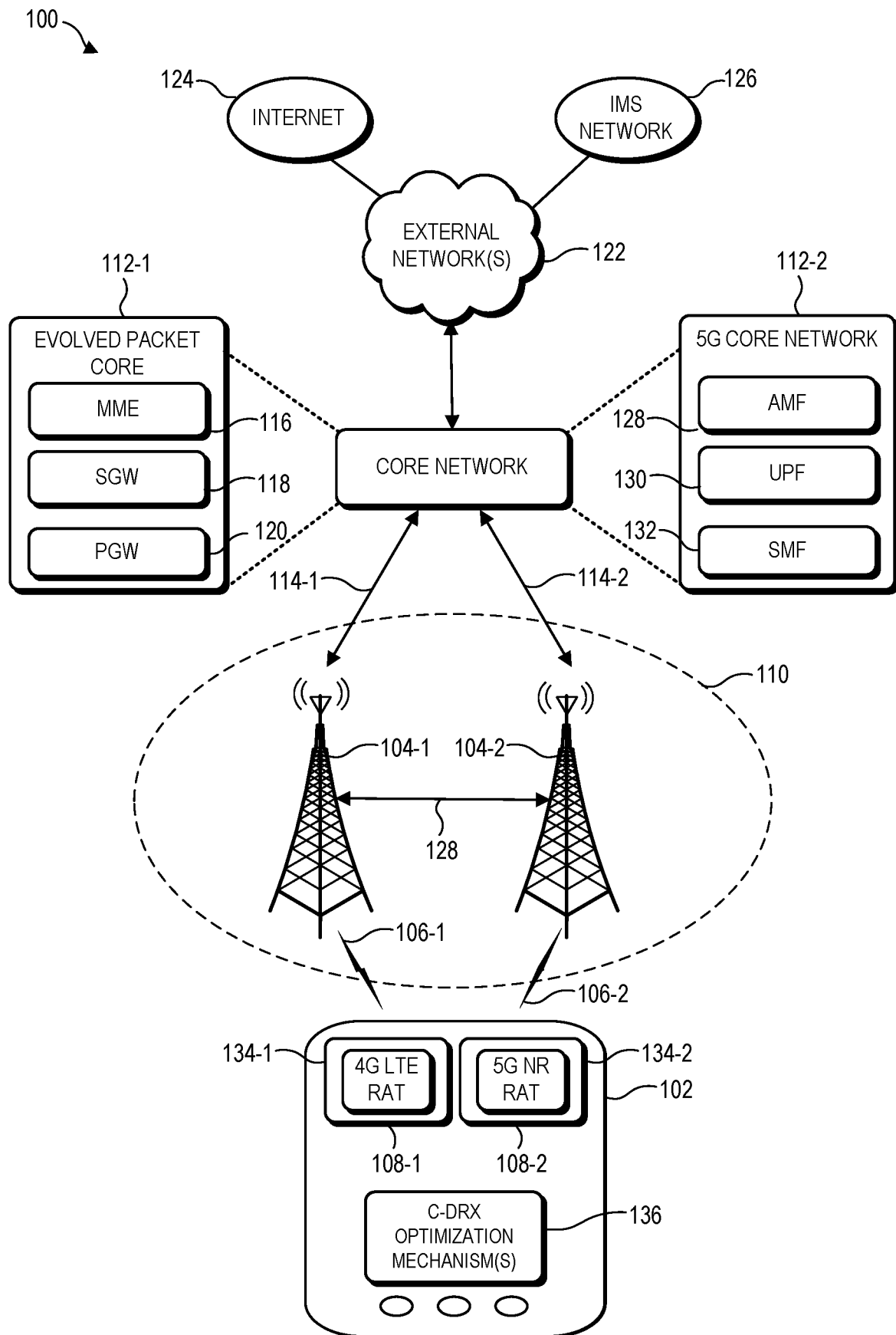
WHAT IS CLAIMED IS:

1. A method for configuring Connected Mode Discontinuous Reception (C-DRX) timers (210) at a user equipment (UE) device (102) in a cellular network (100), the method comprising:
responsive to completing a last Physical Uplink Shared Channel (PUSCH) transmission (524) in a set of scheduled PUSCH transmissions,
suspending a C-DRX retransmission timer (430); and
entering into a low-power state in response to suspending the C-DRX retransmission timer.
2. The method of claim 1, further comprising:
resuming the C-DRX retransmission timer according to one or more parameters indicated in a legacy C-DRX configuration (428); and
entering into an active state in response to resuming the C-DRX retransmission timer.
3. The method of any one of claims 1 or 2, further comprising:
responsive to completing the last Physical Uplink Shared Channel (PUSCH) transmission in a set of scheduled PUSCH transmission, stopping a C-DRX inactivity timer (432).
4. The method of any one of claims 1 to 3, further comprising:
initially configuring the C-DRX retransmission timer according to one or more parameters indicated in a relaxed C-DRX configuration (426).
5. The method of claim 4, wherein initially configuring the C-DRX retransmission timer comprises:
configuring the C-DRX retransmission timer to maintain the UE device in an active state for at least a duration of a maximum number of PUSCH repetitions set by the cellular network.

6. The method of claim 5, wherein entering into the low-power state comprises:
entering into the low-power state for any remaining PUSCH repetitions of the
maximum number of PUSCH repetitions.
7. The method of any one of claims 1 to 6, wherein suspending the C-DRX
retransmission timer comprises:
responsive to receiving an uplink (UL) grant (516), determining if a number of
scheduled PUSCH repetitions indicated in the UL grant is lower than a
maximum number of PUSCH repetitions (518); and
responsive to the number of scheduled PUSCH repetitions being lower than
the maximum number of PUSCH repetitions, suspending the C-DRX
retransmission timer when the last Physical Uplink Shared Channel
(PUSCH) transmission has been completed.
8. The method of any one of claims claim 1 to 7, further comprising:
responsive to sending a set of legacy capabilities (506) for the UE device to
the cellular network, receiving a legacy C-DRX configuration (428) from
the cellular network.
9. The method of claim 8, wherein sending the set of legacy capabilities comprises:
determining that an up-to-date legacy C-DRX configuration is not available at
the UE device; and
sending the set of legacy capabilities to the cellular network in response to the
legacy C-DRX configuration being unavailable at the UE device.
10. The method of claim 8, wherein the set of legacy capabilities includes at least
one indication that the UE device does not support a feature despite the UE
device actually supporting the feature.
11. The method of claim 8, further comprising:

responsive to sending a set of actual capabilities for the UE device to the cellular network, receiving a relaxed C-DRX configuration from the cellular network.

12. The method of claim 11, wherein sending the set of actual capabilities comprises:
sending the set of actual capabilities in response to receiving the legacy C-DRX configuration from the cellular network.
13. The method of claim 11, further comprising:
adjusting, based on one or more parameters of the legacy C-DRX configuration, one or more parameters of the C-DRX retransmission timer initially set based on the relaxed C-DRX configuration.
14. A user equipment device (102), comprising:
one or more radio frequency (RF) modems (406) configured to wirelessly communicate with at least one network (100);
one or more processors (410) coupled to the one or more RF modems; and
at least one memory (412) storing executable instructions, the executable instructions configured to manipulate at least one of the one or more processors or the one or more RF modems to perform the method of any of the preceding claims.
15. A computer-readable storage medium (412) embodying a set of executable instructions, the set of executable instructions to manipulate a user equipment device (102) to perform the method of any of claims 1 to 13.

**FIG. 1**

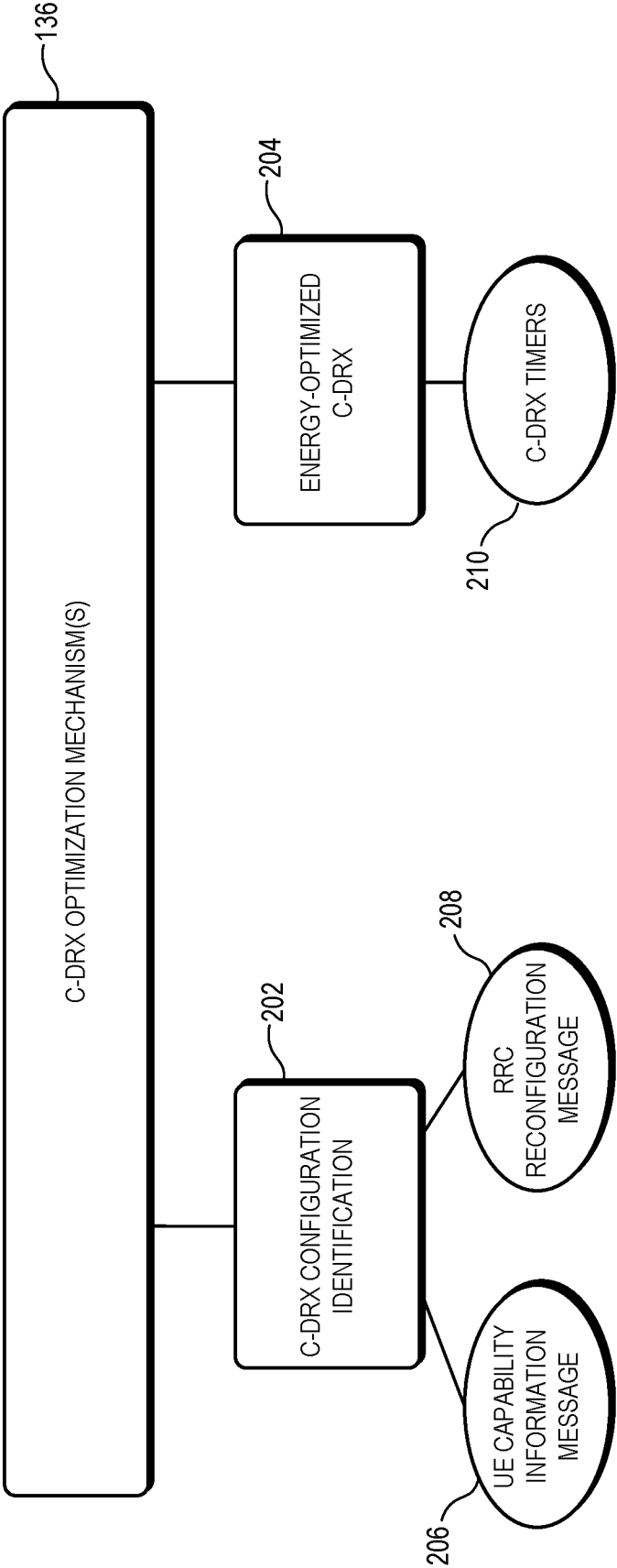


FIG. 2

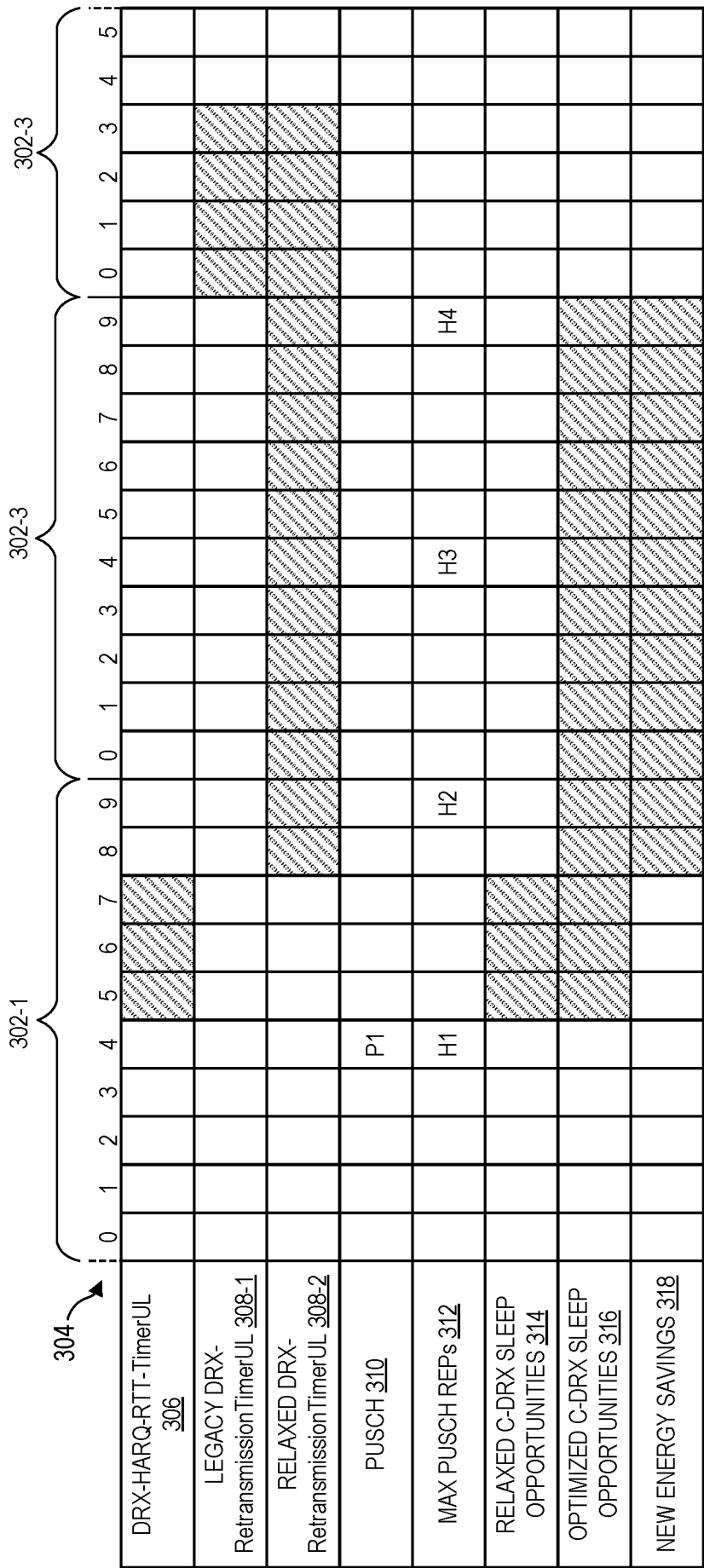
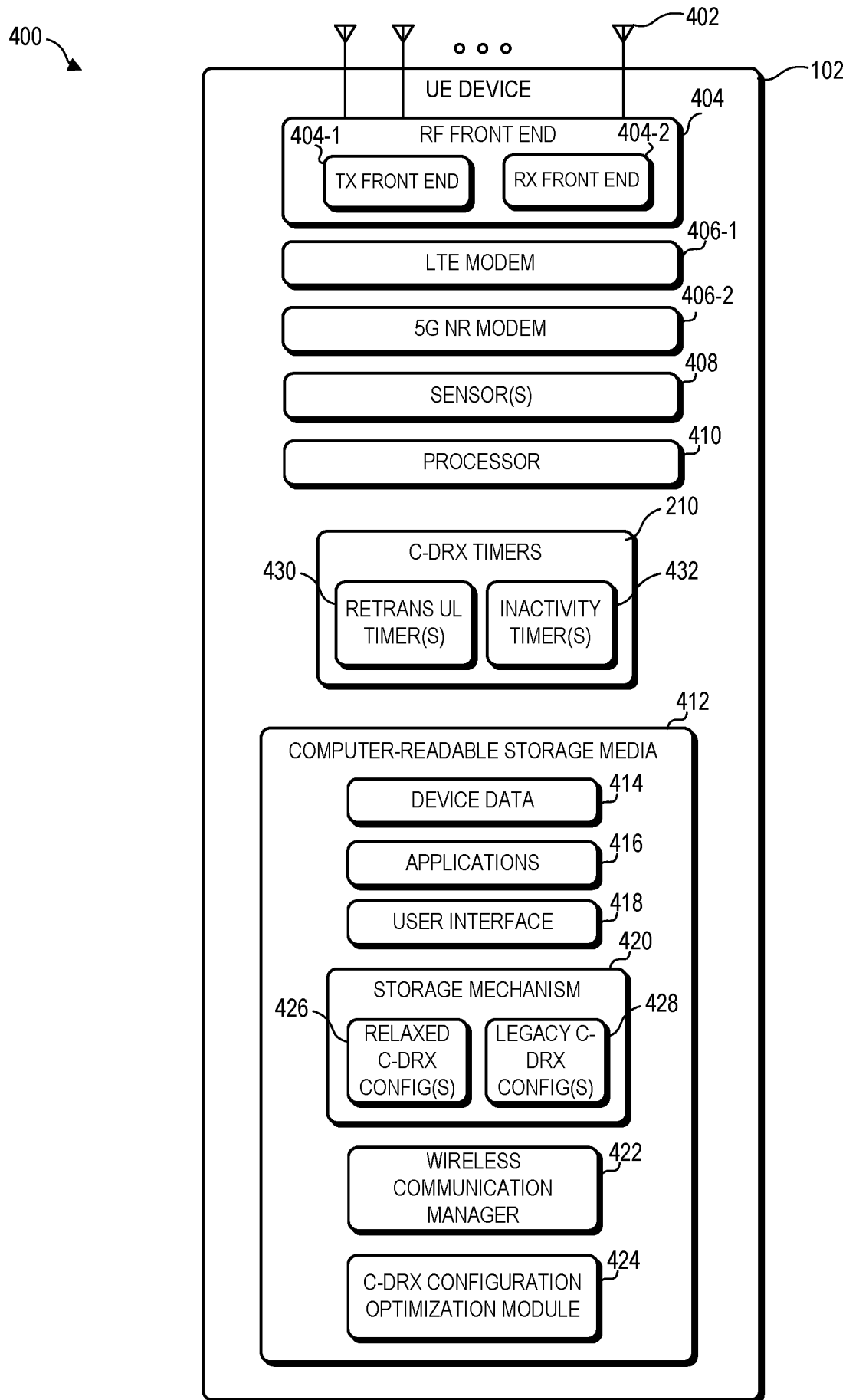


FIG. 3

**FIG. 4**

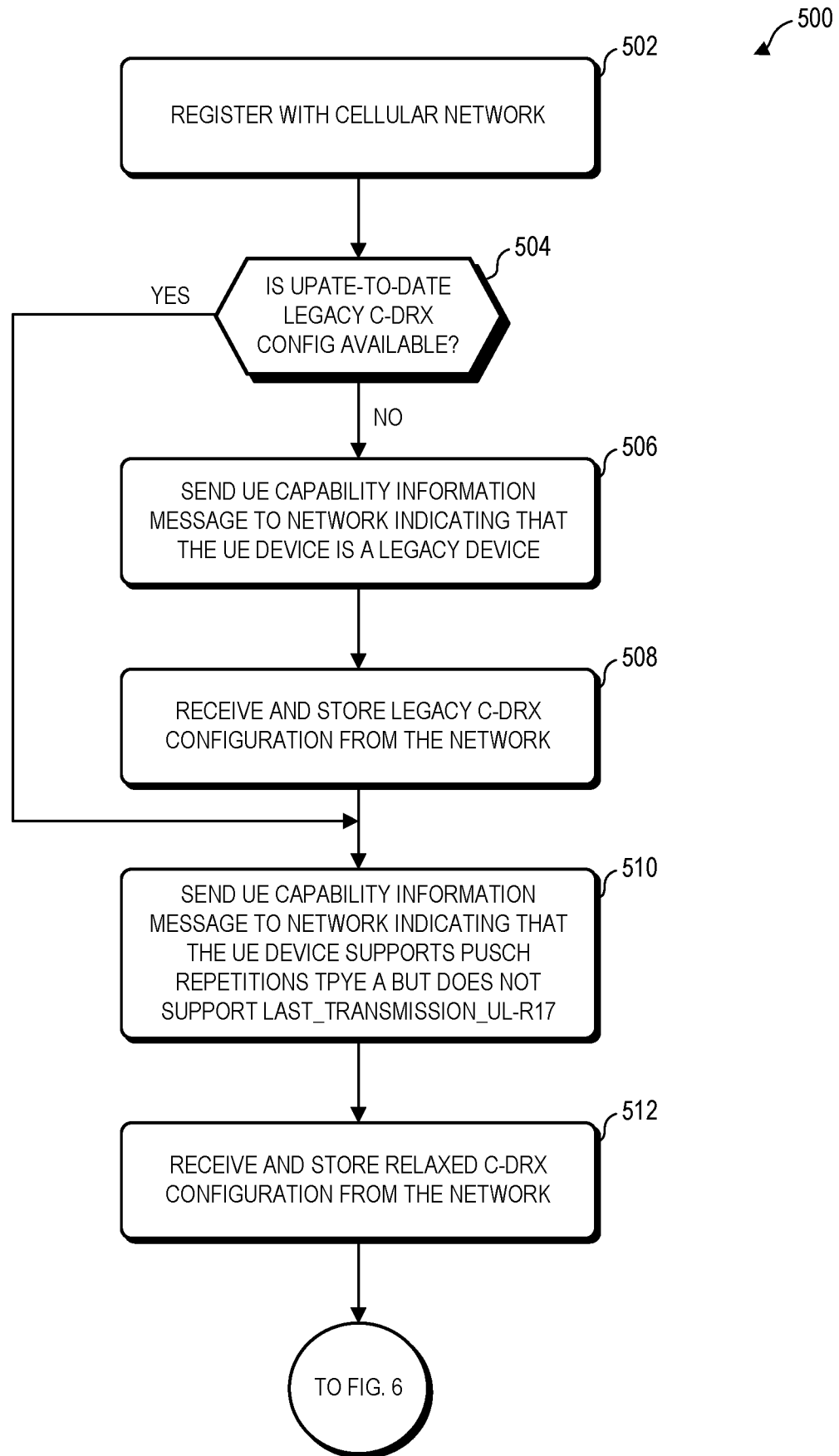
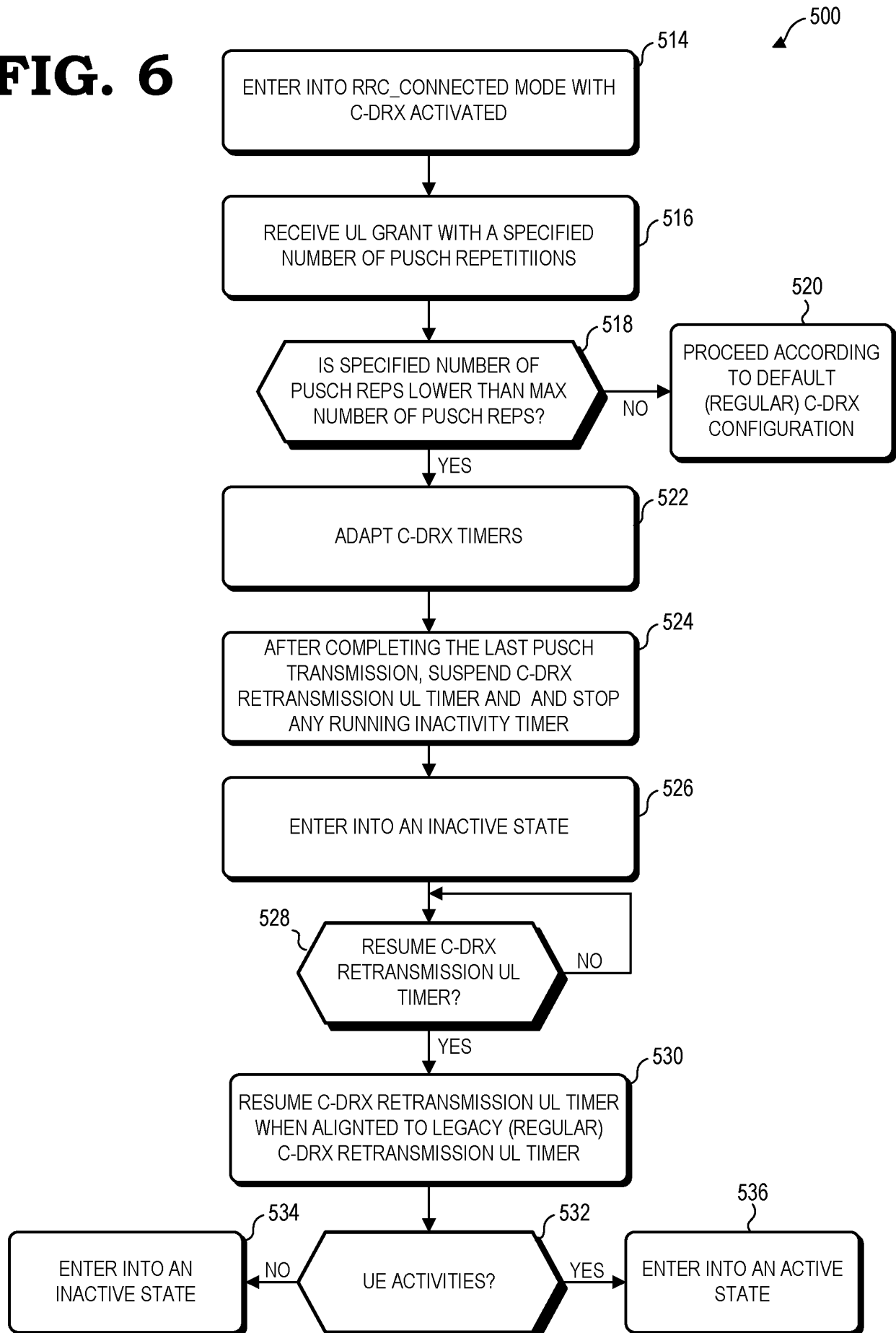
**FIG. 5**

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/084925

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W76/28 H04W52/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W H04L

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MODERATOR (VIVO): "FL summary#3 of DCI-based power saving adaptation", 3GPP DRAFT; R1-2106243, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. e-Meeting; 20210510 - 20210527 26 May 2021 (2021-05-26), XP052014330, Retrieved from the Internet: URL:https://ftp.3gpp.org/tsg_ran/WG1_RL1/T SGR1_105-e/Inbox/R1-2106243.zip R1-2106243_8 7 2_summary_RAN1_105e_dci_P2.docx [retrieved on 2021-05-26] section 2, in particular subsections 2.1 and 2.3, sections 4 and 5 - / - -	1 - 15



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

6 June 2024

Date of mailing of the international search report

18/06/2024

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2023/084925

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	----- MODERATOR (QUALCOMM INCORPORATED): "Moderator Summary #3 on XR specific power saving techniques", 3GPP DRAFT; R1-2210339, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. e-Meeting; 20221010 - 20221019 20 October 2022 (2022-10-20), XP052259807, Retrieved from the Internet: URL:https://ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_110b-e/Docs/R1-2210339.zip R1-2210339.docx [retrieved on 2022-10-20] sections 1, 2 and 3	1 - 15
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X	----- MAXIME GRAU ET AL: "UL considerations for Cell DTX/DRX", 3GPP DRAFT; R2-2310982; TYPE DISCUSSION, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. 3GPP RAN 2, no. Xiamen, CN; 20231009 - 20231013 29 September 2023 (2023-09-29), XP052529964, Retrieved from the Internet: URL:https://www.3gpp.org/ftp/TSG_RAN/WG2_RL2/TSGR2_123bis/Docs/R2-2310982.zip R2-2310982_UL considerations for Cell DTX DRX.docx [retrieved on 2023-09-29] sections 1-3 -----	1 - 15

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Information on patent family members

International application No

PCT/US2023/084925

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