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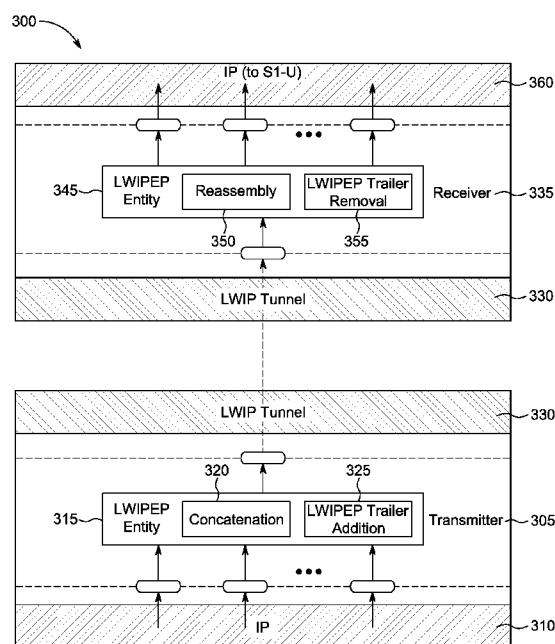


FIG. 3

(57) **Abstract:** A transmitter device encodes a LWIPEP (LWIP Encapsulation Protocol) service data unit (SDU) for transmission to a receiver device via an LWIP tunnel. The transmitter device determines whether adding the LWIPEP SDU to a concatenation buffer will cause a size of the concatenation buffer to exceed a predetermined LWIP maximum transfer unit (MTU) size. If adding the LWIPEP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined LWIP MTU size or concatenation timer has expired: the transmitter device encodes a transmission of one or more LWIPEP SDUs from the concatenation buffer, within a LWIPEP packet data unit (PDU), to the receiver device. If adding the LWIPEP SDU to the concatenation buffer will not cause the concatenation buffer size to exceed the predetermined LWIP MTU size and concatenation timer has not expired: the transmitter device adds the LWIPEP SDU to the concatenation buffer.

MAMP AND LWIP ENHANCEMENTS FOR CONCATENATION AND SEGMENTATION

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PRIORITY CLAIM

[0001] This application claims priority under 35 U.S.C. § 119 to United States Provisional Patent Application Serial No. 62/336,392, filed May 13, 2016, and titled,
10 “ENHANCEMENTS TO SUPPORT CONCATENATION AND SEGMENTATION IN LTE WIFI INTEGRATION WITH IPSEC (LWIP),” which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

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[0002] Embodiments pertain to wireless communications. Some embodiments relate to radio access network (RAN) layers 2 and 3. Some embodiments relate to LWIP (long term evolution (LTE)/ wireless local area network (WLAN) radio level Integration Protocol) enhancements to support concatenation and segmentation in
20 RAN-based LTE/WLAN integration with Internet Protocol Security (IPSec). Some embodiments relate to Multi-Access Management Protocol (MAMP) in Internet Engineering Task Force (IETF).

BACKGROUND

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[0003] In a cellular network, a user equipment (UE) may sometimes switch from accessing data over a long term evolution (LTE) network to accessing data over a Wi-Fi network, and vice versa, for example, in response to the UE being moved into or out of a Wi-Fi coverage area. Seamlessly switching from one wireless
30 transmission mode (e.g., LTE, Wi-Fi, 5G, MultiFire, etc.) to another may be desirable.

[0004] Thus, there are general needs for systems and methods for LWIP (long term evolution (LTE)/ wireless local area network (WLAN) radio level Integration Protocol) or MAMP (Multi-Access Management Protocol) enhancements to support concatenation and segmentation in radio access network (RAN) based LTE/WLAN
5 integration with Internet Protocol Security (IPSec) or MAMP-based generic integration of multiple access networks.

BRIEF DESCRIPTION OF THE DRAWINGS

10 [0005] FIG. 1 is a block diagram of an example LWIP (long term evolution (LTE)/ wireless local area network (WLAN) radio level Integration Protocol) system, in accordance with some embodiments.

[0006] FIG. 2 is a block diagram of an example LWIP tunneling packet for concatenation, in accordance with some embodiments.

15 [0007] FIG. 3 is a data flow diagram of an example of enhanced LWIPEP (LWIP Encapsulation Protocol) concatenation and segmentation, in accordance with some embodiments.

[0008] FIG. 4 is a block diagram of an example MAMP (Multiple Access Management Protocol) system with generic integration of multiple access networks,
20 in accordance with some embodiments.

[0009] FIG. 5 is a functional diagram of a wireless network, in accordance with some embodiments.

[0010] FIG. 6 illustrates components of a communication device, in accordance with some embodiments.

25 [0011] FIG. 7 illustrates a block diagram of a communication device, in accordance with some embodiments.

[0012] FIG. 8 illustrates another block diagram of a communication device, in accordance with some embodiments.

30 DETAILED DESCRIPTION

[0013] 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.

5 **[0014]** FIG. 1 is a block diagram of an example LWIP (long term evolution (LTE)/ wireless local area network (WLAN) radio level Integration Protocol) system 100, in accordance with some embodiments. As shown, the system 100 includes an evolved NodeB (eNB) 110, a user equipment (UE) 120, a WLAN 130, and a LWIP secure gateway (LWIP-SeGW) 140. The eNB 110 communicates with the UE 120
10 over LTE, and the WLAN 130 communicates with the UE 120 over Wi-Fi. The LWIP-SeGW 140 communicates with the eNB 110 and the WLAN 130.

[0015] The eNB 110 includes the following layers: Internet Protocol (IP), radio resource control (RRC), packet data convergence protocol (PDCP), radio link control (RLC), medium access control (MAC), and physical (PHY). The IP layer
15 includes LWIP encapsulation protocol (LWIP-EP).

[0016] The UE 120 includes the following layers: PHY, MAC, RLC, PDCP, RRC, non-access stratum (NAS), IP, application (APP)/higher layers, WLAN PHY, and WLAN MAC. The IP layer includes LWIP-EP.

[0017] As shown, the LWIP-EP at the UE 120 communicates with the LWIP-SeGW 140 and the LWIP-EP at the eNB 110 using a LWIP tunnel. The LWIP tunnel
20 includes the private IP of the eNB 110 and the public IP of the LWIP-SeGW 140. The LWIP tunnel includes a UE – LWIP-SeGW Internet Protocol Security (IPsec) tunnel. The LWIP tunnel is used to transmit user plane IP packets from data radio bearer (DRB).

25 **[0018]** FIG. 1 shows an example protocol architecture for LWIP. Here, the eNB 110 is the mobility anchor, and WLAN link aggregation is transparent to 3GPP (Third Generation Partnership Project) core network elements (e.g. MME, S-GW, P-GW). The UE 120 establishes a LWIP tunnel with eNB via WLAN through LWIP-SeGW, and IPsec is used to protect the UE's 120 IP traffic over the LWIP tunnel,
30 which is transparent to WLAN and, in some cases, makes no changes to the existing WLAN deployment. Furthermore, traffic steering and multi-RAT (radio access technology) RRM (radio resource management) take place over the top of the LTE RAN u-plane protocol stack (above PDCP).

[0019] Some aspects of the subject technology address the scenario in which the Maximum Transfer Unit (MTU) size of a LWIP tunnel is much than the cellular MTU size. For example, the Wi-Fi link for LWIP tunneling is based on the 60GHz mmWave technology (e.g. IEEE 802.11ad/ay), which can support Gbps peak throughput and very large MTU size (e.g. 8K). In this scenario, it is desirable to concatenate multiple LWIPEP SDUs (service data units) into one LWIPEP PDU (packet data unit). Some aspects of the subject technology provide LWIPEP enhancements to support concatenation.

[0020] FIG. 2 is a block diagram of an example LWIP tunneling packet 200 for concatenation. As shown, the LWIP tunneling packet 20 includes an IP Header (Wi-Fi) 205, an IPsec ESP (Encapsulating Security Payload) Header 210, an LWPEP PDU 215, an IPsec ESP Trailer 250, and an IPsec ESP Auth (Authentication) Trailer 255. The LWIPEP PDU 215 includes multiple LWIPEP SDUs 220.1-3 (while three LWIPEP SDUs are illustrated, the subject technology may include any number of LWIPEP SDUs) and an LWIP Trailer 235. Each LWIPEP SDU 220.k (where k is a number between 1 and 3) includes an IP Header (LTE) 225.k and an IP Payload (LTE) 230.k.

[0021] In some aspects, the subject technology includes adding two new control fields in the LWIPEP Trailer 235, and new functionalities – concatenation and reassembly – to the LWIPEP protocol stack. The new control fields allow putting multiple LWIPEP SDUs 220.1-3 in a single LWIPEP PDU 215. Also, a new timer – the LWIPEP Concatenation Timer – is proposed to limit how long LWIPEP waits at the transmitter for concatenation.

[0022] According to some aspects, the subject technology includes enhancing the existing LWIPEP PDU 215 format to include two new fields: a 1-bit “Concatenation Indicator” field 240, and a 2-byte “IP Length of the First SDU” field 245 in the LWIP Trailer 235.

[0023] FIG. 3 is a data flow diagram of an example of enhanced LWIPEP concatenation and segmentation 300. The enhanced LWIPEP concatenation and segmentation includes a transmitter 305 (eNB for downlink; UE for uplink) and a receiver 335 (UE for downlink; eNB for uplink). The transmitter 335 accesses SDUs from the IP (Internet Protocol) layer 310. The transmitter’s LWIPEP entity 315 concatenates 320 the SDUs into a PDU and adds the LWIPEP trailer 325. The PDU is

provided to the LWIP tunnel 330. The receiver 335 accesses the LWIP tunnel 330 to receive the PDU. The receiver's LWIPEP entity 345 reassembles 350 the SDUs and removes the LWIPEP trailer 355. The SDUs are passed to the IP layer 360, from which they may be provided to the S1-U.

5 **[0024]** FIG. 3 shows the enhanced LWIPEP model supporting concatenation and segmentation. LWIPEP transmitter maintains a Concatenation Buffer and a Concatenation Timer. The buffer stores LWIPEP SDUs temporarily waiting for concatenation. The timer controls how long a LWIPEP SDU may stay in the concatenation buffer, and can be configured by eNB via the RRC signaling during the
10 LWIP tunneling setup procedure.

[0025] The LWIPEP transmitter 305 prepares the LWIPEP PDU based on the SDUs in the buffer and send the LWIPEP PDU out if any of the following events occur: the concatenation timer expires, or including the newly arriving LWIPEP SDU in the current LWIPEP PDU would cause the LWIPEP PDU size to exceed the LWIP
15 MTU size.

[0026] The timer starts when a LWIPEP SDU is placed in the buffer and the buffer is empty, and is cancelled when a LWIPEP PDU is sent out.

[0027] At the transmitter 305, when the LWIPEP entity 315 receives a LWIPEP SDU (IP packet) from upper layers, if the LWIPEP PDU size exceeds the
20 LWIP MTU size when including the newly arriving SDU in the current LWIPEP PDU, the transmitter 305 prepares the LWIPEP PDU based on the LWIPEP SDUs in the buffer and send out the LWIPEP PEDU. Then, the transmitter 305 stores the newly arriving SDU in the buffer. If the buffer is empty, the concatenation timer is started.

25 **[0028]** At the receiver 335, when the LWIPEP entity 345 receives the LWIPEP PDU from the lower layers, the LWIPEP entity 345 checks the "Concatenation Indicator" field 240 in the LWIP trailer 235 to determine if the PDU includes multiple SDUs or not. If the PDU includes multiple SDUs, the LWIPEP entity 345 checks the "IP Length of the First SDU" field 245 in the LWIP trailer 235
30 to obtain the length of the first LWIPEP SDU and get the first SDU. Then, it will check the IP header length in the IP header of the second LWIPEP SDU and get the second SDU. This process continues until the last SDU.

[0029] The subject technology is described above in conjunction with LWIP. However, the subject technology is also applicable to Internet Engineering Task Force (IETF) Multiple Access Management Protocol (MAMP) based generic integration of multiple access networks. The MAMP framework shares many similarities with the LWIP framework. Therefore, the solution proposed herein is applicable to both MAMP and LWIP.

[0030] FIG. 4 is a block diagram of an example MAMP system 400. As shown, the MAMP system includes a Core (IP Anchor) 405.1 for network 1 (e.g., LTE), a Core (IP Anchor) 405.2 for network 2 (e.g., WLAN), a NCM (network connection manager) 410, a MADP (multi-access data proxy) 415, an access 420.1 for network 1, an access 420.2 for network 2, and a client device 425.

[0031] The client device 425 is an end-user device supporting connections with multiple access nodes, possibly over different technologies.

[0032] The access 420 network elements are functional elements in the network that deliver user data packets to the client device 425 via a point-to-point access link, such as Wi-Fi airlink, LTE airlink, or digital subscriber line (DSL).

[0033] The core 405 is a functional element that anchors the IP address of the client device 425 used for communication with applications via the network.

[0034] The NCM 410 is a functional entity in the network that oversees distribution of data packets over the multiple available access 420 and core 405 network paths.

[0035] The client device 425 includes a CCM (client connection manager) 430. The CCM 430 is a functional entity in the client device 425 that exchanges MAMS (multi-access management system) signalling with the NCM 410 and configures the multiple network paths for the transport of user data. The CCM also provides MAMS-specific u-plane functionalities at the client device 425.

[0036] The MADP 415 handles user data traffic forwarding across multiple network paths. The MADP 415 provides MAMS-specific u-plane functionalities at the network.

[0037] In some cases of the subject technology, LWIP can be seen as an example of the MAMP framework. One difference is that the transport of control signalling in LWIP is supported by RRC messages, while the control signalling in MAMP is delivered over the top of user-plane packets, such as user datagram protocol

(UDP) or transport control protocol (TCP). In terms of similarity, the CCM 430 in MAMP is similar to the LWIPEP (u-plane) and RRC (c-plane) at the UE in LWIP. The NCM 410 is similar to the RRC at the eNB implementing LWIP. The MADP 415 is similar to the LWIPEP at the eNB. The solution for LWIP disclosed herein is applicable to MAMP.

[0038] FIG. 5 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network 500 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 500 may comprise a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 501 and core network 520 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 515. For convenience and brevity, only a portion of the core network 520, as well as the RAN 501, is shown in the example. The network 500 includes the UE 502, which is configured to select an eNB Tx beam in a 6G eNB based on BRS measurements; transmit a PRACH or SR on a dedicated resource allocated by a LTE eNB; transmit a report indicating the selected eNB Tx beam in the 6G eNB via a PUSCH or PUCCH in the LTE eNB; receive a PDCCH order from the LTE eNB or a xPDCCH order from the 6G eNB for triggering a xPRACH transmission in the 6G eNB; and transmit xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 6G eNB.

[0039] The core network 520 may include a mobility management entity (MME) 522, serving gateway (serving GW) 524, and packet data network gateway (PDN GW) 526. The RAN 501 may include evolved node Bs (eNBs) 504 (which may operate as base stations) for communicating with user equipment (UE) 502. The eNBs 504 may include macro eNBs 504a and low power (LP) eNBs 504b. The UEs 502 may correspond to the UE 120, the transmitter 610 or the receiver 620. The eNBs 504 may correspond to the eNB 80, the transmitter 610 or the receiver 620.

[0040] The MME 522 may be similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 522 may manage mobility aspects in access such as gateway selection and tracking area list management. The serving GW 524 may terminate the interface toward the RAN 501, and route data packets between the RAN 501 and the core network 520. In addition, the serving GW

524 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 524 and the MME 522 may be implemented in one physical node or separate physical nodes.

5 [0041] The PDN GW 526 may terminate a SGi interface toward the packet data network (PDN). The PDN GW 526 may route data packets between the EPC 520 and the external PDN, and may perform policy enforcement and charging data collection. The PDN GW 526 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
10 IP Multimedia Subsystem (IMS) domain. The PDN GW 526 and the serving GW 524 may be implemented in a single physical node or separate physical nodes.

[0042] The eNBs 504 (macro and micro) may terminate the air interface protocol and may be the first point of contact for a UE 502. In some embodiments, an eNB 504 may fulfill various logical functions for the RAN 501 including, but not
15 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 502 may be configured to communicate orthogonal frequency division multiplexed (OFDM) communication signals with an eNB 504 over a multicarrier communication
20 channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0043] The S1 interface 515 may be the interface that separates the RAN 501 and the EPC 520. It may be split into two parts: the S1-U, which may carry traffic data between the eNBs 504 and the serving GW 524, and the S1-MME, which may be
25 a signaling interface between the eNBs 504 and the MME 522. The X2 interface may be the interface between eNBs 504. 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 504, while the X2-U may be the user plane interface between the eNBs 504.

[0044] With cellular networks, LP cells 504b may be typically used to extend
30 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 60 meters. Thus, a LP eNB 504b might be a femtocell eNB since it is coupled through the PDN GW 526. Similarly, a picocell may be a wireless 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 504a via an X2 interface. Picocell eNBs or other LP eNBs LP eNB 504b may incorporate some or all functionality of a macro eNB LP eNB 504a. In some cases, this may be referred to as an access point base station or enterprise femtocell.

[0045] In some embodiments, the UE 502 may communicate with an access point (AP) 504c. The AP 504c may use only the unlicensed spectrum (e.g., WiFi bands) to communicate with the UE 502. The AP 504c may communicate with the macro eNB 504A (or LP eNB 504B) through an Xw interface. In some embodiments, the AP 504c may communicate with the UE 502 independent of communication between the UE 502 and the macro eNB 504A. In other embodiments, the AP 504c may be controlled by the macro eNB 504A and use LWA, as described in more detail below.

[0046] Communication over an LTE network may be split up into 7ms 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 (f_1 and f_2). 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 7-7 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 PRB 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 8.5 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 7ms 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 500 in the time domain corresponds to one subframe or two resource blocks. Each resource grid may comprise 12 (subcarriers) * 14 (symbols) = 168 resource elements.

[0047] 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.

[0048] 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.

- 5 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
- 10 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
- 15 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.

- [0049]** Embodiments described herein may be implemented into a
- 20 system using any suitably configured hardware and/or software. FIG. 6 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 502 or eNB 504 shown in FIG. 5. The UE 600 and other components may be configured to use the synchronization signals as described herein. The UE 600 may be one of the
- 25 UEs 602 shown in FIG. 1 and may be a stationary, non-mobile device or may be a mobile device. In some embodiments, the UE 600 may include application circuitry 602, baseband circuitry 604, Radio Frequency (RF) circuitry 606, front-end module (FEM) circuitry 608 and one or more antennas 610, coupled together at least as
- 30 shown. At least some of the baseband circuitry 604, RF circuitry 606, and FEM circuitry 608 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. 6. 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.

[0050] The application or processing circuitry 602 may include one or more application processors. For example, the application circuitry 602 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
5 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.

[0051] The baseband circuitry 604 may include circuitry such as, but not
10 limited to, one or more single-core or multi-core processors. The baseband circuitry 604 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 606 and to generate baseband signals for a transmit signal path of the RF circuitry 606. Baseband processing circuitry 604 may interface with the application circuitry 602 for generation
15 and processing of the baseband signals and for controlling operations of the RF circuitry 606. For example, in some embodiments, the baseband circuitry 604 may include a second generation (2G) baseband processor 604a, third generation (3G) baseband processor 604b, fourth generation (4G) baseband processor 604c, and/or other baseband processor(s) 604d for other existing generations, generations in
20 development or to be developed in the future (e.g., fifth generation (5G), 7G, etc.). The baseband circuitry 604 (e.g., one or more of baseband processors 604a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 606. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio
25 frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 604 may include FFT, precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 604 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC)
30 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.

[0052] In some embodiments, the baseband circuitry 604 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (E-UTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data
5 convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 604e of the baseband circuitry 604 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) 604f. The audio DSP(s) 604f may be
10 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 604 and the application
15 circuitry 602 may be implemented together such as, for example, on a system on a chip (SOC).

[0053] In some embodiments, the baseband circuitry 604 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 604 may support communication with an
20 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 604 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry. In some
25 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) 502.16 wireless technology (WiMax), IEEE 502.11 wireless technology (WiFi) including IEEE 502.11 ad, which operates in the 70 GHz millimeter wave spectrum, various other wireless technologies such as
30 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, 5G, 6G, etc. technologies either already developed or to be developed.

[0054] RF circuitry 606 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various
5 embodiments, the RF circuitry 606 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 606 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 608 and provide baseband signals to the baseband circuitry 604. RF circuitry 606 may also include a transmit signal path which may
10 include circuitry to up-convert baseband signals provided by the baseband circuitry 604 and provide RF output signals to the FEM circuitry 608 for transmission.

[0055] In some embodiments, the RF circuitry 606 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 606 may include mixer circuitry 606a, amplifier circuitry 606b and filter circuitry 606c.

15 The transmit signal path of the RF circuitry 606 may include filter circuitry 606c and mixer circuitry 606a. RF circuitry 606 may also include synthesizer circuitry 606d for synthesizing a frequency for use by the mixer circuitry 606a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 606a of the receive signal path may be configured to down-convert RF signals received from the
20 FEM circuitry 608 based on the synthesized frequency provided by synthesizer circuitry 606d. The amplifier circuitry 606b may be configured to amplify the down-converted signals and the filter circuitry 606c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided
25 to the baseband circuitry 604 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 606a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

30 **[0056]** In some embodiments, the mixer circuitry 606a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 606d to generate RF output signals for the FEM circuitry 608. The baseband signals may be provided by the baseband

circuitry 604 and may be filtered by filter circuitry 606c. The filter circuitry 606c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0057] In some embodiments, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a 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 606a of the receive signal path and the mixer circuitry 606a 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 606a of the receive signal path and the mixer circuitry 606a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may be configured for super-heterodyne operation.

[0058] 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 606 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 604 may include a digital baseband interface to communicate with the RF circuitry 606.

[0059] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[0060] In some embodiments, the synthesizer circuitry 606d 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 606d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0061] The synthesizer circuitry 606d may be configured to synthesize an output frequency for use by the mixer circuitry 606a of the RF circuitry 606 based on

a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 606d may be a fractional $N/N+1$ synthesizer.

[0062] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input
5 may be provided by either the baseband circuitry 604 or the applications processor 602 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 602.

[0063] Synthesizer circuitry 606d of the RF circuitry 606 may include a
10 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
15 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 N_d equal packets of phase, where N_d 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.

[0064] In some embodiments, synthesizer circuitry 606d may be configured to
20 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
25 with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 606 may include an IQ/polar converter.

[0065] FEM circuitry 608 may include a receive signal path which may
include circuitry configured to operate on RF signals received from one or more
30 antennas 610, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 606 for further processing. FEM circuitry 608 may also include a transmit signal path which may include circuitry configured to amplify

signals for transmission provided by the RF circuitry 606 for transmission by one or more of the one or more antennas 610.

[0066] In some embodiments, the FEM circuitry 608 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 606). The transmit signal path of the FEM circuitry 608 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 606), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 610).

[0067] In some embodiments, the UE 600 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 600 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 600 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 600 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.

[0068] The antennas 610 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 610 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0069] Although the UE 600 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.

[0070] 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.

[0071] FIG. 7 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 502 or eNB 504 shown in FIG. 5. The physical layer circuitry 702 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. The communication device 700 may also include medium access control layer (MAC) circuitry 704 for

controlling access to the wireless medium. The communication device 700 may also include processing circuitry 706, such as one or more single-core or multi-core processors, and memory 708 arranged to perform the operations described herein. The physical layer circuitry 702, MAC circuitry 704 and processing circuitry 706 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 700 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, 5G, 6G, etc. technologies either already developed or to be developed. The communication device 700 may include transceiver circuitry 712 to enable communication with other external devices wirelessly and interfaces 714 to enable wired communication with other external devices. As another example, the transceiver circuitry 712 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.

[0072] The antennas 701 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 701 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0073] Although the communication device 700 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.

5 [0074] FIG. 8 illustrates another block diagram of a communication device 800 in accordance with some embodiments. The communication device 800 may correspond to the UE 502 or the eNB 504. In alternative embodiments, the communication device 800 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the
10 communication device 800 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 800 may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 800 may be a UE, eNB, PC, a tablet PC, a STB, a PDA, a
15 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
20 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.

[0075] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities
25 (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
30 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.

[0076] Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g.,
5 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
10 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.

[0077] Communication device (e.g., computer system) 800 may include a
15 hardware processor 802 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 804 and a static memory 806, some or all of which may communicate with each other via an interlink (e.g., bus) 808. The communication device 800 may further include a display unit 810, an alphanumeric input device 812 (e.g., a keyboard), and a user
20 interface (UI) navigation device 814 (e.g., a mouse). In an example, the display unit 810, input device 812 and UI navigation device 814 may be a touch screen display. The communication device 800 may additionally include a storage device (e.g., drive unit) 816, a signal generation device 818 (e.g., a speaker), a network interface device 820, and one or more sensors 821, such as a global positioning system (GPS) sensor,
25 compass, accelerometer, or other sensor. The communication device 800 may include an output controller 828, 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.).

[0078] The storage device 816 may include a communication device readable
30 medium 822 on which is stored one or more sets of data structures or instructions 824 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 824 may also reside, completely or at

least partially, within the main memory 804, within static memory 806, or within the hardware processor 802 during execution thereof by the communication device 800.

In an example, one or any combination of the hardware processor 802, the main memory 804, the static memory 806, or the storage device 816 may constitute

5 communication device readable media.

[0079] While the communication device readable medium 822 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 824.

10 **[0080]** 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 800 and that cause the communication device 800 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
15 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
20 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
25 media that is not a transitory propagating signal.

[0081] The instructions 824 may further be transmitted or received over a communications network 826 using a transmission medium via the network interface device 820 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol
30 (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) 502.11 family of standards known as Wi-Fi®, IEEE 502.16 family of standards known as WiMax®, IEEE 502.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P)

5 networks, among others. In an example, the network interface device 820 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 826. In an example, the network interface device 820 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), MIMO, or multiple-input
10 single-output (MISO) techniques. In some examples, the network interface device 820 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 800, and includes digital or analog communications signals or
15 other intangible medium to facilitate communication of such software.

[0082] The subject technology is described below in conjunction with various examples.

[0083] Example 1 is an apparatus of a wireless device, the apparatus comprising: processing circuitry and memory; the processing circuitry to: encode a
20 MAMP (multiple access management protocol) service data unit (SDU) for transmission via a MAMP tunnel; determine whether adding the MAMP SDU to a concatenation buffer will cause a size of the concatenation buffer to exceed a predetermined MAMP maximum transfer unit (MTU) size; if adding the MAMP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed
25 the predetermined MAMP MTU size or a concatenation timer has expired: encode one or more of MAMP SDUs from the concatenation buffer, within a MAMP packet data unit (PDU), for transmission; and if adding the MAMP SDU to the concatenation buffer will not cause the concatenation buffer size to exceed the predetermined MAMP MTU size and the concatenation timer has not expired: add the MAMP SDU
30 to the concatenation buffer.

[0084] Example 2 is the apparatus of Example 1, wherein the MAMP PDU comprises: an Internet Protocol (IP) header, a tunneling header, the one or more MAMP SDUs, a MAMP trailer or a MAMP header, and a tunneling trailer.

[0085] Example 3 is the apparatus of Example 2, wherein the processing circuitry is further to: add the MAMP trailer to the MAMP PDU prior to transmission of the MAMP PDU, wherein the MAMP trailer comprises a concatenation indicator and an indication of an IP length of a first MAMP SDU from the one or more MAMP SDUs.

[0086] Example 4 is the apparatus of Example 3, wherein the concatenation indicator indicates whether the one or more MAMP SDUs include a single MAMP SDU or multiple MAMP SDUs.

[0087] Example 5 is the apparatus of Example 4, wherein the IP length of the first MAMP SDU is included only if the concatenation indicator indicates that multiple SDUs are included in the one or more MAMP SDUs.

[0088] Example 6 is the apparatus of Example 2, wherein the processing circuitry is further to: add the MAMP header to the MAMP PDU prior to transmission of the MAMP PDU, wherein the MAMP header comprises a concatenation indicator.

[0089] Example 7 is the apparatus of any of Examples 1-2, wherein the MAMP SDU includes an Internet Protocol (IP) header and an IP payload.

[0090] Example 8 is the apparatus of any of Examples 1-2, wherein the processing circuitry is further to: decode a network connection manager (NCM) signal, the NCM signal indicating a length of the concatenation timer.

[0091] Example 9 is the apparatus of any of Examples 1-2, wherein the MAMP MTU size exceeds an MTU size of an access network (e.g., cellular network).

[0092] Example 10 is the apparatus of any of Examples 1-2, wherein the MAMP SDU comprises a fragmentation control field, the fragmentation control field including information for reconstructing fragmented MAMP SDUs.

[0093] Example 11 is the apparatus of Example 10, wherein the information comprises two bits indicating whether the MAMP SDU is from a first fragment, a last fragment, a middle fragment, or an unfragmented packet.

[0094] Example 12 is the apparatus of any of Examples 1-2, wherein the wireless device comprises a user equipment (UE).

[0095] Example 13 is the apparatus of any of Examples 1-2, wherein the wireless device comprises an evolved NodeB (eNB).

[0096] Example 14 is the apparatus of any of Examples 1-2, wherein the processing circuitry comprises a baseband processor.

[0097] Example 15 is the apparatus of any of Examples 1-2, further comprising transceiver circuitry to: if adding the MAMP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined MAMP MTU size or the concatenation timer has expired: transmit the LWIPEP PDU.

5 **[0098]** Example 16 is the apparatus of Example 15, further comprising an antenna coupled to the transceiver circuitry.

[0099] Example 17 is the apparatus of a wireless device, the apparatus comprising: processing circuitry and memory; the processing circuitry to: decode an LWIPEP (long term evolution (LTE) / wireless local area network (WLAN) radio
10 level Integration Protocol Encapsulation Protocol) packet data unit (PDU) received via an LWIP (LTE/WLAN radio level Integration Protocol) tunnel; determine that the LWIPEP PDU includes multiple LWIPEP service data units (SDUs); determine, based on an LWIP trailer of the LWIPEP PDU, a length of a first SDU from the multiple LWIPEP SDUs; decode the first SDU based on the determined length of the
15 first SDU; determine, for each additional SDU from the multiple LWIPEP SDUs, a length based on an Internet Protocol (IP) header of the additional SDU; and decode each additional SDU.

[00100] Example 18 is the apparatus of Example 17, wherein the processing circuitry is to determine that the LWIPEP PDU includes multiple LWIPEP SDUs
20 based on a concatenation indicator in the LWIP trailer.

[00101] Example 19 is the apparatus of Example 17, wherein the LWIPEP PDU comprises: an Internet Protocol (IP) header, a tunneling header, the multiple LWIPEP SDUs, the LWIP trailer, and a tunneling trailer.

[00102] Example 20 is the apparatus of Example 17, wherein the processing
25 circuitry is further to: remove the LWIP trailer from the LWIPEP PDU.

[00103] Example 21 is the apparatus of Example 17, wherein the processing circuitry comprises a baseband processor.

[00104] Example 22 is the apparatus of Examples 17, further comprising transceiver circuitry to: receive the LWIPEP PDU.

30 **[00105]** Example 23 is the apparatus of Example 22, further comprising an antenna coupled to the transceiver circuitry.

[00106] Example 24 is a machine-readable medium storing instructions for execution by processing circuitry of a LWIP (long term evolution (LTE) / wireless

local area network (WLAN) radio level Integration Protocol) wireless device, the instructions causing the processing circuitry to: encode a LWIPEP (LTE/WLAN radio level Integration Protocol Encapsulation Protocol) service data unit (SDU) for transmission via an LWIP tunnel; determine whether adding the LWIPEP SDU to a concatenation buffer will cause a size of the concatenation buffer to exceed a predetermined LWIP maximum transfer unit (MTU) size; if adding the LWIPEP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined LWIP MTU size or a concatenation timer has expired: encode a transmission of one or more LWIPEP SDUs from the concatenation buffer within a LWIPEP packet data unit (PDU); and if adding the LWIPEP SDU to the concatenation buffer will not cause the concatenation buffer size to exceed the predetermined LWIP MTU size and the concatenation timer has not expired: add the LWIPEP SDU to the concatenation buffer.

[00107] Example 25 is the machine-readable medium of Example 24, wherein the LWIP wireless device comprises a user equipment (UE).

[00108] Example 26 is the machine-readable medium of Example 24, wherein the LWIP wireless device comprises an evolved NodeB (eNB).

[00109] Example 27 is an apparatus of a LWIP (long term evolution (LTE) / wireless local area network (WLAN) radio level Integration Protocol) wireless device, the apparatus comprising: means for decoding an LWIPEP (LTE/WLAN radio level Integration Protocol Encapsulation Protocol) packet data unit (PDU) received via an LWIP tunnel; means for determining that the LWIPEP PDU includes multiple LWIPEP service data units (SDUs); means for determining, based on an LWIP trailer of the LWIPEP PDU, a length of a first SDU from the multiple LWIPEP SDUs; means for decoding the first SDU based on the determined length of the first SDU; means for determining, for each additional SDU from the multiple LWIPEP SDUs, a length based on an Internet Protocol (IP) header of the additional SDU; and means for decoding each additional SDU.

[00110] Example 28 is the apparatus of Example 27, wherein the LWIP wireless device comprises an evolved NodeB (eNB).

[00111] Example 29 is the apparatus of Example 27, wherein the LWIP wireless device comprises a user equipment (UE).

[00112] Example 30 is an apparatus of a transmitter device, the apparatus comprising: processing circuitry and memory; the processing circuitry to: encode a LWIPEP (long term evolution (LTE) / wireless local area network (WLAN) radio level Integration Protocol Encapsulation Protocol) service data unit (SDU) for transmission to a receiver device via an LWIP (LTE/WLAN radio level Integration Protocol) tunnel; determine whether adding the LWIPEP SDU to a concatenation buffer will cause a size of the concatenation buffer to exceed a predetermined LWIP maximum transfer unit (MTU) size; if adding the LWIPEP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined LWIP MTU size or a concatenation timer has expired: encode a transmission of one or more LWIPEP SDUs from the concatenation buffer, within a LWIPEP packet data unit (PDU), to the receiver device; and if adding the LWIPEP SDU to the concatenation buffer will not cause the concatenation buffer size to exceed the predetermined LWIP MTU size and the concatenation timer has not expired: add the LWIPEP SDU to the concatenation buffer.

[00113] Example 31 is the apparatus of Example 30, wherein the LWIPEP PDU comprises: an Internet Protocol (IP) header, an IP security (IPSec) Encapsulating Security Payload (ESP) header, the one or more LWIPEP SDUs, an LWIP trailer or an LWIP header, an IPSec ESP trailer, and an IPSec ESP authentication (Auth) trailer.

[00114] Example 32 is the apparatus of Example 31, wherein the processing circuitry is further to: add the LWIP trailer to the LWIPEP PDU prior to transmission of the LWIPEP PDU, wherein the LWIP trailer comprises a concatenation indicator and an indication of an IP length of a first LWIPEP SDU from the one or more LWIPEP SDUs.

[00115] Example 33 is the apparatus of Example 32, wherein the concatenation indicator indicates whether the one or more LWIPEP SDUs include a single LWIPEP SDU or multiple LWIPEP SDUs.

[00116] Example 34 is the apparatus of Example 33, wherein the IP length of the first LWIPEP SDU is included only if the concatenation indicator indicates that multiple SDUs are included in the one or more LWIPEP SDUs.

[00117] Example 35 is the apparatus of Example 30, wherein the processing circuitry is further to: add the LWIP header to the LWIPEP PDU prior to transmission of the LWIPEP PDU, wherein the LWIP header comprises a concatenation indicator.

5 [00118] Example 36 is the apparatus of any of Examples 29-30, wherein the LWIPEP SDU includes an Internet Protocol (IP) header and an IP payload.

[00119] Example 37 is the apparatus of any of Examples 29-30, wherein the processing circuitry is further to: decode a radio resource control (RRC) signal from an evolved NodeB (eNB), the RRC signal indicating a length of the concatenation timer.

10 [00120] Example 38 is the apparatus of any of Examples 29-30, wherein the LWIP MTU size exceeds a cellular MTU size.

[00121] Example 39 is the apparatus of any of Examples 29-30, wherein the LWIPEP SDU comprises a fragmentation control field, the fragmentation control field including information for reconstructing fragmented LWIPEP SDUs at the
15 receiver device.

[00122] Example 40 is the apparatus of Example 39, wherein the information comprises two bits indicating whether the LWIPEP SDU is from a first fragment, a last fragment, a middle fragment, or an unfragmented packet.

[00123] Example 41 is the apparatus of any of Examples 29-30, wherein the
20 transmitter device comprises a user equipment (UE) and the receiver device comprises an evolved NodeB (eNB).

[00124] Example 42 is the apparatus of any of Examples 29-30, wherein the transmitter device comprises an evolved NodeB (eNB) and the receiver device comprises a user equipment (UE).

25 [00125] Example 43 is the apparatus of any of Examples 29-30, wherein the processing circuitry comprises a baseband processor.

[00126] Example 44 is the apparatus of any of Examples 29-30, further comprising transceiver circuitry to: if adding the LWIPEP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined
30 LWIP MTU size or the concatenation timer has expired: transmit the LWIPEP PDU to the receiver device.

[00127] Example 45 is the apparatus of Example 44, further comprising an antenna coupled to the transceiver circuitry.

[00128] 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. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings
5 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
10 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.

[00129] Although specific embodiments have been illustrated and described
15 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
20 description.

[00130] 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
25 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
30 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.

[00131] 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 a wireless device, the apparatus comprising:
5 processing circuitry and memory; the processing circuitry to:
encode a MAMP (multiple access management protocol) service data unit
(SDU) for transmission via a MAMP tunnel;
determine whether adding the MAMP SDU to a concatenation buffer will
cause a size of the concatenation buffer to exceed a predetermined MAMP maximum
10 transfer unit (MTU) size;
if adding the MAMP SDU to the concatenation buffer will cause the size of
the concatenation buffer to exceed the predetermined MAMP MTU size or a
concatenation timer has expired: encode one or more of MAMP SDUs from the
concatenation buffer, within a MAMP packet data unit (PDU), for transmission; and
15 if adding the MAMP SDU to the concatenation buffer will not cause the
concatenation buffer size to exceed the predetermined MAMP MTU size and the
concatenation timer has not expired: add the MAMP SDU to the concatenation buffer.
2. The apparatus of claim 1, wherein the MAMP PDU comprises: an
20 Internet Protocol (IP) header, a tunneling header, the one or more MAMP SDUs, a
MAMP trailer or a MAMP header, and a tunneling trailer.
3. The apparatus of claim 2, wherein the processing circuitry is further to:
add the MAMP trailer to the MAMP PDU prior to transmission of the MAMP
25 PDU, wherein the MAMP trailer comprises a concatenation indicator and an
indication of an IP length of a first MAMP SDU from the one or more MAMP SDUs.
4. The apparatus of claim 3, wherein the concatenation indicator indicates
whether the one or more MAMP SDUs include a single MAMP SDU or multiple
30 MAMP SDUs.

5. The apparatus of claim 4, wherein the IP length of the first MAMP SDU is included only if the concatenation indicator indicates that multiple SDUs are included in the one or more MAMP SDUs.

5 6. The apparatus of claim 2, wherein the processing circuitry is further to:
add the MAMP header to the MAMP PDU prior to transmission of the MAMP
PDU, wherein the MAMP header comprises a concatenation indicator.

7. The apparatus of any of claims 1-2, wherein the MAMP SDU includes
10 an Internet Protocol (IP) header and an IP payload.

8. The apparatus of any of claims 1-2, wherein the processing circuitry is
further to:
decode a network connection manager (NCM) signal, the NCM signal
15 indicating a length of the concatenation timer.

9. The apparatus of any of claims 1-2, wherein the MAMP MTU size
exceeds an MTU size of an access network.

20 10. The apparatus of any of claims 1-2, wherein the MAMP SDU
comprises a fragmentation control field, the fragmentation control field including
information for reconstructing fragmented MAMP SDUs.

11. The apparatus of claim 10, wherein the information comprises two bits
25 indicating whether the MAMP SDU is from a first fragment, a last fragment, a middle
fragment, or an unfragmented packet.

12. The apparatus of any of claims 1-2, wherein the wireless device
comprises a user equipment (UE).

30

13. The apparatus of any of claims 1-2, wherein the wireless device
comprises an evolved NodeB (eNB).

14. The apparatus of any of claims 1-2, wherein the processing circuitry comprises a baseband processor.

15. The apparatus of any of claims 1-2, further comprising transceiver circuitry to:

if adding the MAMP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined MAMP MTU size or the concatenation timer has expired: transmit the LWIPEP PDU.

16. The apparatus of claim 15, further comprising an antenna coupled to the transceiver circuitry.

17. An apparatus of a wireless device, the apparatus comprising: processing circuitry and memory; the processing circuitry to:

decode an LWIPEP (long term evolution (LTE) / wireless local area network (WLAN) radio level Integration Protocol Encapsulation Protocol) packet data unit (PDU) received via an LWIP (LTE/WLAN radio level Integration Protocol) tunnel; determine that the LWIPEP PDU includes multiple LWIPEP service data units (SDUs);

determine, based on an LWIP trailer of the LWIPEP PDU, a length of a first SDU from the multiple LWIPEP SDUs;

decode the first SDU based on the determined length of the first SDU;

determine, for each additional SDU from the multiple LWIPEP SDUs, a length based on an Internet Protocol (IP) header of the additional SDU; and

decode each additional SDU.

18. The apparatus of claim 17, wherein the processing circuitry is to determine that the LWIPEP PDU includes multiple LWIPEP SDUs based on a concatenation indicator in the LWIP trailer.

30

19. The apparatus of claim 17, wherein the LWIPEP PDU comprises: an Internet Protocol (IP) header, a tunneling header, the multiple LWIPEP SDUs, the LWIP trailer, and a tunneling trailer.

20. The apparatus of claim 17, wherein the processing circuitry is further to:

remove the LWIP trailer from the LWIPEP PDU.

5

21. The apparatus of claim 17, wherein the processing circuitry comprises a baseband processor.

10

22. The apparatus of claims 17, further comprising transceiver circuitry to: receive the LWIPEP PDU.

23. The apparatus of claim 22, further comprising an antenna coupled to the transceiver circuitry.

15

24. A machine-readable medium storing instructions for execution by processing circuitry of a LWIP (long term evolution (LTE) / wireless local area network (WLAN) radio level Integration Protocol) wireless device, the instructions causing the processing circuitry to:

20

encode a LWIPEP (LTE/WLAN radio level Integration Protocol Encapsulation Protocol) service data unit (SDU) for transmission via an LWIP tunnel; determine whether adding the LWIPEP SDU to a concatenation buffer will cause a size of the concatenation buffer to exceed a predetermined LWIP maximum transfer unit (MTU) size;

25

if adding the LWIPEP SDU to the concatenation buffer will cause the size of the concatenation buffer to exceed the predetermined LWIP MTU size or a concatenation timer has expired: encode a transmission of one or more LWIPEP SDUs from the concatenation buffer within a LWIPEP packet data unit (PDU); and

30

if adding the LWIPEP SDU to the concatenation buffer will not cause the concatenation buffer size to exceed the predetermined LWIP MTU size and the concatenation timer has not expired: add the LWIPEP SDU to the concatenation buffer.

25. The machine-readable medium of claim 24, wherein the LWIP wireless device comprises a user equipment (UE).

26. The machine-readable medium of claim 24, wherein the LWIP
5 wireless device comprises an evolved NodeB (eNB).

27. An apparatus of a LWIP (long term evolution (LTE) / wireless local area network (WLAN) radio level Integration Protocol) wireless device, the apparatus comprising:

10 means for decoding an LWIPEP (LTE/WLAN radio level Integration Protocol Encapsulation Protocol) packet data unit (PDU) received via an LWIP tunnel;

means for determining that the LWIPEP PDU includes multiple LWIPEP service data units (SDUs);

15 means for determining, based on an LWIP trailer of the LWIPEP PDU, a length of a first SDU from the multiple LWIPEP SDUs;

means for decoding the first SDU based on the determined length of the first SDU;

means for determining, for each additional SDU from the multiple LWIPEP SDUs, a length based on an Internet Protocol (IP) header of the additional SDU; and

20 means for decoding each additional SDU.

28. The apparatus of claim 27, wherein the LWIP wireless device comprises an evolved NodeB (eNB).

25 29. The apparatus of claim 27, wherein the LWIP wireless device comprises a user equipment (UE).

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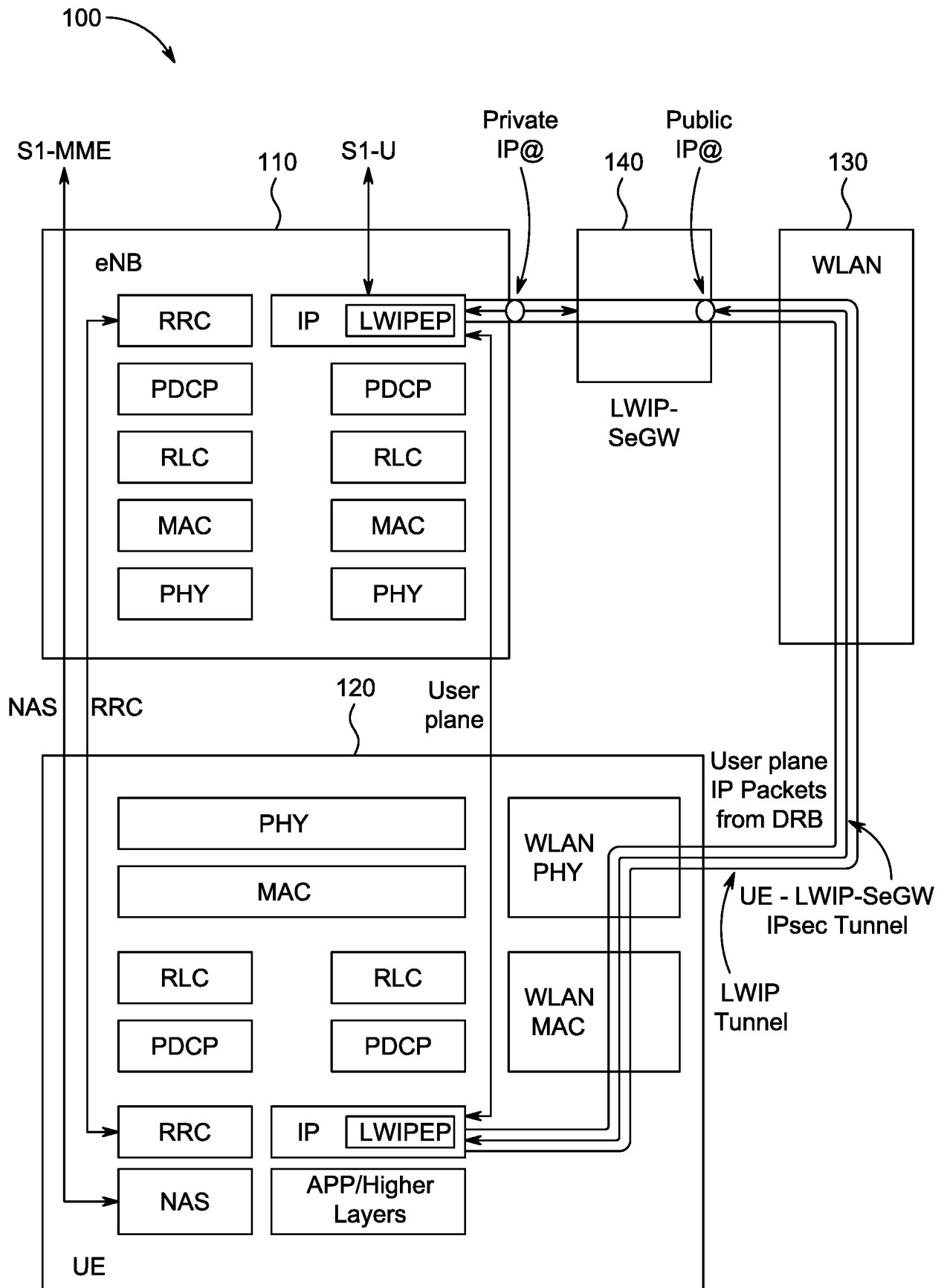


FIG. 1

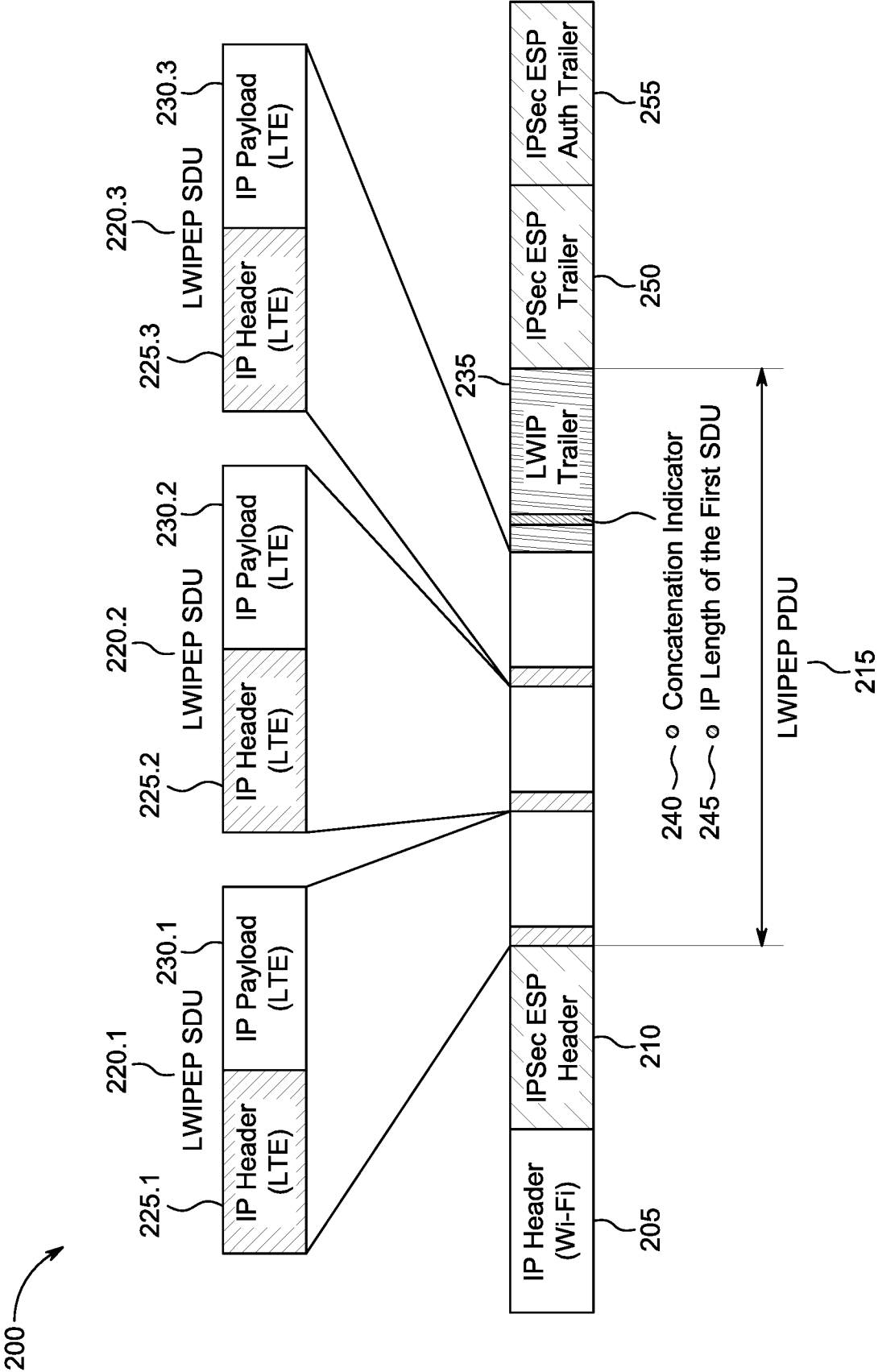


FIG. 2

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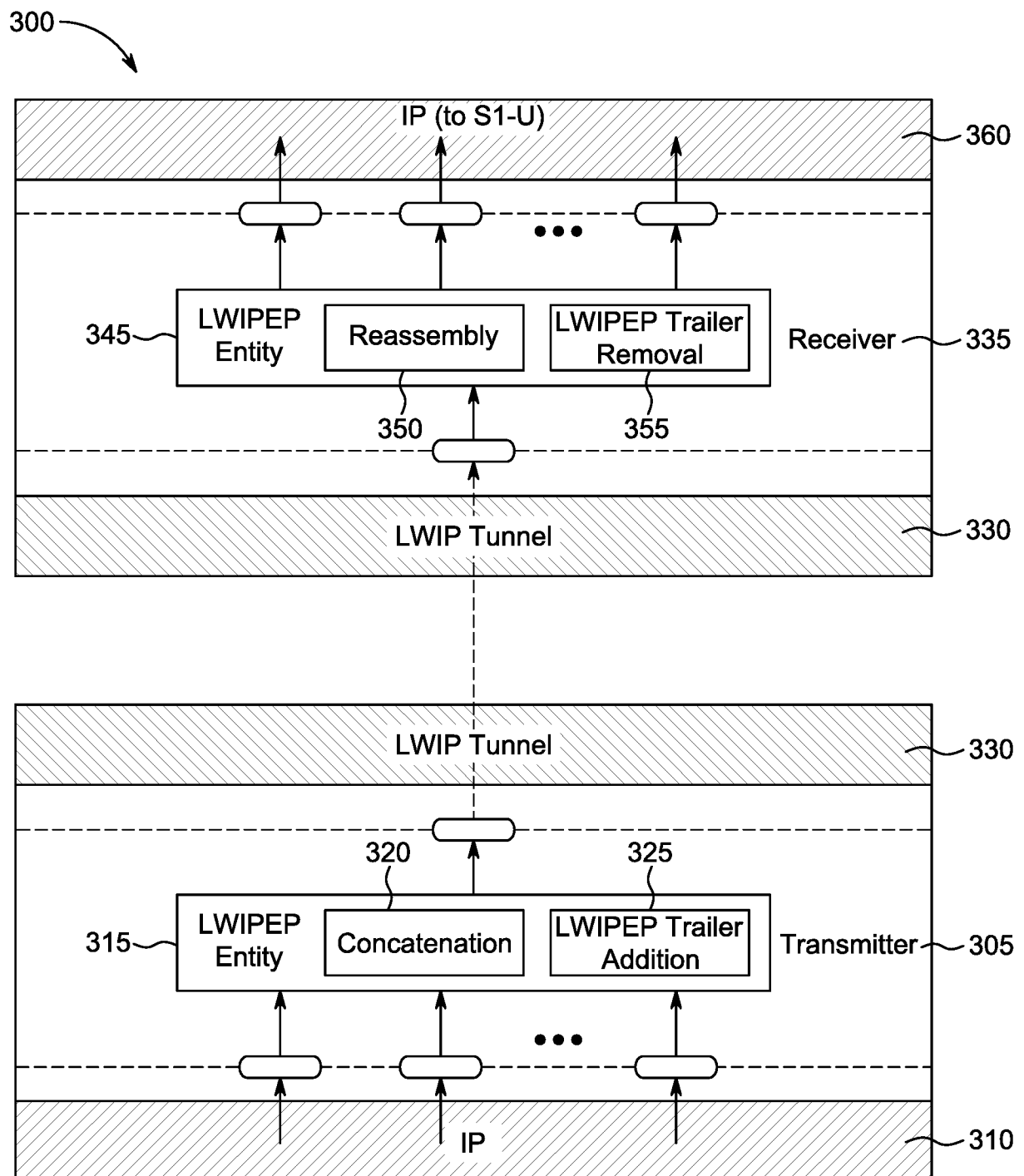


FIG. 3

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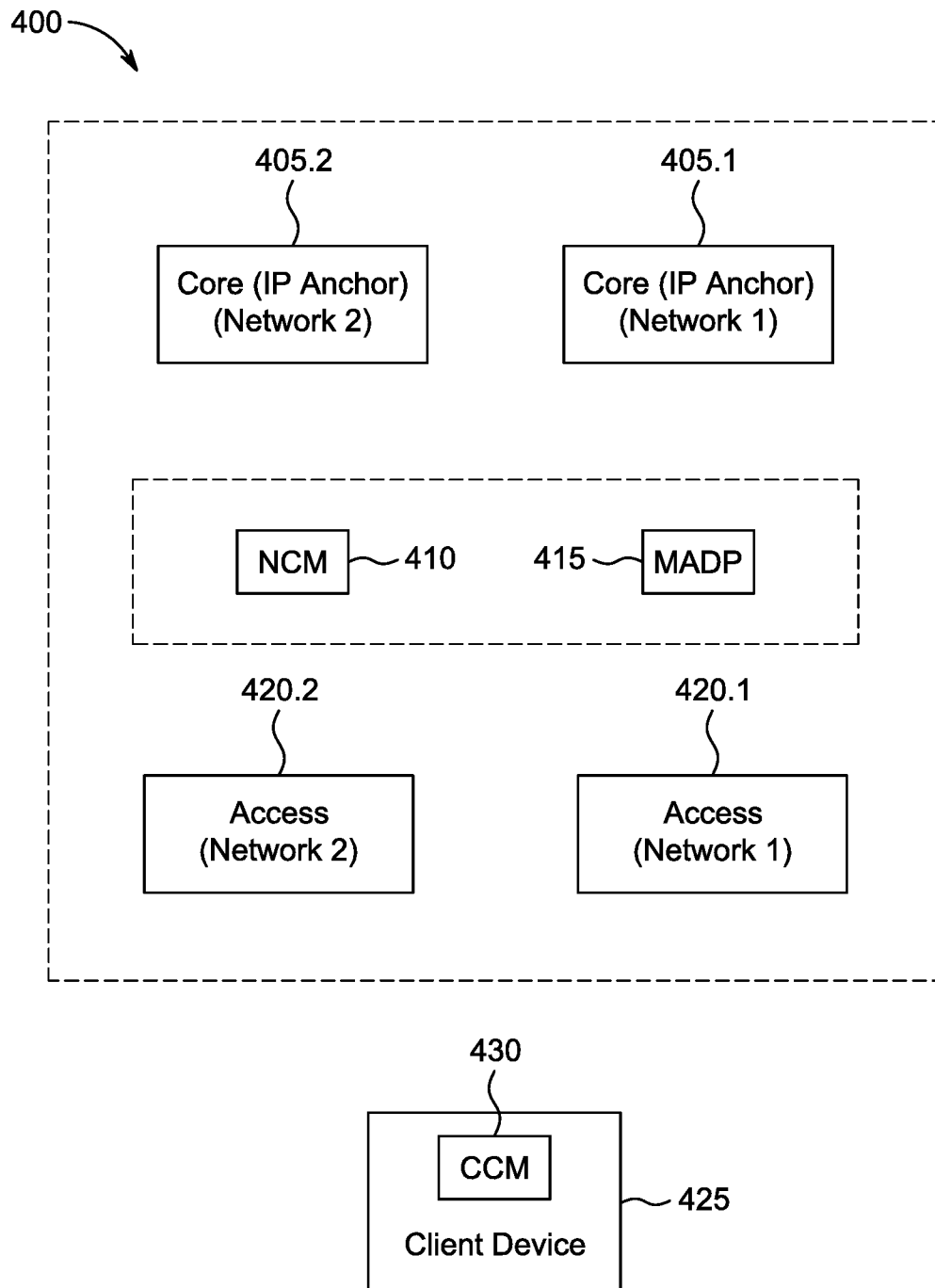


FIG.4

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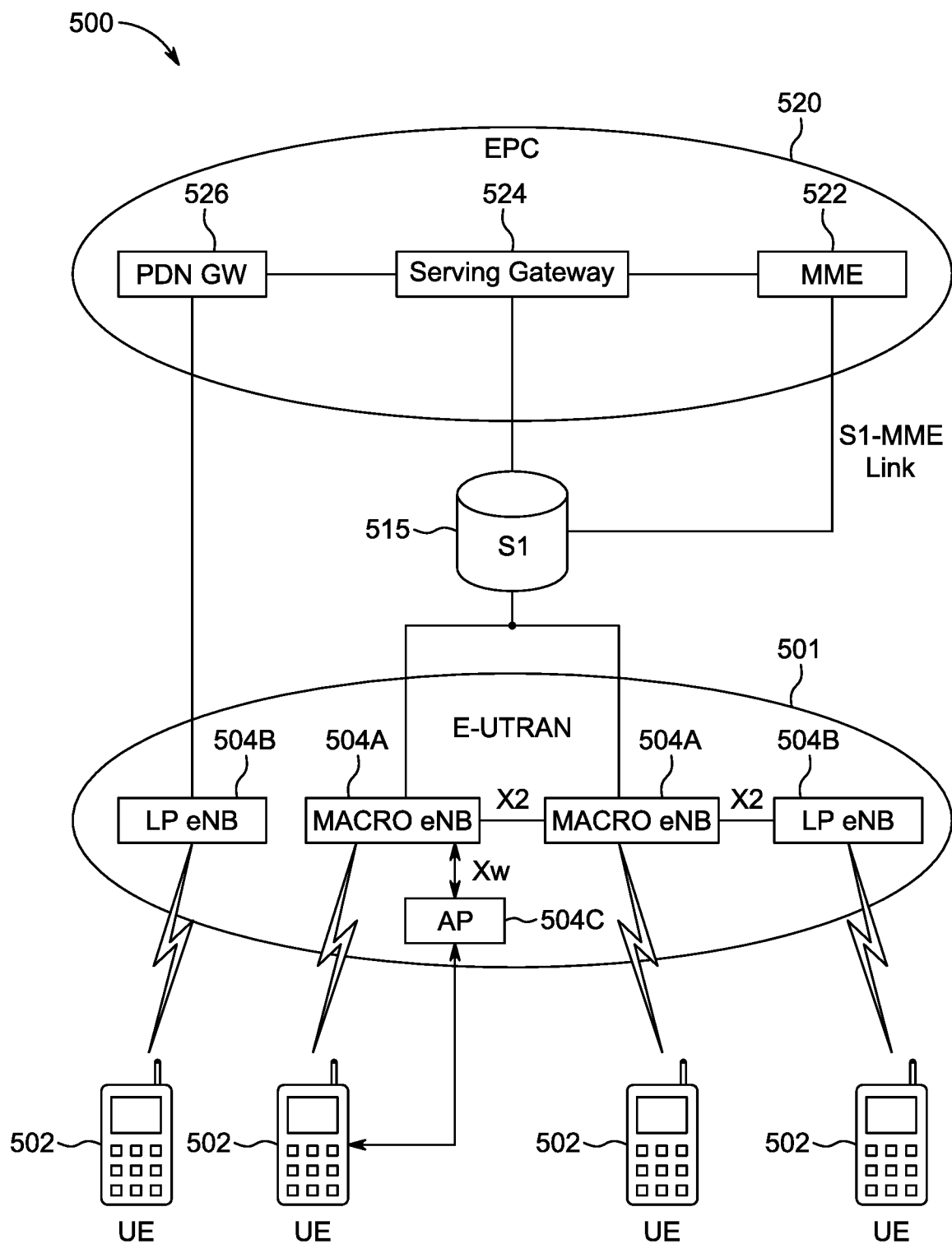


FIG. 5

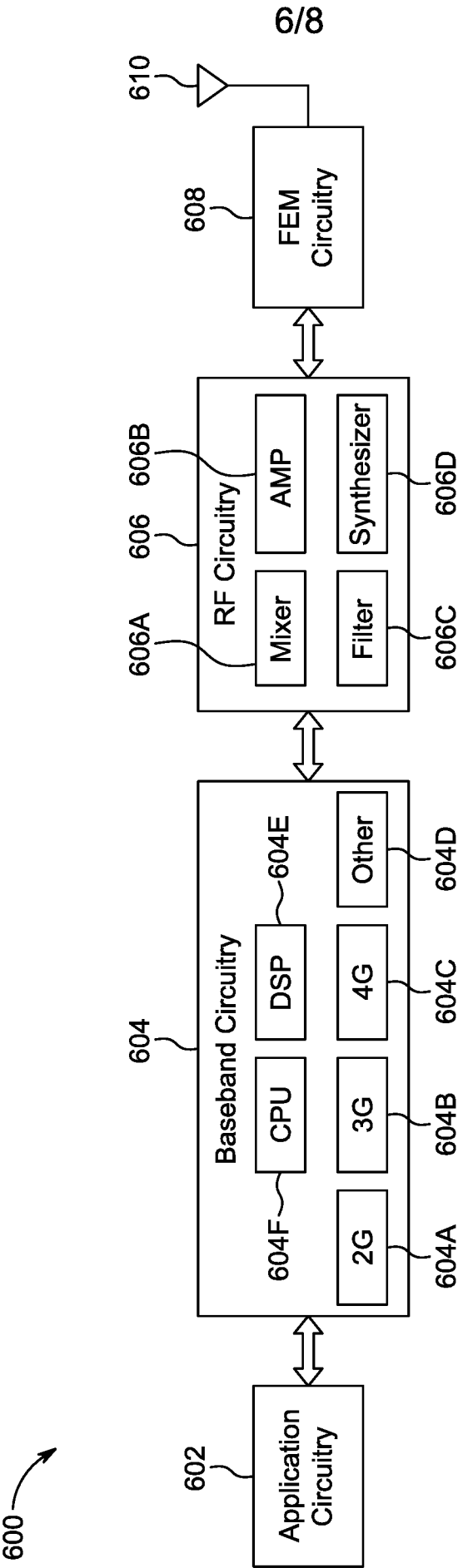


FIG. 6

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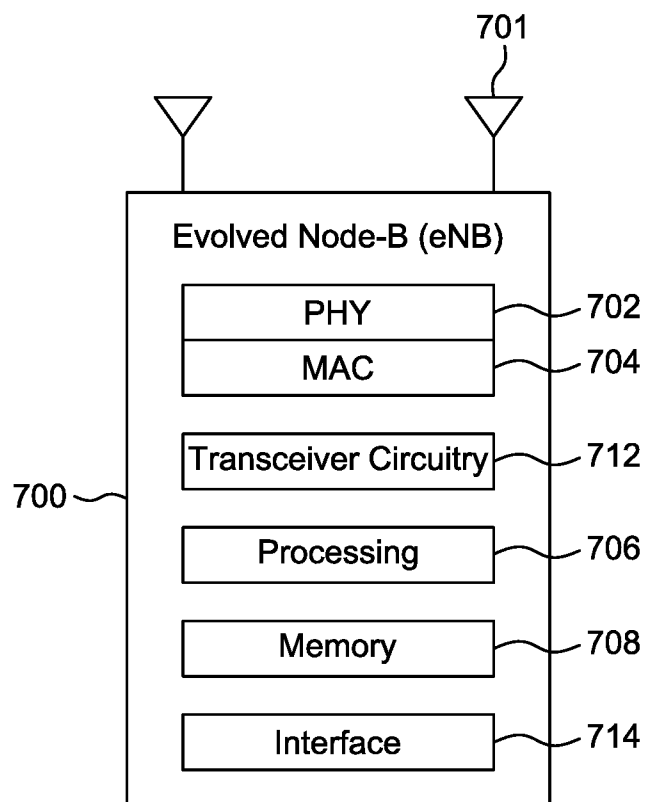


FIG. 7

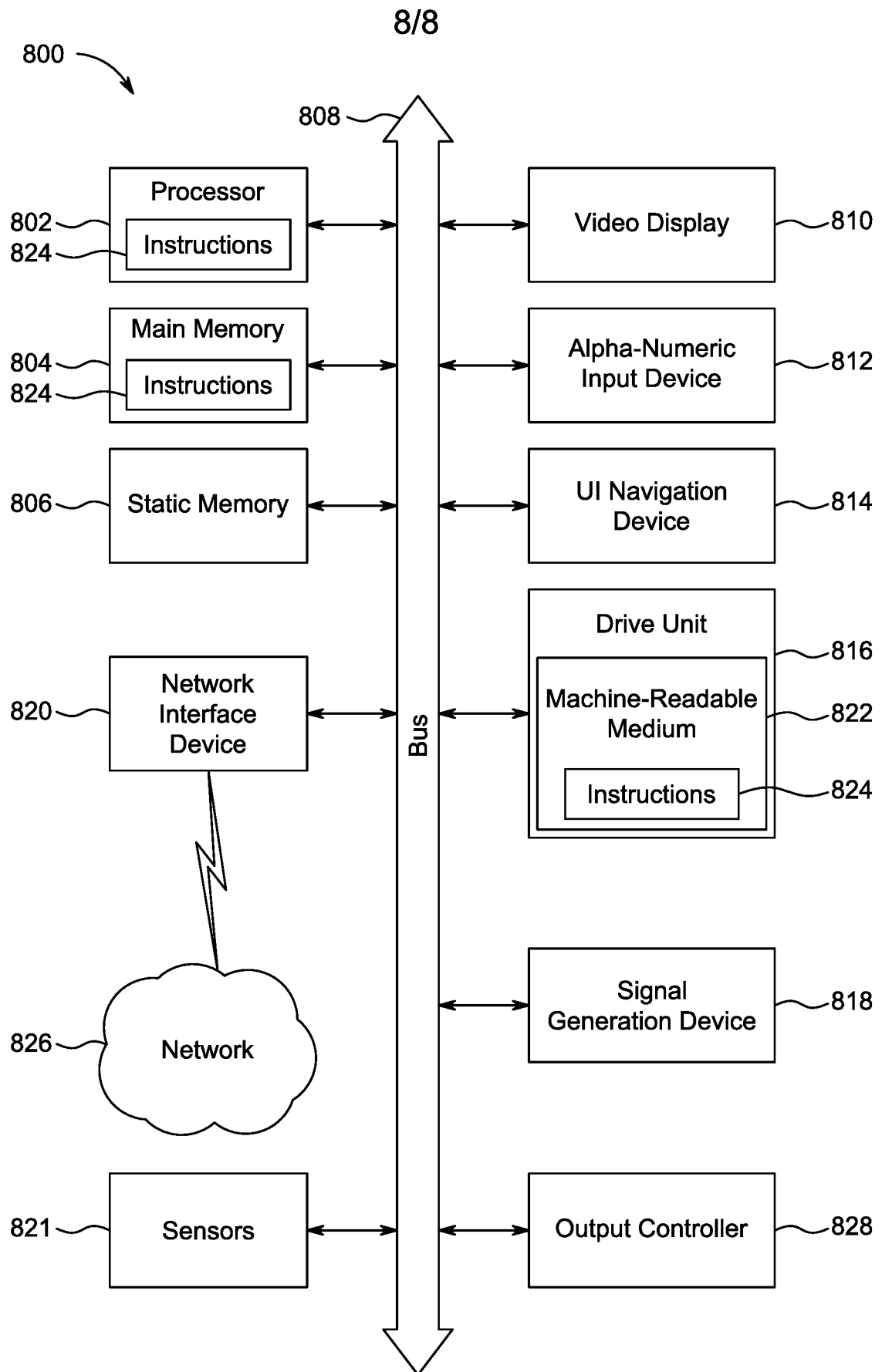


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/054243**A. CLASSIFICATION OF SUBJECT MATTER****H04L 29/08(2006.01)i, H04L 29/06(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L 29/08; H04W 72/12; H04L 5/00; H04W 76/02; H04W 48/18; H04W 28/02; H04W 12/08; H04L 29/06

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: MAMP, LWIPEP, LTE, WLAN, PDU, SDU, concatenation, buffer, size, tunnel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RICHARD BURBIDGE, "LTE-WLAN Aggregation (LWA) and LTE WLAN Radio Level Integration with IPsec Tunnel (LWIP)", IEEE meeting, Macao, 18 March 2016 < http://www.3gpp.org/images/PDF/2016_03_LWA_LWIP_3GPPpresentation.pdf > See pages 3-24.	1-29
A	US 2016-0119939 A1 (INTEL IP CORPORATION) 28 April 2016 See paragraphs [0015], [0017], [0074], [0083]; and figure 1.	1-29
A	KR 10-1480703 B1 (NTELS CO., LTD.) 09 January 2015 See paragraphs [0036]-[0050] and figure 1.	1-29
A	US 2013-0272260 A1 (YIGAL BITTRAN et al.) 17 October 2013 See paragraphs [0034]-[0055] and figure 1.	1-29
A	US 2015-0188680 A1 (FUJITSU LIMITED) 02 July 2015 See paragraphs [0002], [0119]-[0120]; and figures 6(A)-6(B).	1-29

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"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

20 January 2017 (20.01.2017)

Date of mailing of the international search report

01 February 2017 (01.02.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

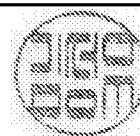
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/054243

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