**Abstract:** Devices and methods of linking LTE DRX mode and PCM in LWA scenarios are generally described. After the UE enters the DRX mode, the UE or eNB transmits to the AP an indication that the UE is to enter the PCM. After the UE exits the DRX mode, the UE or eNB transmits an indication to the AP that the UE is ready to receive data buffered at the AP. For PSM, the UE waits to receive a beacon frame from the AP indicating that data for the UE is buffered at the AP before transmitting a PS-Poll frame as the exit indication. For U-APSD mode, the UE transmits a trigger frame as the exit indication upon exiting the DRX mode without waiting to receive the beacon frame. The eNB transmits the indications through an internal interface if colocated with the AP or through an Xw interface otherwise.

**Title:** DEVICES AND METHODS OF DRX AND WLAN POWER SAVING MODE SYNCHRONIZATION FOR LWA

**Fig. 5**
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG). Published:

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DEVICES AND METHODS OF DRX AND WLAN POWER SAVING MODE SYNCHRONIZATION FOR LWA

PRIORITY CLAIM:

This application claims the benefit of priority to United States Provisional Patent Application Serial No. 62/250,426, filed November 3, 2015, and entitled "LTE DRX AND WLAN POWER SAVING MODE SYNCHRONIZATION FOR LWA," which is incorporated herein by reference in their entirety.

TECHNICAL FIELD

Embodiments pertain to radio access networks. Some embodiments relate to Discontinuous Reception (DRX) and Power Saving Mode (PSM) in cellular and wireless local area network (WLAN) networks, including Third Generation Partnership Project Long Term Evolution (3GPP LTE) networks and LTE advanced (LTE-A) networks as well as 4th generation (4G) networks and 5th generation (5G) networks.

BACKGROUND

With the increase in different types of devices communicating with various network device, usage of 3GPP LTE systems has increased. In particular, both typical user equipment (UE) such as cell phones and Machine Type Communications (MTC) UEs currently use 3GPP LTE systems. MTC UEs pose a particular challenges for a number of reasons, including small battery, power availability as well as non-mobility. MTC UEs may include, for example, sensors (e.g., sensing environmental conditions) or microcontrollers in appliances or vending machines and provide a variety of services, such as smart utility metering, intelligent tracking in supply chain, fleet management and theft tracking.

One continuing issue with UEs in the face of the increasing amount of power-draining applications and services, is the desire to increase battery life. This may be of particular desire in MTC UEs, which may be
designed to operate for years in, at best, difficult to reach locations. In particular UEs may use DRX and PSM independently, which may in some cases decrease the effectiveness of one or both types of power saving operations.

**BRIEF DESCRIPTION OF THE FIGURES**

[0005] In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The figures illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0006] FIG. 1 is a functional diagram of a wireless network in accordance with some embodiments.

[0007] FIG. 2 illustrates components of a communication device in accordance with some embodiments.

[0008] FIG. 3 illustrates a block diagram of a communication device in accordance with some embodiments.

[0009] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments.

[0010] FIG. 5 illustrates a method of DRX mode and PSM operation in accordance with some embodiments.

**DETAILED DESCRIPTION OF THE INVENTION**

[0011] 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.

[0012] FIG. 1 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network with various components of the network in accordance with some embodiments. As used herein, an LTE network refers to both LTE and LTE Advanced (LTE-A) networks as well as other versions of LTE networks to be developed. The network 1/0 may
comprise a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 101 and core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an SI interface 115. For convenience and brevity, only a portion of the core network 120, as well as the RAN 101, is shown in the example.

[0013] The core network 120 may include a mobility management entity (MME) 122, serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 101 may include evolved node Bs (eNBs) 104 (which may operate as base stations) for communicating with user equipment (UE) 102. The eNBs 104 may include macro eNBs 104a and low power (LP) eNBs 104b. The eNBs 104 and UEs 102 may employ the synchronization techniques as described herein.

[0014] The MME 122 may be similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 may manage mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 may terminate the interface toward the RAN 101, and route data packets between the RAN 101 and the core network 120. In addition, the serving GW 124 may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes.

[0015] The PDN GW 126 may terminate a SGi interface toward the packet data network (PDN). The PDN GW 126 may route data packets between the EPC 120 and the external PDN, and may perform policy enforcement and charging data collection. The PDN GW 126 may also provide an anchor point for mobility devices with non-LTE access. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in a single physical node or separate physical nodes.

[0016] The eNBs 104 (macro and micro) may terminate the air interface protocol and may be the first point of contact for a UE 102. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 101
including, but not limited to, RNC (radio network controller functions) such as
radio bearer management, uplink and downlink dynamic radio resource
management and data packet scheduling, and mobility management. In
accordance with embodiments, UEs 102 may be configured to communicate
orthogonal frequency division multiplexed (OFDM) communication signals with
an eNB 104 over a multicarrier communication channel in accordance with an
OFDMA communication technique. The OFDM signals may comprise a
plurality of orthogonal subcarriers.

The SI interface 115 may be the interface that separates the RAN
101 and the EPC 120. It may be split into two parts: the SI-U, which may carry
traffic data between the eNBs 104 and the serving GW 124, and the SI-MME,
which may be a signaling interface between the eNBs 104 and the MME 122.
The X2 interface may be the interface between eNBs 104. The X2 interface may
comprise two parts, the X2-C and X2-U. The X2-C may be the control plane
interface between the eNBs 104, while the X2-U may be the user plane interface
between the eNBs 104.

With cellular networks, LP cells 104b may be typically used to
extend coverage to indoor areas where outdoor signals do not reach well, or to
add network capacity in areas with dense usage. In particular, it may be
desirable to enhance the coverage of a wireless communication system using
cells of different sizes, macrocells, microcells, picocells, and femtocells, to boost
system performance. The cells of different sizes may operate on the same
frequency band, or may operate on different frequency bands with each cell
operating in a different frequency band or only cells of different sizes operating
on different frequency bands. As used herein, the term LP eNB refers to any-
suitable relatively LP eNB for implementing a smaller cell (smaller than a macro

cell) such as a femtocell, a picocell, or a microcell. Femtocell eNBs may be
typically provided by a mobile network operator to its residential or enterprise

customers. A femtocell may be typically the size of a residential gateway or
smaller and generally connect to a broadband line. The femtocell may connect
to the mobile operator’s mobile network and provide extra coverage in a range of
typically 30 to 50 meters. Thus, a LP eNB 104b might be a femtocell eNB since
it is coupled through the PDN GW 126. Similarly, a picocell may be a wireless
A communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB may generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it may be coupled to a macro eNB 104a via an X2 interface. Picocell eNBs or other LP eNBs LP eNB 104b may incorporate some or all functionality of a macro eNB LP eNB 104a. In some cases, this may be referred to as an access point base station or enterprize femtocell.

[0019] In some embodiments, the UE 102 may communicate with an access point (AP) 104c. The AP 104c may use only the unlicensed spectrum (e.g., WiFi bands) to communicate with the UE 102. The AP 104c may communicate with the macro eNB 104A (or LP eNB 104B) through an Xw interface. In some embodiments, the AP 104c may communicate with the UE 102 independent of communication between the UE 102 and the macro eNB 104A. In other embodiments, the AP 104c may be controlled by the macro eNB 104A and use LWA, as described in more detail below.

[0020] Communication over an LTE network may be split up into 10ms frames, each of which may contain ten 1ms subframes. Each subframe of the frame, in turn, may contain two slots of 0.5ms. Each subframe may be used for uplink (UL) communications from the UE to the eNB or downlink (DL) communications from the eNB to the UE. In one embodiment, the eNB may allocate a greater number of DL communications than UL communications in a particular frame. The eNB may schedule transmissions over a variety of frequency bands (fi and f1). The allocation of resources in subframes used in one frequency band and may differ from those in another frequency band. Each slot of the subframe may contain 6-7 OFDM symbols, depending on the system used. In one embodiment, the subframe may contain 12 subcarriers. A downlink resource grid may be used for downlink transmissions from an eNB to a UE, while an uplink resource grid may be used for uplink transmissions from a UE to an eNB or from a UE to another UE. The resource grid may be a time-frequency grid, which is the physical resource in the downlink in each slot. The smallest time-frequency unit in a resource grid may be denoted as a resource
element (RE). Each column and each row of the resource grid may correspond to one OFDM symbol and one OFDM subcarrier, respectively. The resource grid may contain resource blocks (RBs) that describe the mapping of physical channels to resource elements and physical RBs (PRBs). A PRE may be the smallest unit of resources that can be allocated to a UE. A resource block may be 180 kHz wide in frequency and 1 slot long in time. In frequency, resource blocks may be either 12 x 15 kHz subcarriers or 24 x 7.5 kHz subcarriers wide. For most channels and signals, 12 subcarriers may be used per resource block, dependent on the system bandwidth. In Frequency Division Duplexed (FDD) mode, both the uplink and downlink frames may be 10ms and frequency (full-duplex) or time (half-duplex) separated. In Time Division Duplexed (TDD), the uplink and downlink subframes may be transmitted on the same frequency and are multiplexed in the time domain. The duration of the resource grid 400 in the time domain corresponds to one subframe or two resource blocks. Each resource grid may comprise 12 (subcarriers) * 14 (symbols) = 168 resource elements.

[0021] Each OFDM symbol may contain a cyclic prefix (CP) which may be used to effectively eliminate Inter Symbol Interference (ISI), and a Fast Fourier Transform (FFT) period. The duration of the CP may be determined by the highest anticipated degree of delay spread. Although distortion from the preceding OFDM symbol may exist within the CP, with a CP of sufficient duration, preceding OFDM symbols do not enter the FFT period. Once the FFT period signal is received and digitized, the receiver may ignore the signal in the CP.

[0022] There may be several different physical downlink channels that are conveyed using such resource blocks, including the physical downlink control channel (PDCCH) and the physical downlink shared channel (PDSCH). Each subframe may be partitioned into the PDCCH and the PDSCH. The PDCCH may normally occupy the first two symbols of each subframe and carries, among other things, information about the transport format and resource allocations related to the PDSCH channel, as well as H-ARQ information related to the uplink shared channel. The PDSCH may carry user data and higher layer signaling to a UE and occupy the remainder of the subframe. Typically,
downlink scheduling (assigning control and shared channel resource blocks to UEs within a cell) may be performed at the eNB based on channel quality information provided from the UEs to the eNB, and then the downlink resource assignment information may be sent to each UE on the PDCCH used for (assigned to) the UE. The PDCCH may contain downlink control information (DCI) in one of a number of formats that indicate to the UE how to find and decode data, transmitted on PDSCH in the same subframe, from the resource grid. The DCI format may provide details such as number of resource blocks, resource allocation type, modulation scheme, transport block, redundancy version, coding rate etc. Each DCI format may have a cyclic redundancy code (CRC) and be scrambled with a Radio Network Temporary Identifier (RNTI) that identifies the target UE for which the PDSCH is intended. Use of the UE-specific RNTI may limit decoding of the DCI format (and hence the corresponding PDSCH) to only the intended UE.

[0023] The UE 102 may use DRX mode to extend battery life. In particular, the UE 102 may terminate monitoring the PDCCH for a predetermined amount of time when in DRX mode. The UE 102 may use different types of DRX mode, idle DRX mode (also called paging DRX), in which the UE 102 is in an idle state and does not have a Radio Resource Control (RRC) connection with the eNB 104, and active DRX mode, in which the UE 102 is in an RRC connected state. Idle DRX mode may be used by the UE 102 primarily to monitor the data and broadcast channels. The UE 102 in idle DRX mode may enter the RRC connected state from the idle state prior to monitoring the data channel. Active DRX mode may also permit power savings without the UE 102 entering the idle state, leading to a latency increase as the RRC connection may already be established. This may be beneficial for applications that do not use real-time data transfer, such as web browsing and instant messaging, in which the UE 102 may avoid continuous monitoring of the data connection and associated processing.

[0024] To establish a DRX mode, the eNB 104 may broadcast or transmit a DRX configuration to the UE 102 through the RRC connection, during initial setup or reconfiguration of the UE 102. The DRX configuration may indicate which DRX modes are to be used, as well as various timers
associated with the DRX mode(s). These timers may include on-duration, inactivity-timer, active-time, Hybrid Automatic Repeat Request (HARQ) round trip (RTT), drx-retransmissionTimer, and DRX Cycle Length.

[0025] The on duration timer may indicate the period of time (i.e., number of subframes) for the UE 102 to keep awake (i.e., prior to reentering DRX mode) after waking up from the DRX mode. The UE 102 may search for a PDCCH during this period.

[0026] The inactivity timer may indicate the period of time for the UE 102 to keep awake after successfully decoding a PDCCH indicating an original transmission, not a re-transmission. After the inactivity timer expires, the UE 102 may enter a short DRX cycle whose period is shorter than the normal long DRX cycle. If the short DRX cycle expires without data being received by the UE 102, the UE 102 may enter the DRX mode using the long DRX cycle.

[0027] The HARQ RTT timer may indicate the minimum interval time that retransmission of data from the eNB 104 is expected to arrive. The retransmission timer may indicate the maximum time period (and thus PDCCH subframes for the UE 102 to monitor) in which retransmission of data from the eNB 104 is expected.

[0028] The active timer may indicate the total time for the UE 102 to keep awake after waking up. During this time period, the UE 102 may monitor the PDCCH, including all states causing the UE 102 to be active (e.g., the on-duration begins, the UE 102 receives the PDCCH, or monitors a retransmission). The active timer may include the On Duration Timer, the Inactivity Timer, the DRX Retransmission Timer and the media access control (MAC) Layer Contention Resolution Timer, as well as any other time period that the UE 102 determines (e.g., via control signaling) it is to stay active for communication with the eNB 104. The DRX cycle length may indicate a period of time between succeeding DRX cycles.

[0029] When the UE 102 exits the DRX mode (whether a short or long DRX cycle), the UE 102 may start the on duration timer as well as starting to monitor the PDCCH in a specific subframe corresponding to a specific system frame number (SFN) provided in the DRX configuration to acquire a paging-radio network temporary identifier (P-RNTI). The UE 102 may thus exit the
DRX mode to determine whether it has been paged by the eNB 104. Paging may occur when the network has data to be transmitted to the UE 102, to update system information or to provide an Earthquake and Tsunami Warning System (ETWS) indication to the UE 102. The MME 122 may initiate the paging sequence by transmitting an S1AP paging message to all eNB 104s within the tracking area in which the UE 102 is registered. The MME 122 may then start the paging timer T3413. The eNB 104 may receive the S1AP paging message from the MME 122 and construct an RRC paging message for the UE 102 (along with possibly other UE 102s to be paged). The UE 102 may check for paging in a paging occasion once every DRX cycle, as above searching for its P-RNTI within the PDCCH of subframe belong to paging occasion.

[0030] A retransmission may be received at any point after expiry of the HARQ RTT timer (the shortest time in which to expect a retransmission). If data is to be retransmitted by the eNB 104 to the UE 102, the UE 102 may start the retransmission timer to start monitoring for the PDCCH carrying the retransmitted data. If the UE 102 receives control information, specifically a DRX command MAC control information unit, from the eNB 104 indicating that the UE 102 is to enter a sleep state, and the UE 102 may stop the on duration and inactivity timers, but not stop the retransmission timer. When the inactivity timer expires or the DRX command MAC control information unit is received, the UE 102 may start the DRX short or long cycle timer, dependent on which DRX mode is active.

[0031] In addition to DRX mode, which may be LTE-based, Power Save Mode (PSM) may be WLAN/WiFi-based. In PSM, the UE 102 may suspend radio activity after a variable but predetermined period of inactivity, and then wake up periodically based on a beacon frame transmitted by the AP 104b to see if any traffic for the UE 102 has been queued at the AP 104b. The inactive period may be about three 100 ms beacon frames. An unscheduled Automatic Power Save Delivery (U-APSD) mode may also be used as an asynchronous approach to power conservation. This is to say that the UE 102 may request queued traffic at any time, rather than waiting for the next beacon frame. The U-APSD mode may thus be more efficient with lighter traffic loads, like voice. The UE may also employ other power saving modes, such as Wireless
Multimedia Power Save (WMM-PS), Power Save Multi-Poll (PSMP) in which a time slot for a given UE may be reserved and other UEs temporarily silenced, Dynamic MIMO Power Save, which allows UEs using MIMO to shift to less-aggressive radio configurations (e.g., from 2x2 to 1x1) when traffic loads are light, and Wake on Wireless, which allows the AP 104b to initiate the waking of a dozing UE 102. The UE 102 may thus be able to enter a WLAN power conservation mode, which may include PSM and U-APSD mode.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 2 illustrates components of a UE in accordance with some embodiments. At least some of the components shown may be used in an eNB or MME, for example, such as the UE 102 or eNB 104 shown in FIG. 1. The UE 200 and other components may be configured to use the synchronization signals as described herein. The UE 200 may be one of the UEs 102 shown in FIG. 1 and may be a stationary, non-mobile device or may be a mobile device. In some embodiments, the UE 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208 and one or more antennas 210, coupled together at least as shown. At least some of the baseband circuitry 204, RF circuitry 206, and FEM circuitry 208 may form a transceiver. In some embodiments, other network elements, such as the eNB may contain some or all of the components shown in FIG. 2. Other of the network elements, such as the MME, may contain an interface, such as the S1 interface, to communicate with the eNB over a wired connection regarding the UE.

The application or processing circuitry 202 may include one or more application processors. For example, the application circuitry 202 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.
The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 204 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuitry 204 may interface with the application circuitry 202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, and/or other baseband processor(s) 204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 204 may include FFT, precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry 204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 204e of the baseband circuitry 204 may be configured to run elements of the protocol stack for signaling of the
PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 204f. The audio DSP(s) 204f may be include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 204 and the application circuitry 202 may be implemented together such as, for example, on a system on a chip (SOC).

[0036] In some embodiments, the baseband circuitry 204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 204 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry. In some embodiments, the device can be configured to operate in accordance with communication standards or other protocols or standards, including Institute of Electrical and Electronic Engineers (IEEE) 802.16 wireless technology (WiMax), IEEE 802.11 wireless technology (WiFi) including IEEE 802.11 ad, which operates in the 60 GHz millimeter wave spectrum, various other wireless technologies such as global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), universal mobile telecommunications system (UMTS), UMTS terrestrial radio access network (UTRAN), or other 2G, 3G, 4G, 5G, etc. technologies either already developed or to be developed.

[0037] RF circuitry 206 may enable communication with wireless networks using modulated electromagnetic radiation through a H2O1-solid medium. In various embodiments, the RF circuitry 206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network.
RF circuitry 206 may include a receive signal path which may include circuitry
to down-convert RF signals received from the FEM circuitry 208 and provide
baseband signals to the baseband circuitry 204. RF circuitry 206 may also
include a transmit signal path which may include circuitry to up-convert
baseband signals provided by the baseband circuitry 204 and provide RF output
signals to the FEM circuitry 208 for transmission.

[0038] In some embodiments, the RF circuitry 206 may include a receive
signal path and a transmit signal path. The receive signal path of the RF circuitry
206 may include mixer circuitry 206a, amplifier circuitry 206b and filter
circuitry 206c. The transmit signal path of the RF circuitry 206 may include
filter circuitry 206c and mixer circuitry 206a. RF circuitry 206 may also include
synthesizer circuitry 206d for synthesizing a frequency for use by the mixer
circuitry 206a of the receive signal path and the transmit signal path. In some
embodiments, the mixer circuitry 206a of the receive signal path may be
configured to down-convert RF signals received from the FEM circuitry 208
based on the synthesized frequency provided by synthesizer circuitry 206d. The
amplifier circuitry 206b may be configured to amplify the down-converted
signals and the filter circuitry 206c may be a low-pass filter (LPF) or band-pass
filter (EPF) configured to remove unwanted signals from the down-converted
signals to generate output baseband signals. Output baseband signals may be
provided to the baseband circuitry 204 for further processing. In some
embodiments, the output baseband signals may be zero-frequency baseband
signals, although this is not a requirement. In some embodiments, mixer circuitry
206a of the receive signal path may comprise passive mixers, although the scope
of the embodiments is not limited in this respect.

[0039] In some embodiments, the mixer circuitry 206a of the transmit
signal path may be configured to up-convert input baseband signals based on the
synthesized frequency provided by the synthesizer circuitry 206d to generate RF
output signals for the FEM circuitry 208. The baseband signals may be provided
by the baseband circuitry 204 and may be filtered by filter circuitry 206c. The
filter circuitry 206c may include a low-pass filter (LPF), although the scope of
the embodiments is not limited in this respect.
In some embodiments, the mixer circuitry 2.06a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 2.06a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 204 may include a digital baseband interface to communicate with the RF circuitry 206.

In some dual-mode embodiments, a separate radio circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

In some embodiments, the synthesizer circuitry 206d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 206d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry 206d may be configured to synthesize an output frequency for use by the mixer circuitry 206a of the RF circuitry 206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 206d may be a fractional N/N+1 synthesizer.
In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 204 or the applications processor 202 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 202.

Synthesizer circuitry 206d of the RF circuitry 206 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

In some embodiments, synthesizer circuitry 206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (flo). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

FEM circuitry 208 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 210, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry 208 may also include a transmit signal path which may include circuitry
configured to amplify signals for transmission provided by the RF circuitry 2.06 for transmission by one or more of the one or more antennas 210.

[0049] In some embodiments, the FEM circuitry 208 may include a TX/RX switch to switch between transmit mode and receive mode operation.

The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 210.

[0050] In some embodiments, the UE 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface as described in more detail below. In some embodiments, the UE 200 described herein may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 200 may include one or more user interfaces designed to enable user interaction with the system and/or peripheral component interfaces designed to enable peripheral component interaction with the system. For example, the UE 200 may include one or more of a keyboard, a keypad, a touchpad, a display, a sensor, a non-volatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, one or more antennas, a graphics processor, an application processor, a speaker, a microphone, and other I/O components. The display may be an LCD or LED screen including a touch screen. The sensor may include a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may communicate with
components of a positioning network, e.g., a global positioning system (GPS) satellite.

[0051] The antennas 210 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 210 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0052] Although the UE 200 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

[0053] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0054] FIG. 3 is a block diagram of a communication device in accordance with some embodiments. The device may be a UE or eNB, for
example, such as the UE 102 or eNB 104 shown in FIG. 1 that may be configured to track the UE as described herein. The physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. The communication device 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The communication device 300 may also include processing circuitry 306, such as one or more single-core or multi-core processors, and memory 308 arranged to perform the operations described herein. The physical layer circuitry 302, MAC circuitry 304 and processing circuitry 306 may handle various radio control functions that enable communication with one or more radio networks compatible with one or more radio technologies. The radio control functions may include signal modulation, encoding, decoding, radio frequency shifting, etc. For example, similar to the device shown in FIG. 2, in some embodiments, communication may be enabled with one or more of a WMAN, a WLAN, and a WPAN. In some embodiments, the communication device 300 can be configured to operate in accordance with 3GPP standards or other protocols or standards, including WiMax, WiFi, WiGig, GSM, EDGE, GERAN, UMTS, UTRAN, or other 3G, 3G, 4G, 5G, etc. technologies either already developed or to be developed. The communication device 300 may include transceiver circuitry 312 to enable communication with other external devices wirelessly and interfaces 314 to enable wired communication with other external devices. As another example, the transceiver circuitry 312 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.

The antennas 301 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some MIMO embodiments, the antennas 301 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

Although the communication device 300 is illustrated as having several separate functional elements, one or more of the functional elements may
be combined and may be implemented by combinations of software-configured elements, such as processing elements including DSPs, and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, FPGAs, ASICs, RFICs and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements. Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein.

[0057] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments. In alternative embodiments, the communication device 400 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 400 may operate in the capacity of a server communication device, a client communication device, or both in server-client network environments. In an example, the communication device 400 may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 400 may be a UE, eNB, PC, a tablet PC, a STB, a PDA, a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any communication device capable of executing instructions (sequential or otherwise) that specify actions to be taken by that communication device. Further, while only a single communication device is illustrated, the term "communication device" shall also be taken to include any collection of communication devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0058] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may
be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a communication device readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

Accordingly, the term "module" is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

Communication device (e.g., computer system) 400 may include a hardware processor 402 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 404 and a static memory 406, some or all of which may communicate with each other via an interlink (e.g., bus) 408. The communication device 400 may further include a display unit 410, an alphanumeric input device 412 (e.g., a keyboard), and a user interface (UI) navigation device 414 (e.g., a mouse). In an example, the display unit 410, input device 412 and UI navigation device 414 may be a touch screen display. The communication device 400 may additionally include a storage device (e.g., drive unit) 416, a signal generation device 418 (e.g., a speaker), a network interface device 420, and one or more sensors 421, such as a global positioning system.
(GPS) sensor, compass, accelerometer, or other sensor. The communication
device 400 may include an output controller 428, such as a serial (e.g., universal
serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near
field communication (NFC), etc.) connection to communicate or control one or
more peripheral devices (e.g., a printer, card reader, etc.).

The storage device 416 may include a communication device
readable medium 422 on which is stored one or more sets of data structures or
instructions 424 (e.g., software) embodying or utilized by any one or more of the
techniques or functions described herein. The instructions 424 may also reside,
completely or at least partially, within the main memory 404, within static
memory 406, or within the hardware processor 402 during execution thereof by
the communication device 400. In an example, one or any combination of the
hardware processor 402, the main memory 404, the static memory 406, or the
storage device 416 may constitute communication device readable media.

While the communication device readable medium 422 is
illustrated as a single medium, the term "communication device readable
medium" may include a single medium or multiple media (e.g., a centralized or
distributed database, and/or associated caches and servers) configured to store
the one or more instructions 424.

The term "communication device readable medium" may include
any medium that is capable of storing, encoding, or carrying instructions for
execution by the communication device 400 and that cause the communication
device 400 to perform any one or more of the techniques of the present
disclosure, or that is capable of storing, encoding or carrying data structures used
by or associated with such instructions. Non-limiting communication device
readable medium examples may include solid-state memories, and optical and
magnetic media. Specific examples of communication device readable media
may include: non-volatile memory, such as semiconductor memory devices
(e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically
Erasable Programmable Read-Only Memory (EEPROM)) and flash memory
devices; magnetic disks, such as internal hard disks and removable disks;
magneto-optical disks; Random Access Memory (RAM); and CD-ROM and
DVD-ROM disks. In some examples, communication device readable media
may include non-transitory communication device readable media. In some examples, communication device readable media may include communication device readable media that is not a transitory propagating signal.

The instructions 424 may further be transmitted or received over a communications network 426 using a transmission medium via the network interface device 420 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®, IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 420 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 426. In an example, the network interface device 420 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), MIMO, or multiple-input single-output (MISO) techniques. In some examples, the network interface device 420 may wirelessly communicate using Multiple User MIMO techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the communication device 400, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

As the demand for communicating data (e.g., voice and video) continues to increase, LTE networks may experience increasingly heavy communication traffic, leading to adverse network effects such as reduced data rates, increased delay and increased interference. There is a limit, however, to increasing LTE network capacity. Operators have increasingly turned to
unlicensed spectrum use in a WLAN network, such as an IEEE 802.11 network including a WiFi network, that service the location to alleviate network traffic on the LTE licensed spectrum and increase network communication capability.

UEs and eNBs that operate in the unlicensed spectrum in addition to the licensed LTE band may be referred to as LAA UEs and LAA eNBs, which are generally referred to herein merely as UEs and eNBs. In some embodiments, a local transmitter, such as a LP eNB or WLAN access point (AP) may communicate data directly between the core network and the UE. Alternatively, another eNB, such as a macro or local eNB, may act as an intermediary, providing data from the core network to the AP or from the AP to the core network via the WLAN Termination (VVT). In this case, the eNB may control the AP, scheduling at least some packets to be sent to the UE to the AP, thereby providing LTE/WLAN Aggregation (LWA) capabilities according to 3GPP RAN2 and/or 3GPP RAN3 working group (WG) technical specifications (RAN2: TS 36.300, TS 36.331; RAN3: TS 36.461, 36.462, 36.463, 36.464 and 36.465). In LWA, a UE in RRC__CONNECTED mode is configured by the eNB to utilize radio resources of LTE and WLAN. In some embodiments the eNB and the AP may be integrated into the same device. In other non-collocated embodiments, the eNB and the AP may be connected via the WT using an Xw interface.

[0066] UEs and eNBs may operate, over a particular time period, in the unlicensed spectrum in addition to or instead of the licensed LTE band and in addition to LWA. In some embodiments, carrier aggregation (CA) may be used to increase bandwidth, and thus bitrate, by using multiple component carriers (CCs) to form a larger overall transmission bandwidth. The channels (frequency ranges) of the CCs can either be adjacent or separated by a substantial distance, e.g., being in different frequency bands. Thus, for example, CA may be used to aggregate carriers in the licensed band and carriers in the unlicensed spectrum to increase capacity. In other embodiments, traffic may be offloaded from the LTE network to the WLAN network without using CA.

[0067] In some embodiments, LWA may be provided based on an architecture with aggregation below Packet Data Convergence Protocol (PDCP) and LWA split and switched bearer configuration and optionally a General Packet Radio Service (GPRS) Tunneling Protocol (GTP)-User (GTP-U) tunnel.
between the eNB and the WT. The GTP-U tunnel may be employed in the user plane to carry LTE user data traffic between the tunnel endpoints. The WT may be located in either an AP, an Admission Control (AC) or deployed as a standalone network node.

To make efficient use of the LTE and WLAN networks when LWA (or CA) is used, the UE may, as shown in FIGS. 2-4, have one or more transceivers configured to communicate with the eNB and the AP. In some embodiments, the UE may have separate transceivers to communicate with the eNB and the AP. As above, two modes of operation may allow the UE to conserve power: LTE-based active DRX, which may operate when the UE is in the RRC Connected state, and WLAN-based power conservation mode (PCM), which may include PSM and U-APSD mode. The DRX and PCM may operate independently, which may result in inefficient power saving. For example, even though the UE is in a DRX cycle, the UE may not be in PCM and thus the WLAN modem may be in operation. Note that although DRX is referred to herein, in other embodiments the discussion may be applied to extended DRX (eDRX) mode.

As described above, in the active DRX mode, the UE remains in the RRC connected mode. The eNB or MME may configure the active, on-duration and inactivity timer values to the UE in an RRC Connection Reconfiguration message, e.g., when the UE first connects to the core network or during handover. The UE may enter the active DRX mode after the inactivity timer expires. When the UE awakes from active DRX mode, the UE may wait for an on-duration time to decode the PDCCH. The eNB or MME may also configure the short and long DRX cycle during which the UE is in sleep mode.

PCM may be controlled by the UE (also called a station (STA)). The UE may send a PCM frame with a Power Management bit set (and no data) to the AP and then enter PCM. In some embodiments, the frame may be a null frame, without actual data; in other embodiments, the frame may have uplink data (and the UE is able to determine and to indicate that the UE is to enter PSM with the last packet the UE sends to the AP). The AP, having received the PCM frame, may start buffering packets for that UE, and when packets are buffered for the UE, may indicate so to the UE by setting an information element in a
traffic indication map (TIM) field in a beacon frame. The UE may wake up periodically to receive beacon frames. In PSM, if the UE detects that the AP has buffered packets for the UE, the UE may send a trigger frame such as a Power-Save Poll (PS-Poll) frame to indicate that the UE is able to receive the packets.

[0071] In various embodiments, the UE may synchronize the DRX mode and the PCM. In some embodiments, when the UE enters the DRX mode, the UE may also enter the PCM after transmitting information to the eNB. In particular, in response to expiration of the active timer, the UE may transmit to the AP a PCM frame and then enter the PCM. The PCM frame may be an IEEE 802.11 frame (e.g., a null frame) with the Power Management bit set. Tims, in this embodiment although the eNB may control the DRX mode, by initially transmitting to the UE the DRX mode timing parameters, the UE may control the PCM.

[0072] In some embodiments, whether or not the UE enters the PCM and transmits the PCM frame containing the Power Management bit may depend on which DRX cycle the UE has entered. For example, in some embodiments, the UE may enter PCM at essentially the same point that the UE enters the long DRX cycle, but may not enter PCM (or transmit the null frame) when the UE enters the short DRX cycle. In other embodiments, the UE may enter PCM independent of which DRX cycle the UE enters.

[0073] In some embodiments, whether or not the UE enters the PCM may depend on recent history of whether the AP has data to transmit to the UE. In some embodiments, the UE may enter the DRX mode on the LTE band, wait a predetermined amount of time after receiving the last packet from the AP and then enter the PSM. For example, the UE upon entering the DRX mode may wait until the AP indicates via a beacon frame that no more data is buffered for the UE before transmitting the null frame to the AP. In other embodiments, the UE may immediately transmit the frame to the AP regardless of whether the AP has data buffered for the UE. In some embodiments, whether or not the UE enters the PCM may depend on the amount of data the AP has buffered for the UE. For example, if the AP has a large amount of data buffered and is able to indicate this to the UE, or the UE has been receiving data constantly over an immediately previous period (i.e. the recent data transmission history), the UE
may determine not to enter the PCM as the UE may determine that the buffered data may be too stale by the time the UE exits the PCM. In this case, the UE may wait a predetermined amount of time or delivered frames prior to entering the PCM or may wait an amount of time or delivered frames proportional to the amount of data buffered by the AP.

[0074] In some embodiments, whether or not the UE enters the PCM may depend both on whether the AP has data to transmit to the UE and in which DRX cycle the UE is entering. For example, the UE having entered the short DRX cycle may wait until the AP indicates via a beacon frame that no more data is buffered for the UE before transmitting the frame to the AP and having entered the long DRX cycle may immediately transmit the frame to the AP regardless of whether the AP has data buffered for the UE. Alternatively, the UE having entered the DRX cycle may wait for a predetermined time after receiving the last packet from the AP before entering the PCM mode by transmitting the PCM frame with the power management bit set.

[0075] As above, once the UE has entered the PSM and detected in a beacon frame a TIM indicating that the AP has stored frames for the UE, the UE may exit the PSM and transmit a PS-Poll frame to the AP to indicate that the UE is able to receive the packets. In some embodiments, the UE may wait to exit the DRX mode. The UE may be constrained to wait for up to 100 ms after exiting the DRX mode to receive the latest beacon frame from the AP before transmitting a PS-poll frame, causing a delay in packet reception from the AP.

[0076] As above, U-APSD mode is similar to the PSM in that the AP may buffer downlink packets for the UE. However, unlike the PSM, in the U-APSD mode the UE may not wait for a listen interval to detect the beacon frame, instead, as soon as the UE exits the U-APSD mode, the UE may send a trigger frame such as a Quality of Service (QoS) or QoS data frame (instead of a PS-Poll) to indicate that the UE is able to accept downlink packets whenever the AP is ready to transmit the packets to the UE. Unlike a PS-poll, a QoS frame can be sent by the UE at any time (e.g., as soon as the UE exits the DRX mode), so the UE may not wait to decode the beacon frame to determine whether the AP has data for the UE.
In some embodiments, since the UE may be able to transmit a U-APSD mode trigger frame at any time, the UE may transmit the U-APSD mode trigger frame prior to the UE exiting the DRX mode. This may permit better synchronization between the UE active cycle and WLAN.

In some embodiments, the 802.11 power saving signaling between the UE and the AP may not be used. Both the LTE and WLAN power saving modes may be controlled by the DRX mode, as determined by the eNB. The eNB and the AP may be connected and synchronized, such as in the collocated deployment scenario in which the eNB and the AP are integrated into the same device. In some embodiments, the eNB and the AP may be non-collocated and connected via the WT using the Xw interface. The eNB and the AP may be synchronized, e.g., using Xw or other methods such as GPS, and the Xw interface may support power saving signaling.

In some embodiments, the eNB may indicate DRX mode parameters (e.g., timers, UE ID) for the UE to the AP prior to the UE entering DRX mode. In particular, the eNB may transmit to the AP the DRX mode parameters either in a new Xw-Application Protocol (AP) message passed via the Xw interface or in a modified message containing a new information element. The modified message may be, for example, an eNB Initiated WT Modification Preparation Xw-AP message or LWA activation message (WT Addition Preparation Xw-AP message) to the AP. Other new messages, in embodiments below in which the eNB rather than the UE controls the PSM, may be used to indicate that the UE is entering the DRX mode and thus the PCM (i.e., to terminate packet transmission from the AP to the UE). In some embodiments, the eNB may transmit an indication of entry of the UE into the DRX mode and the PCM separately, e.g., the AP suspending transmission to the UE only after receiving the PCM such that the eNB may continue to transmit data to the AP for transmission to the LTE or the AP may continue to transmit and empty the AP buffer. The eNB may similarly transmit a message to the AP to indicate that the UE is exiting the DRX mode and thus simultaneously exiting the PCM.

In some embodiments, when the UE enters a DRX mode, the UE may also enter the PCM without the UE notifying the AP using IEEE 802.11
signaling (referred to herein as a virtual WLAN power saving mode). In one embodiment, the eNB serving the UE, which may retain knowledge of the DRX cycle for the UE, may transmit a notification to the AP serving the UE that the UE is in the DRX mode. The eNB may communicate the DRX information to the AP, for example, via an internal interface in the collocated case or via the WT using the Xw control plane interface in the non-collocated case. To support the virtual WLAN power saving mode in a non-collocated deployment in which the eNB and AP are connected via the Xw interface, control plane signaling on the Xw interface between the eNB and the WLAN infrastructure may allow the eNB to indicate to the WT when UE enters and exits the DRX mode. This may be implemented, for example, with an Xw class 2 procedure/UE associated signaling. The signaling may include an Xw-AP DRX message containing the UE ID and DRX start/stop indication and/or UE DRX configuration (e.g. DRX-Config IE defined in TS 36.331).

The AP, having received an indication from the eNB that the UE is in the DRX mode, may determine not to send downlink WLAN packets to the UE during the DRX cycle. When the UE exits the DRX mode, the eNB may communicate this information to the AP. The AP may then begin transmitting packets stored for the UE upon receiving the information, without receiving a trigger frame from the UE. The eNB and AP may thus reinstate data transmission to the UE upon determining that the UE has exited the DRX mode and/or the PCM.

Moreover, in embodiments in which the eNB schedules downlink packets to both LTE and WLAN links, the eNB may not transmit downlink packets to the AP via the WT using the Xw user plane interface during the DRX cycle. The eNB may simply delay transmission of the packets to the AP. In other embodiments, the eNB may continue to transmit packets for the UE to the AP and may indicate, as above, via the Xw control plane interface that the UE has entered the DRX mode and the AP should buffer the packets for the UE, perhaps delaying the buffering if a large number of packets are already buffered. In this case, the AP may later transmit an indication to the eNB to stop transmitting packets for the UE to the AP, e.g., after a predetermined amount of data for the UE has been buffered by the AP. The amount of data for the UE
may be dependent on the storage capabilities of the AP, the UE characteristics such as QoS, as well as the amount of data to be transmitted to other UEs (and perhaps characteristics of the UEs).

[0083] In some embodiments, the determination of whether the eNB communicates the DRX mode indication to the AP and/or whether the eNB transmits packets to the AP for transmission to the UE may at least in part be based on other factors. The determination may be based, for example, on the DRX cycle of the UE. As above, the eNB may either or both determine not to transmit the DRX mode indication to the AP and/or packets to the AP for transmission to the UE when the UE is in the short DRX cycle, but may do so when the UE is in the long DRX cycle. The determination may be based, in another example, on the amount of data for the UE already stored in the AP and/or the UE QoS. In these embodiments, the UE may suspend entry into the PCM until a predetermined event has occurred, e.g., the UE entering the long DRX cycle or having received a predetermined number of packets from the AP after having entered the DRX mode.

[0084] In some embodiments, the eNB may indicate to the UE whether the UE is to indicate to the AP whether the UE has entered DRX mode. This information may be provided to the UE in higher layer signaling, such as via a dedicated RRC message, e.g. RRC Connection Reconfiguration, a broadcast RRC message, e.g. SIB, or other higher layer signaling. Which of the UE or the eNB indicates to the AP entry of the UE into the DRX mode, may be determined based on the type of UE or other UE characteristics. For example, normal UEs, such as smart phones, may transmit the indication to the AP while other UEs, such as MTC UEs, may permit the eNB to communicate this information to the AP. In some embodiments, the UE may make the determination of whether the UE or the eNB is to communicate entry of the UE into the DRX mode to the AP and transmit this determination to the eNB.

[0085] FIG. 5 illustrates a method of DRX mode and PCM operation in accordance with some embodiments. The operations shown in FIG. 5 may be performed by the UE, eNB and/or AP shown in FIGS. 1-4. At operation 502, the UE may enter DRX mode. The DRX mode may be the active DRX mode in which the UE is still in RRC connection to the eNB or the idle DRX mode.
some embodiments, the DRX mode may be an eDRX mode, which has an inactivity timer much greater than the DRX mode. The UE may use a short or long DRX cycle, dependent on the timing and configuration indicated by the RRC Connection Reconfiguration message transmitted to the UE.

At operation 504, an indication may be transmitted to the AP that the UE has entered the DRX mode and/or that the UE is to enter PCM. In various embodiments, the UE or eNB may transmit the indication to the AP. The determination of which device is to transmit the indication to the AP and/or the timing of the transmission may be based on the type of UE, the amount of data the AP has already buffered for the UE, and the DRX cycle the UE has entered, among others. The UE may also enter PCM at this point, thereby synchronizing the DRX mode and PSM at the UE. In some embodiments, when the indication is sent from the UE to the AP, the indication may be sent after the UE enters PCM, and when the indication is sent from the eNB to the AP, the indication may be sent prior to the UE entering the DRX mode.

In some embodiments, the UE may transmit a frame to the AP. The frame may be a PCM frame with the Power Management bit set (i.e., to 1). In some embodiments, the eNB may transmit an indication to the AP. The eNB and AP may be collocated, in which case, the indication may be transmitted between logical components via an internal interface within the eNB. In other embodiments in which the eNB and AP are not collocated, the eNB may communicate the DRX entry indication to the AP via the WT using the Xw control plane interface. In some embodiments, the indication may be transmitted to the AP (either from the UE or the eNB) prior to the UE entering the DRX mode and/or PCM. At this point the DRX mode and PCM may thus be synchronized at the eNB and AP as well as the UE.

After the UE has entered both the DRX mode and PCM, the UE may determine at some point that the DRX cycle time has elapsed. At operation 508, the UE may exit DRX mode and to monitor the PDCCH. The UE may also exit the PCM in response to exiting the DRX mode so that the PSM and DRX mode in the UE are synchronized - either both on or both off. The UE may detect in a beacon frame a TIM indicating that the AP has stored frames for the UE.
At operation 510, an indication that the UE has exited DRX mode may be transmitted to the AP. In some embodiments, the UE may transmit a PS-Poll frame to the AP to indicate that the UE is able to receive buffered packets. The UE may wait for a predetermined amount of time after exiting the DRX mode before transmitting a PS-poll.

In some embodiments, the UE may be in U-APSD mode instead of PSM. In this case, the UE may not wait for a listen interval to detect the beacon frame. Instead, the UE may send a trigger frame such as a Quality of Service (QoS) or QoS data frame (instead of a PS-Poll) to indicate that the UE is able to accept downlink packets whenever the AP is ready to transmit the packets to the UE. Unlike a PS-poll, a QoS frame can be sent by the UE at any time so the UE may not wait to decode the beacon frame to determine whether the AP has data for the UE.

In some embodiments, the UE may not transmit a frame to the AP to indicate that the UE is ready to receive the buffered packets. Instead, the eNB may transmit the DRX exit indication to the AP. If the eNB and the AP are integrated into the same device, the transmission may be through an internal interface; if the eNB and the AP are separate entities (not collocated) the transmission may be via the WT using the Xw interface.

The AP, having received an indication from the eNB that the UE is no longer in the DRX mode (and thus PCM), may reinstate transmission of the buffered packets, which may be received by the UE at operation 512. The AP may transmit the packets whether or not a trigger frame is received from the UE, so long as an indication that the UE has exited DRX mode is received. The eNB may also reinstate transmission of the packets to the UE directly or scheduled through the AP.

Example 1 is an apparatus of user equipment (UE) comprising: an evolved NodeB (eNB) transceiver arranged to communicate with an eNB and a Wireless Local Area Network (WLAN) access point (AP) transceiver arranged to communicate with an AP; and processing circuitry arranged to: configure the eNB and AP transceivers to respectively receive data from the eNB and the AP using Long Term Evolution (LTE)/AVLAN Aggregation (LWA); enter a discontinuous reception (DRX) mode and, in response to entering the DRX
mode, enter a WLAN power conservation mode (PCM); and exit the DRX mode and, after exiting the DRX mode, configure the eNB and AP transceivers to respectively receive data from the eNB and the AP using LWA.

[0094] In Example 2, the subject matter of Example 1 optionally includes that the PCM is a power saving mode (PSM), and in response to exiting the DRX mode, the processing circuitry is further arranged to: configure the AP transceiver to receive a beacon frame from the AP, determine from the beacon frame whether the AP has buffered data for the UE during the PSM, in response to a determination that the AP has buffered data for the UE during the PSM configure the AP transceiver to transmit a trigger frame to the AP, and after transmission of the trigger frame to the AP, configure the AP transceiver to receive the buffered data from the AP.

[0095] In Example 3, the subject matter of Example 2 optionally includes that the trigger frame comprises a Power-Save Poll (PS-Poll) frame.

[0096] In Example 4, the subject matter of any one or more of Examples 1-3 optionally include that the PCM is a Unscheduled Automatic Power Save Delivery (U-APSD) mode, and in response to exiting the DRX mode, the processing circuitry is further arranged to: exit the U-APSD mode, configure the AP transceiver to transmit a trigger frame to the AP indicating that the UE is ready to receive buffered data from the AP prior to receiving a beacon frame from the AP, and after transmission of the trigger frame to the AP, configure the AP transceiver to receive the buffered data from the AP.

[0097] In Example 5, the subject matter of Example 4 optionally includes that the trigger frame comprises one of a Quality of Service (QoS) null frame and QoS data frame.

[0098] In Example 6, the subject matter of any one or more of Examples 1-5 optionally include that the processing circuitry is further arranged to: configure the AP transceiver to transmit a PCM frame with a Power Management bit set to the AP to indicate entry of the UE into the PCM after entering the DRX mode and prior to entering the PCM.

[0099] In Example 7, the subject matter of Example 6 optionally includes that the processing circuitry is further arranged to: determine whether to transmit the PCM frame to the AP based on a length of the DRX mode.
[00100] In Example 8, the subject matter of any one or more of Examples 6-7 optionally include that the processing circuitry is further arranged to:
determine whether to transmit the PCM frame to the AP based on a recent data
transmission history of the AP.

[00101] In Example 9, the subject matter of any one or more of Examples 1-8 optionally include that the processing circuitry is further arranged to:
configure the AP transceiver to receive buffered data from the AP after exiting
the DRX mode and PCM free from transmission by the UE of an indication to
the AP that the UE is ready to receive the buffered data.

[00102] In Example 10, the subject matter of any one or more of Examples 1-9 optionally include, further comprising: a plurality of antennas
configured to provide communications between the eNB transceiver and the
eNB and the AP transceiver and the AP.

[00103] Example 11 is an apparatus of an evolved NodeB (eNB)
comprising: a transceiver arranged to communicate with a user equipment (UE);
an interface arranged to communicate with an access point (AP); and processing
circuitry arranged to: configure the transceiver to transmit data for the UE to the
UE and to the AP using Long Term Evolution (LTE)/Wireless Local Area
Network (WLAN) Aggregation (LWA); determine that the UE has entered a
discontinuous reception (DRX) mode; and at least one of: in response to a
determination that the UE has entered the DRX mode, configure the transceiver
to suspend transmission of the data to the UE and at least one of suspend
transmission of the data for the UE to the AP and transmit an indication to the
AP that the UE is in at least one of the DRX mode and a WLAN power
conservation mode (PCM); and in response to a determination that the UE has
exited the DRX mode, configure the transceiver to reinstate transmission of the
data to the UE and at least one of reinstate transmission of the data for the UE to
the AP and transmit an indication to the AP that the UE has exited at least one of
the DRX mode and the PCM.

[00104] In Example 12, the subject matter of Example 11 optionally
includes that the processing circuitry is further arranged to: prior to entry of the
UE into the DRX mode and the PCM, transmit to the AP DRX parameters via
the interface.
[00105] In Example 13, the subject matter of any one or more of Examples 11-12 optionally include that in response to a determination that the UE has entered the DRX mode, configure the transceiver to suspend transmission of the data to the UE, suspend transmission of the data for the UE to the AP and transmit the indication to the AP that the UE is in the DRX mode; and in response to a determination that the UE has exited the DRX mode, configure the transceiver to reinstate transmission of the data to the UE, reinstate transmission of the data for the UE to the AP and transmit an indication to the AP that the UE has exited the DRX mode.

[00106] In Example 14, the subject matter of any one or more of Examples 11-13 optionally include that the eNB and AP are integrated into a single device and the interface is an internal interface.

[00107] In Example 15, the subject matter of any one or more of Examples 11-14 optionally include that the eNB and AP are non-collocated and connected via an Xw interface.

[00108] Example 16 is an apparatus of an access point (AP) comprising: a transceiver arranged to communicate with a user equipment (UE); an interface arranged to communicate with an evolved NodeB (eNB); and processing circuitry arranged to: configure the transceiver to receive data from the eNB and transmit the data to the UE using Long Term Evolution (LTE) AVireless Local Area Network (WLAN) Aggregation (LWA); receive an indication that the UE has entered at least one of a discontinuous reception (DRX) mode and a WLAN power conservation mode (PCM) from at least one of the eNB and the UE and, in response, configure the transceiver to suspend transmission of the data to the UE; and in response to reception of an indication that the UE has exited the at least one of the DRX mode and the PCM from at least one of the eNB and the UE, configure the transceiver to reinstate transmission of the data to the UE.

[00109] In Example 17, the subject matter of Example 16 optionally includes that the PCM is a power saving mode (PSM), and the processing circuitry is further arranged to: determine whether the AP has buffered data for the UE during the PSM, configure the transceiver to transmit a beacon frame to the UE indicating that data for the UE is buffered at the AP, after transmission of the beacon frame configure the transceiver to receive a trigger frame from the
UE, and in response to reception of the trigger frame, configure the transceiver to transmit the buffered data from the AP.

In Example 18, the subject matter of Example 17 optionally includes that the PCM is a Unscheduled Automatic Power Save Delivery (U-APSD) mode, and the processing circuitry is further arranged to: configure the transceiver to receive a trigger frame from the UE indicating that the UE is ready-to-receive buffered data from the AP, and in response to reception of the trigger frame, configure the transceiver to transmit the buffered data from the AP.

In Example 19, the subject matter of any one or more of Examples 16-18 optionally include that the processing circuitry is further arranged to: configure the transceiver to receive a PCM frame with a Power Management bit set as the indication that the UE has entered the at least one of the DRX mode and the PCM.

In Example 20, the subject matter of any one or more of Examples 16-19 optionally include that the processing circuitry is further arranged to: configure the transceiver to receive at least one of the indication the UE has entered the at least one of the DRX mode and the PCM and the indication the UE has exited the at least one of the DRX mode and the PCM from the eNB via the interface.

In Example 21, the subject matter of Example 20 optionally includes that the processing circuitry is further arranged to: prior to entry of the UE into the at least one of the DRX mode and the PCM, receive from the eNB DRX parameters via the interface.

In Example 22, the subject matter of any one or more of Examples 16-21 optionally include that the eNB and AP are integrated into a single device and the interface is an internal interface.

In Example 23, the subject matter of any one or more of Examples 16-22 optionally include that the eNB and AP are non-collocated and connected via an Xw interface.

Example 24 is a computer-readable storage medium that stores instructions for execution by one or more processors of user equipment (UE) to communicate with an evolved NodeB (eNB) and with an access point (AP), the one or more processors to configure the UE to: receive data from the eNB and
the AP using Long Term Evolution (LTE)/Wireless Local Area Network (WLAN) Aggregation (LWA); enter a discontinuous reception (DRX) mode and, in response to entering the DRX mode, transmit a PCM frame with a Power Management bit set as an indication that the UE is to enter a WLAN power conservation mode (PCM) and subsequently enter the PCM; and exit the DRX mode and, in response to exiting the DRX mode, transmit an indication to the AP that the UE is ready to receive data buffered at the AP and receive data from the eNB and the AP using LWA.

[0117] In Example 25, the subject matter of Example 24 optionally includes that one of: a) the PCM is a power saving mode (PSM), and the one or more processors further configure the UE to: after exiting from the DRX mode receive a beacon frame from the AP indicating that data for the UE is buffered at the AP, in response to reception of the beacon frame, transmit to the AP a Power-Save Poll (PS-Poll) frame, and in response to transmission of the PS-Poll frame, receive the buffered data from the AP; and b) the PCM is an Unscheduled Automatic Power Save Delivery (U-APSD) mode, and the one or more processors further configure the UE to: prior to reception of a beacon frame from the AP indicating that data for the UE is buffered at the AP, transmit one of a Quality of Service (QoS) null frame and QoS data frame to the AP indicating that the UE is ready to receive data buffered at the AP, and after transmission of the one of the Quality of Service (QoS) null frame and QoS data frame, receive the buffered data from the AP.

[0118] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope
of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00119] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[00120] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, UE, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00121] The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b), requiring an abstract that will allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen
that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.
CLAIMS

What is claimed is:

1. An apparatus of user equipment (UE) comprising:
   an evolved NodeB (eNB) transceiver arranged to communicate with an
   eNB and a Wireless Local Area Network (VVLAN) access point (AP) transceiver
   arranged to communicate with an AP; and
   processing circuitry arranged to:
   configure the eNB and AP transceivers to respectively receive
data from the eNB and the AP using Long Term Evolution (LTE)AVLAN Aggregation (LWA);
   enter a discontinuous reception (DRX) mode and, in response to
   entering the DRX mode, enter a VVLAN power conservation mode (PCM); and
   exit the DRX mode and, after exiting the DRX mode, configure
the eNB and AP transceivers to respectively receive data from the eNB
and the AP using LWA.

2. The apparatus of claim 1, wherein:
   the PCM is a power saving mode (PSM), and
   in response to exiting the DRX mode, the processing circuitry is further
arranged to:
   configure the AP transceiver to receive a beacon frame from the
   AP,
   determine from the beacon frame whether the AP has buffered
data for the UE during the PSM,
   in response to a determination that the AP has buffered data for
   the UE during the PSM configure the AP transceiver to transmit a trigger
   frame to the AP, and
   after transmission of the trigger frame to the AP, configure the
   AP transceiver to receive the buffered data from the AP.

3. The apparatus of claim 2, wherein:
the trigger frame comprises a Power-Save Poll (PS-Poll) frame.

4. The apparatus of claim 1, wherein:
the PCM is a Unscheduled Automatic Power Save Delivery (U-APSD)

5. in response to exiting the DRX mode, the processing circuitry is further arranged to:
   exit the U-APSD mode,
   configure the AP transceiver to transmit a trigger frame to the AP
   indicating that the UE is ready to receive buffered data from the AP prior
to receiving a beacon frame from the AP, and
   after transmission of the trigger frame to the AP, configure the
   AP transceiver to receive the buffered data from the AP.

5. The apparatus of claim 4, wherein:
the trigger frame comprises one of a Quality of Service (QoS) null frame
and QoS data frame.

6. The apparatus of any one or combination of claims 1-5, wherein the
   processing circuitry is further arranged to:
   configure the AP transceiver to transmit a PCM frame with a Power
   Management bit set to the AP to indicate entry of the UE into the PCM after
   entering the DRX mode and prior to entering the PCM.

7. The apparatus of claim 6, wherein the processing circuitry is further arranged to:
   determine whether to transmit the PCM frame to the AP based on a
   length of the DRX mode.

8. The apparatus of claim 6, wherein the processing circuitry is further arranged to:
   determine whether to transmit the PCM frame to the AP based on a
   recent data transmission history of the AP.
9. The apparatus of any one or combination of claims 1-5, wherein the processing circuitry is further arranged to:
   configure the AP transceiver to receive buffered data from the AP after exiting the DRX mode and PCM free from transmission by the UE of an indication to the AP that the UE is ready to receive the buffered data.

10. The apparatus of any one or combination of claims 1-5, further comprising:
   a plurality of antennas configured to provide communications between the eNB transceiver and the eNB and the AP transceiver and the AP.

11. An apparatus of an evolved NodeB (eNB) comprising:
    a transceiver arranged to communicate with a user equipment (UE);
    an interface arranged to communicate with an access point (AP); and
    processing circuitry arranged to:
        configure the transceiver to transmit data for the UE to the UE and to the AP using Long Term Evolution (LTE)/Wireless Local Area Network (WLAN) Aggregation (LWA);
        determine that the UE has entered a discontinuous reception (DRX) mode; and at least one of:
            in response to a determination that the UE has entered the DRX mode, configure the transceiver to suspend transmission of the data to the UE and at least one of suspend transmission of the data for the UE to the AP and transmit an indication to the AP that the UE is in at least one of the DRX mode and a WLAN power conservation mode (PCM); and
            in response to a determination that the UE has exited the DRX mode, configure the transceiver to reinstate transmission of the data to the UE and at least one of reinstate transmission of the data for the UE to the AP and transmit an indication to the AP that the UE has exited at least one of the DRX mode and the PCM.
12. The apparatus of claim 11, wherein the processing circuitry is further arranged to:
   prior to entry of the UE into the DRX mode and the PCM, transmit to the AP DRX parameters via the interface.

13. The apparatus of claim 11 or 12, wherein:
   in response to a determination that the UE has entered the DRX mode, configure the transceiver to suspend transmission of the data to the UE, suspend transmission of the data for the UE to the AP and transmit the indication to the AP that the UE is in the DRX mode; and
   in response to a determination that the UE has exited the DRX mode, configure the transceiver to reinstate transmission of the data to the UE, reinstate transmission of the data for the UE to the AP and transmit an indication to the AP that the UE has exited the DRX mode.

14. The apparatus of claim 11 or 12, wherein:
   the eNB and AP are integrated into a single device and the interface is an internal interface.

15. The apparatus of claim 11 or 12, wherein:
   the eNB and AP are non-collocated and connected via an Xw interface.

16. An apparatus of an access point (AP) comprising:
   a transceiver arranged to communicate with a user equipment (UE);
   an interface arranged to communicate with an evolved NodeB (eNB);
   and
   processing circuitry arranged to:
   configure the transceiver to receive data from the eNB and transmit the data to the UE using Long Term Evolution (LTE)/Wireless Local Area Network (WLAN) Aggregation (LWA);
   receive an indication that the UE has entered at least one of a discontinuous reception (DRX) mode and a WLAN power conservation mode (PCM) from at least one of the eNB and the UE and, in response,
configure the transceiver to suspend transmission of the data to the UE;
and
in response to reception of an indication that the UE has exited the at least one of the DRX mode and the PCM from at least one of the eNB and the UE, configure the transceiver to reinstate transmission the data to the UE.

17. The apparatus of claim 16, wherein:
the PCM is a power saving mode (PSM), and
the processing circuitry is further arranged to:
- determine whether the AP has buffered data for the UE during the PSM,
- configure the transceiver to transmit a beacon frame to the UE indicating that data for the UE is buffered at the AP,
- after transmission of the beacon frame configure the transceiver to receive a trigger frame from the UE, and
- in response to reception of the trigger frame, configure the transceiver to transmit the buffered data from the AP.

18. The apparatus of claim 17, wherein:
the PCM is a Unscheduled Automatic Power Save Delivery (U-APSD) mode, and
the processing circuitry is further arranged to:
- configure the transceiver to receive a trigger frame from the UE indicating that the UE is ready to receive buffered data from the AP, and
- in response to reception of the trigger frame, configure the transceiver to transmit the buffered data from the AP.

19. The apparatus of any one or combination of claims 16-18, wherein the processing circuitry is further arranged to:
configure the transceiver to receive a PCM frame with a Power Management bit set as the indication that the UE has entered the at least one of the DRX mode and the PCM.
20. The apparatus of any one or combination of claims 16-19 wherein the processing circuitry is further arranged to:

configure the transceiver to receive at least one of the indication the UE has entered the at least one of the DRX mode and the PCM and the indication the UE has exited the at least one of the DRX mode and the PCM from the eNB via the interface.

21. The apparatus of claim 20, wherein the processing circuitry is further arranged to:

prior to entry of the UE into the at least one of the DRX mode and the PCM, receive from the eNB DRX parameters via the interface.

22. The apparatus of any one or combination of claims 16-21, wherein:

the eNB and AP are integrated into a single device and the interface is an internal interface.

23. The apparatus of any one or combination of claims 16-21, wherein:

the eNB and AP are non-collocated and connected via an Xw interface.

24. A computer-readable storage medium that stores instructions for execution by one or more processors of user equipment (UE) to communicate with an evolved NodeB (eNB) and with an access point (AP), the one or more processors to configure the UE to:

receive data from the eNB and the AP using Long Term Evolution (LTE)AVireless Local Area Network (WLAN) Aggregation (LWA);

enter a discontinuous reception (DRX) mode and, in response to entering the DRX mode, transmit a PCM frame with a Power Management bit set as an indication that the UE is to enter a WLAN power conservation mode (PCM) and subsequently enter the PCM; and

exit the DRX mode and, in response to exiting the DRX mode, transmit an indication to the AP that the UE is ready to receive data buffered at the AP and receive data from the eNB and the AP using LWA.
25. The medium of claim 24, wherein one of:
   a) the PCM is a power saving mode (PSM), and
      the one or more processors further configure the UE to:
      after exiting from the DRX mode receive a beacon frame from
      the AP indicating that data for the UE is buffered at the AP,
      in response to reception of the beacon frame, transmit to the AP a
      Power-Save Poll (PS-Poll) frame, and
      in response to transmission of the PS-Poll frame, receive the
      buffered data from the AP; and
   b) the PCM is a Unscheduled Automatic Power Save Delivery (U-APSD)
      mode, and
      the one or more processors further configure the UE to:
      prior to reception of a beacon frame from the AP indicating that
      data for the UE is buffered at the AP, transmit one of a Quality of Service
      (QoS) null frame and QoS data frame to the AP indicating that the UE is
      ready to receive data buffered at the AP, and
      after transmission of the one of the Quality of Service (QoS) null
      frame and QoS data frame, receive the buffered data from the AP.
FIG. 3
FIG. 5

502  ENTER DRX MODE

504  TRANSMIT DRX ENTRY INDICATION TO AP

506  AP BUFFER PACKETS

508  DRX EXIT

510  TRANSMIT DRX EXIT INDICATION TO AP

512  RECEIVE BUFFERED PACKETS
A. CLASSIFICATION OF SUBJECT MATTER

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

H04W 52/02(2009.01)i, H04W 88/06(2009.01)i, H04W 88/10(2009.01)i

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W 52/02; H04W 80/08; H04W 40/02; H04W 88/06; H04W 88/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: dual connectivity, DRX, LTE, WLAN, DRX indication, power conservation mode

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Category</th>
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<td>Y</td>
<td>US 2015-0215840 Al (INTEL IP CORPORATION) 30 July 2015 See paragraphs [0016] , [0028H0029] , [0038] , [0062] ; claims 1, 6, 10; and figures 1, 7.</td>
<td>1, 6-7 , 10-16 , 19-24</td>
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<td>wo 2014-172306 A2 (INTERDIGITAL PATENT HOLDINGS, INC.) 23 October 2014 See paragraphs [0080] , [0089H0114] ; and claims 1-2.</td>
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<td>ALCATEL-LUCENT et al., &quot;Consideration on DRX coordination in dual connectivity&quot;, R2-144509, 3GPP TSG RAN WG2 Meet ing #87bis Shanghai, China, 26 Sept ember 2014 (ht tp ://www.3gpp.org/f tp/t sg_ran/WG2_RL2/TSGR2_87bis s/Docs/R2-144509 .zip) See sect ion 2.</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
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  "O" document referring to an oral disclosure, use, exhibition or other means
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  "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
  "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
  "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  "&" document member of the same patent family

Date of the actual completion of the international search
01 August 2016 (01.08.2016)

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Form PCT/ISA/210 (second sheet) (January 2015)
### DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>A</td>
<td>QUALCOMM INCORPORATED, &quot;DRX and PHY layer aspects for LAA\ RL-153874, 3GPP TSG RAN WG1 #82, 15 August 2015 (<a href="http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_82/Docs/Rl-153874.zip">http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_82/Docs/Rl-153874.zip</a>) See sections 2-3.</td>
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