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(54) **SYSTEMS AND METHODS FOR ACCESSING CELLULAR NETWORK VIA WIRELESS LOCAL AREA NETWORK**

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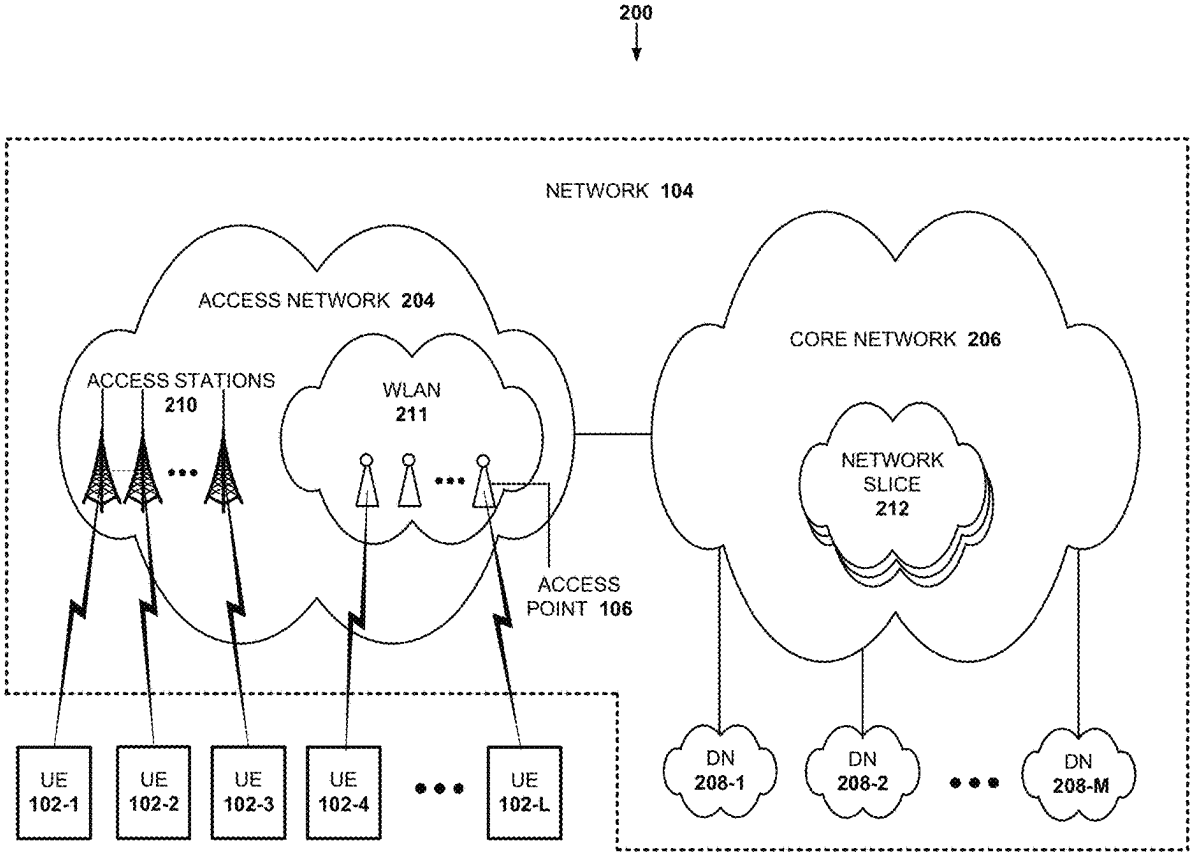
(57) **ABSTRACT**

A device may be hosted by a cellular network. The device may include a processor. The processor may be configured to: receive a request from a User Equipment device (UE) to connect to the cellular network; and determine whether the UE includes a Fifth Generation (5G) Non-Standalone (NSA) device or a 5G Standalone (SA) device. If the UE is determined to include a 5G NSA device, the processor may perform a Fourth Generation (4G) authentication via 4G core network components included in the cellular network; and if the UE is determined to include a 5G SA device, the processor may perform a 5G authentication via 5G core network components included in the cellular network. When the 4G authentication or the 5G authentication is successful, the processor may establish a session with an endpoint in the cellular network.



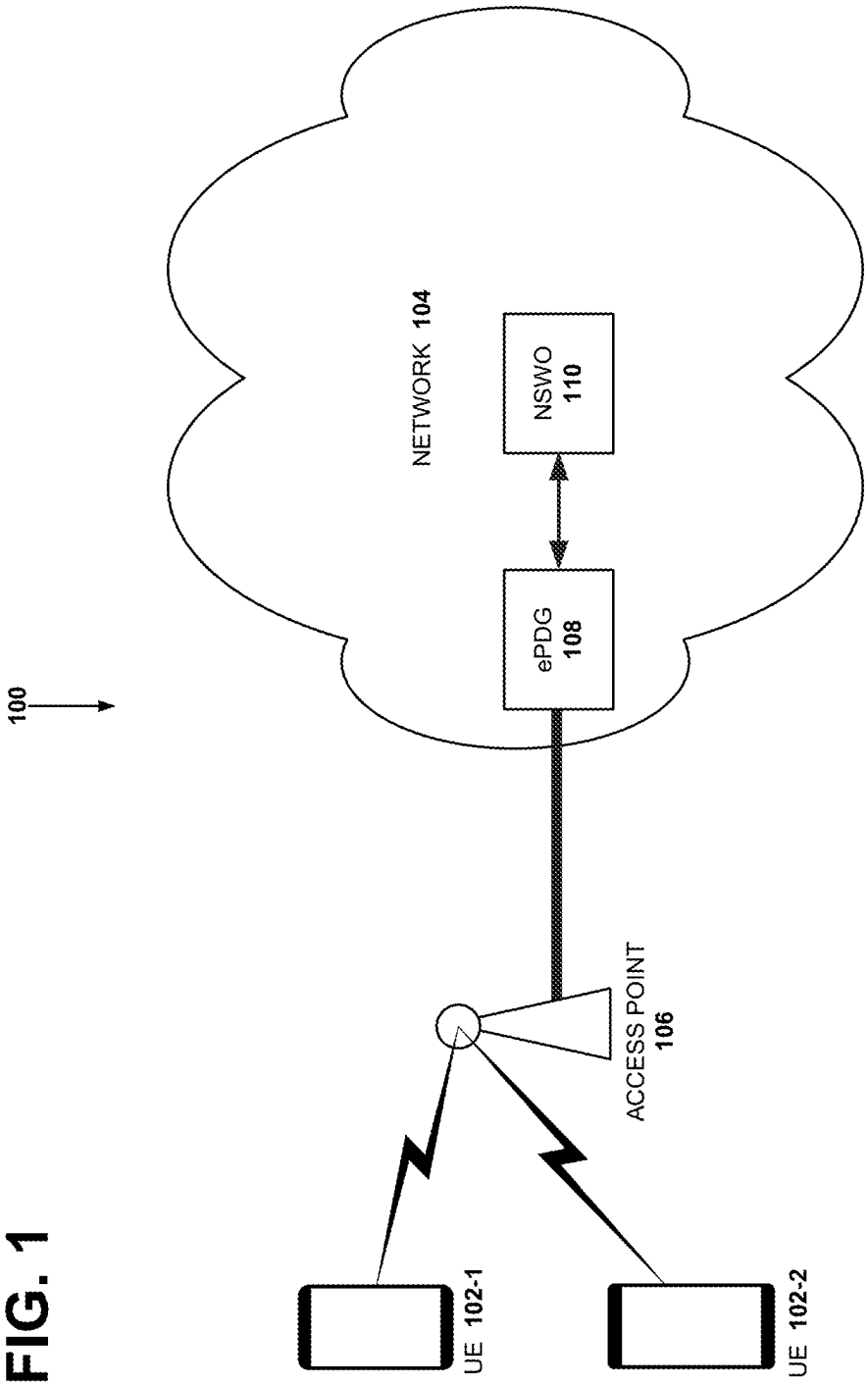
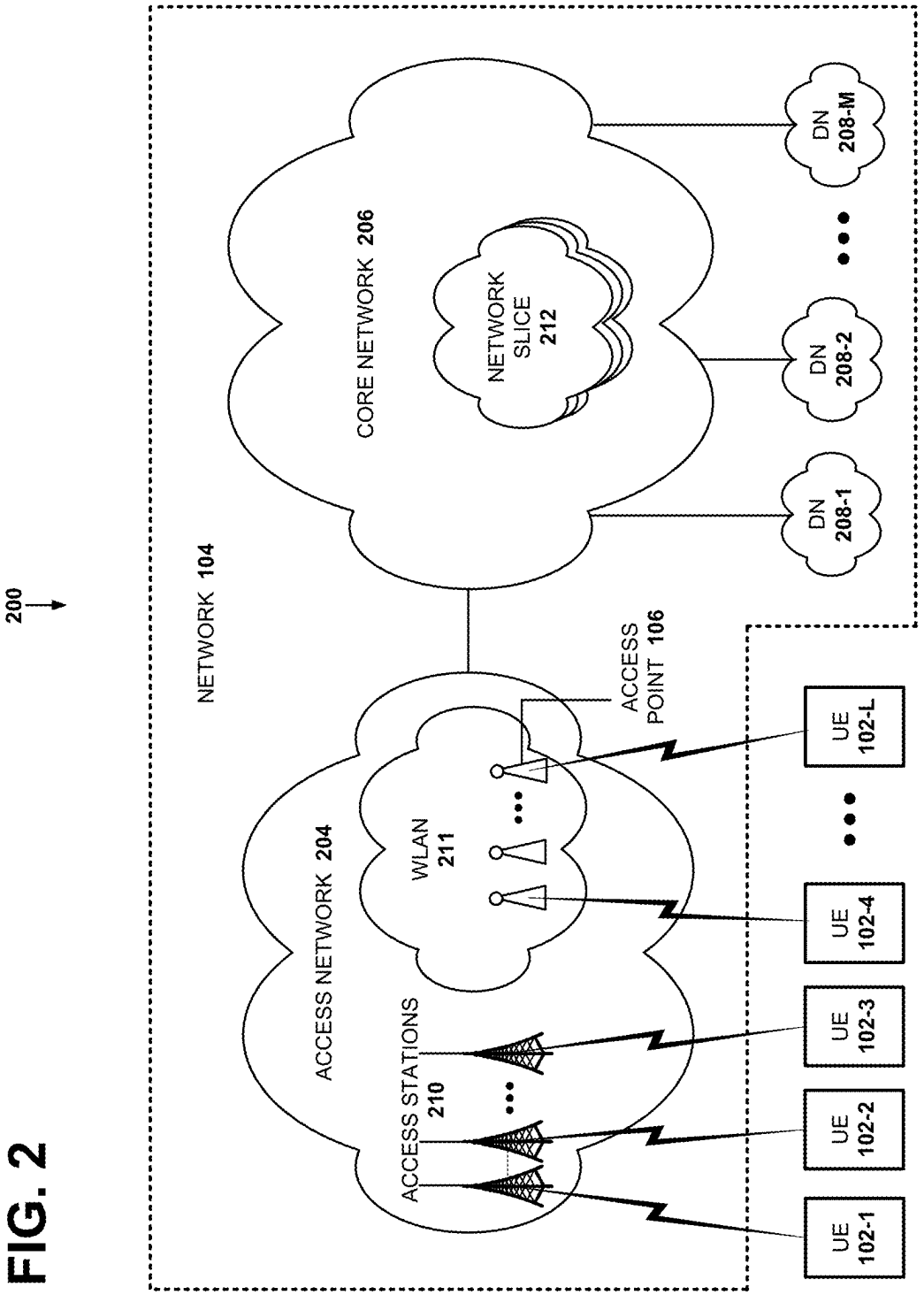

100
NETWORK 104
NSWO 110
ePDG 108
ACCESS POINT 106
UE 102-1
UE 102-2

FIG. 1

FIG. 2


200
NETWORK 104
CORE NETWORK 206
NETWORK SLICE 212
DN 208-1
DN 208-2
DN 208-M
ACCESS NETWORK 204
WLAN 211
ACCESS STATIONS 210
ACCESS POINT 106
UE 102-1
UE 102-2
UE 102-3
UE 102-4
UE 102-L

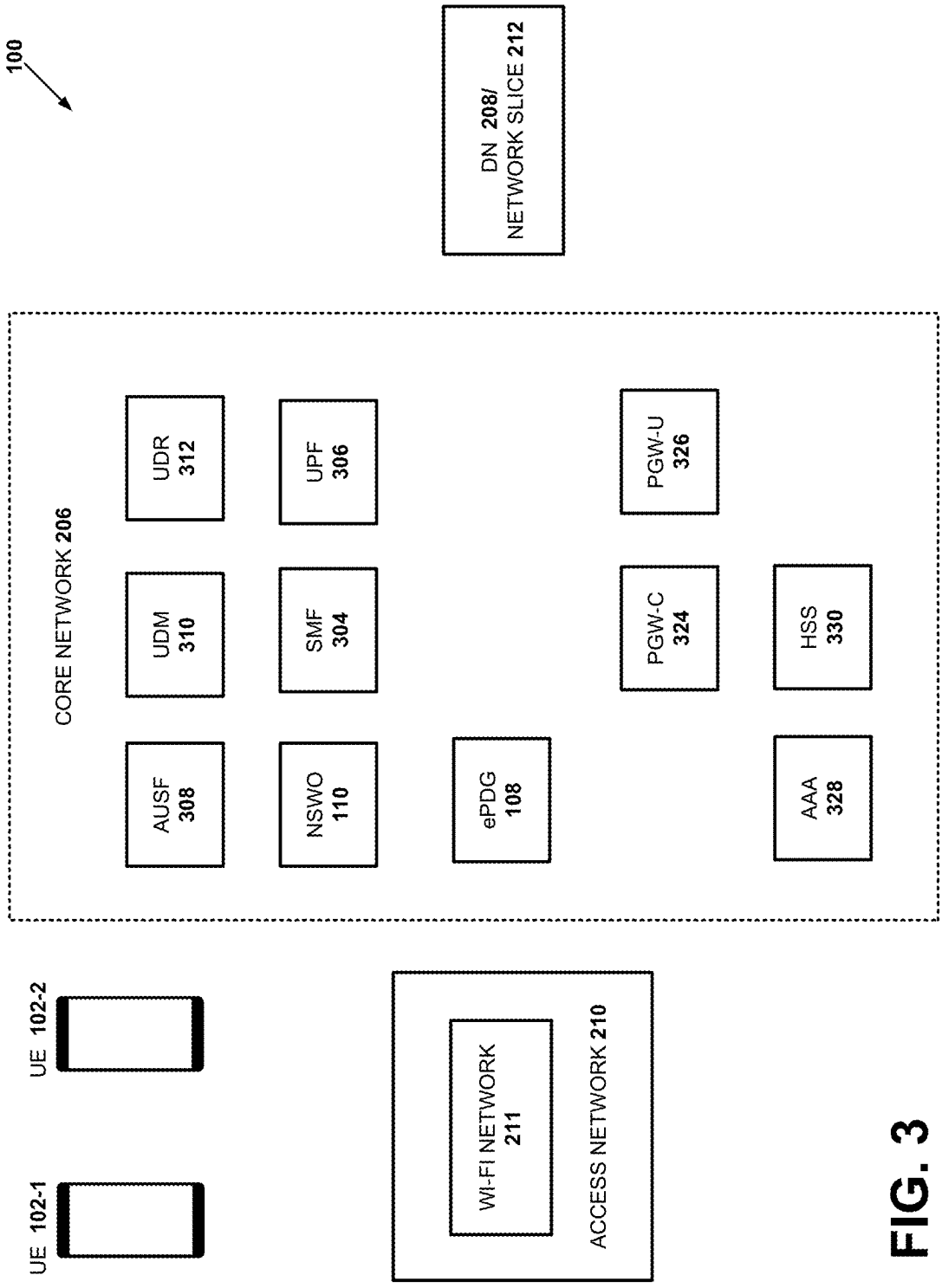

100
DN 208/
NETWORK SLICE 212
CORE NETWORK 206
UDR
312
UPF
306
PGW-U
326
UDM
310
SMF
304
PGW-C
324
HSS
330
AUSF
308
NSWO
110
ePDG
108
AAA
328
UE 102-2
UE 102-1
WI-FI NETWORK
211
ACCESS NETWORK 210

FIG. 3

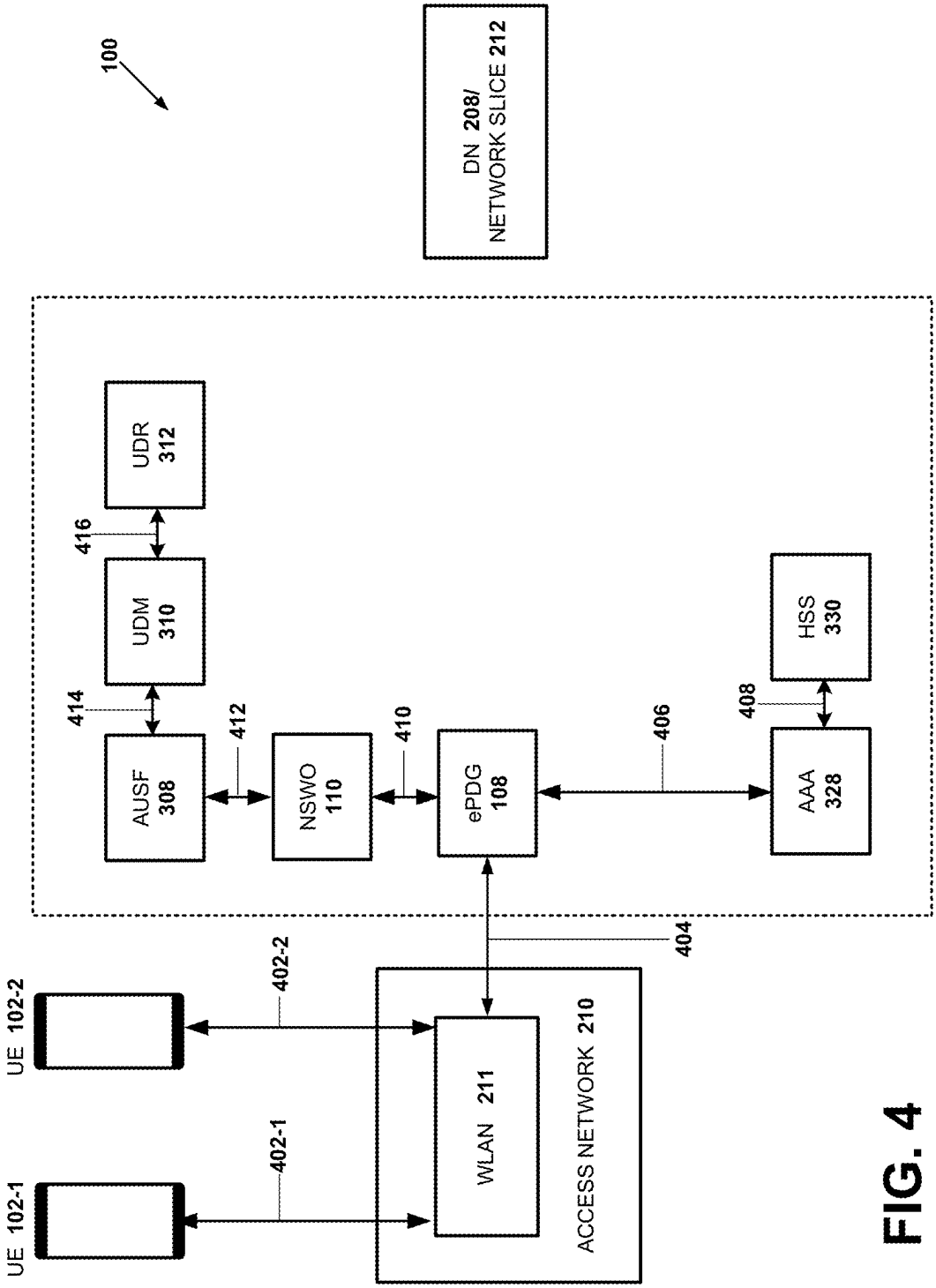

100
DN 208/
NETWORK SLICE 212
UDR
312
416
UDM
310
414
AUSF
308
412
NSWO
110
410
ePDG
108
406
408
HSS
330
AAA
328
404
402-2
402-1
UE 102-2
UE 102-1
WLAN 211
ACCESS NETWORK 210

FIG. 4

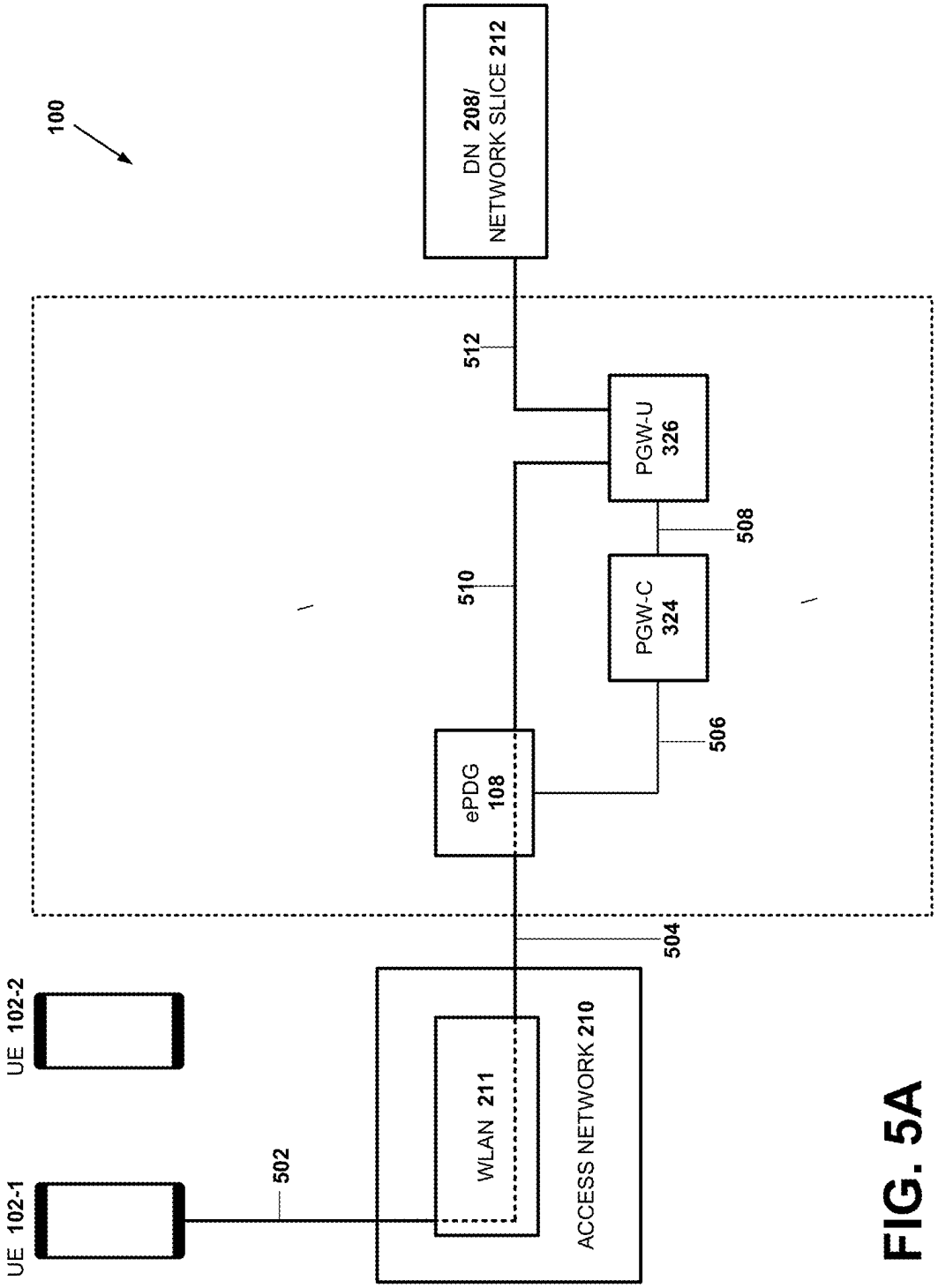

100
DN 208/
NETWORK SLICE 212
512
PGW-U
326
508
510
PGW-C
324
506
ePDG
108
504
UE 102-2
UE 102-1
502
WLAN 211
ACCESS NETWORK 210

FIG. 5A

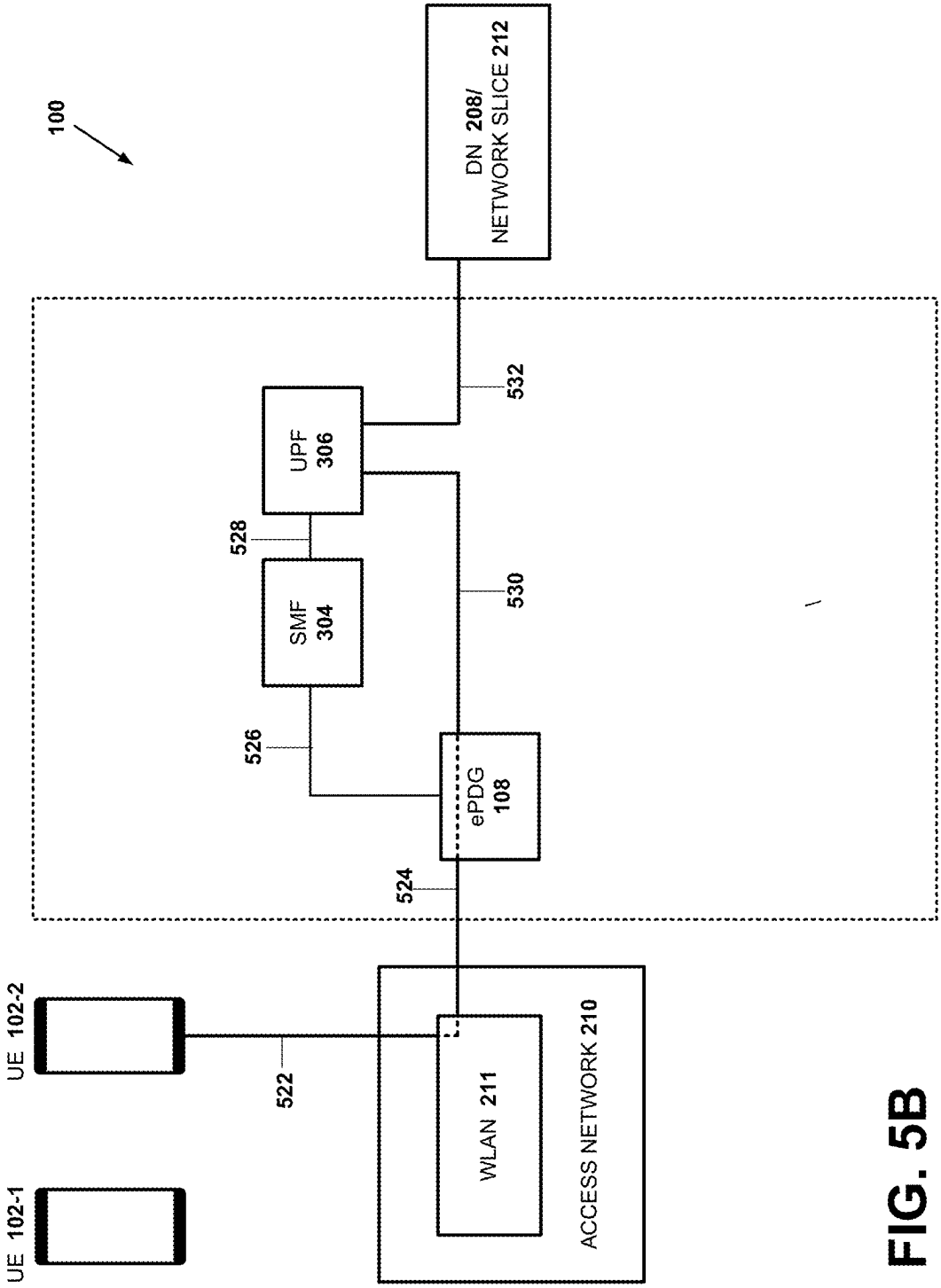

100
DN 208/
NETWORK SLICE 212
532
UPF
306
528
SMF
304
530
526
ePDG
108
524
UE 102-2
522
WLAN 211
ACCESS NETWORK 210
UE 102-1

FIG. 5B

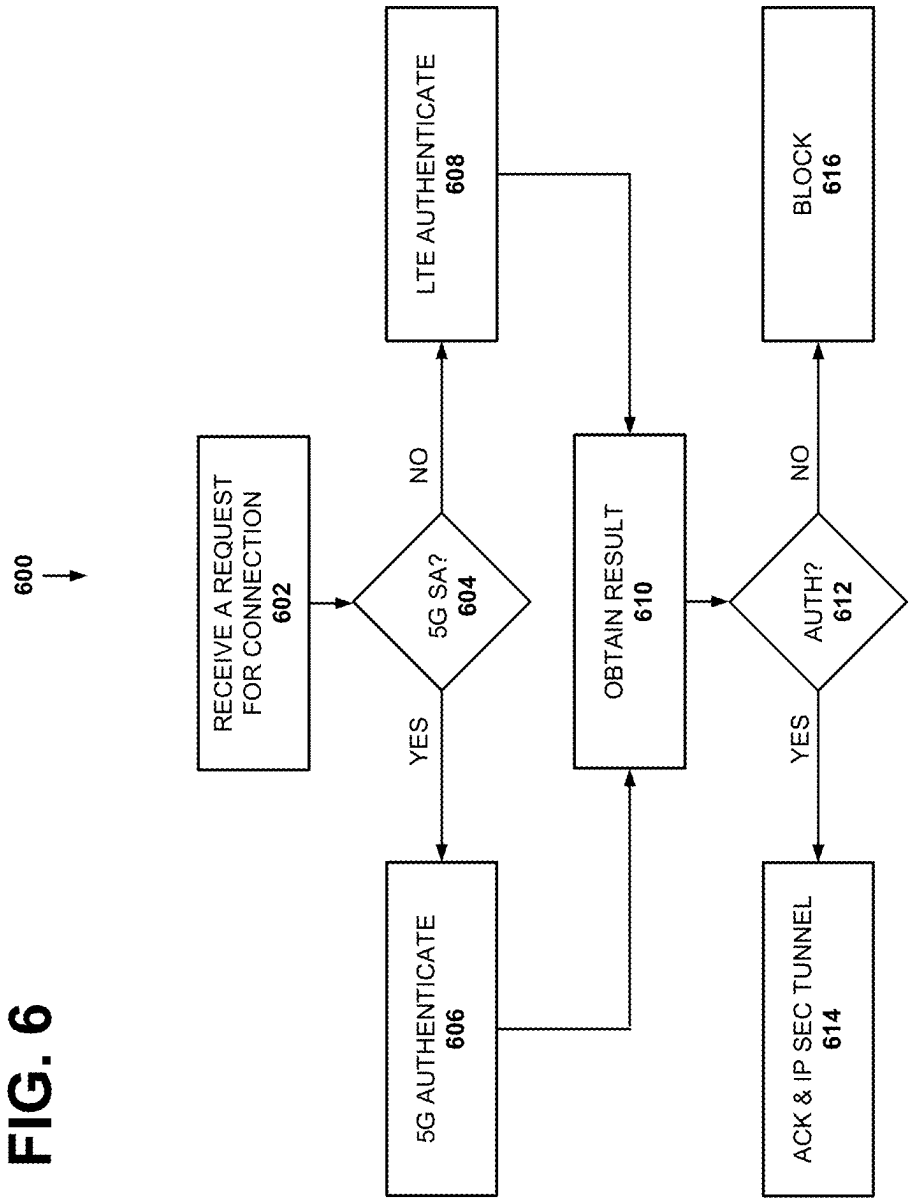

600
RECEIVE A REQUEST FOR CONNECTION 602
5G SA? 604
NO
YES
LTE AUTHENTICATE 608
5G AUTHENTICATE 606
OBTAIN RESULT 610
AUTH? 612
NO
YES
BLOCK 616
ACK & IP SEC TUNNEL 614

FIG. 6

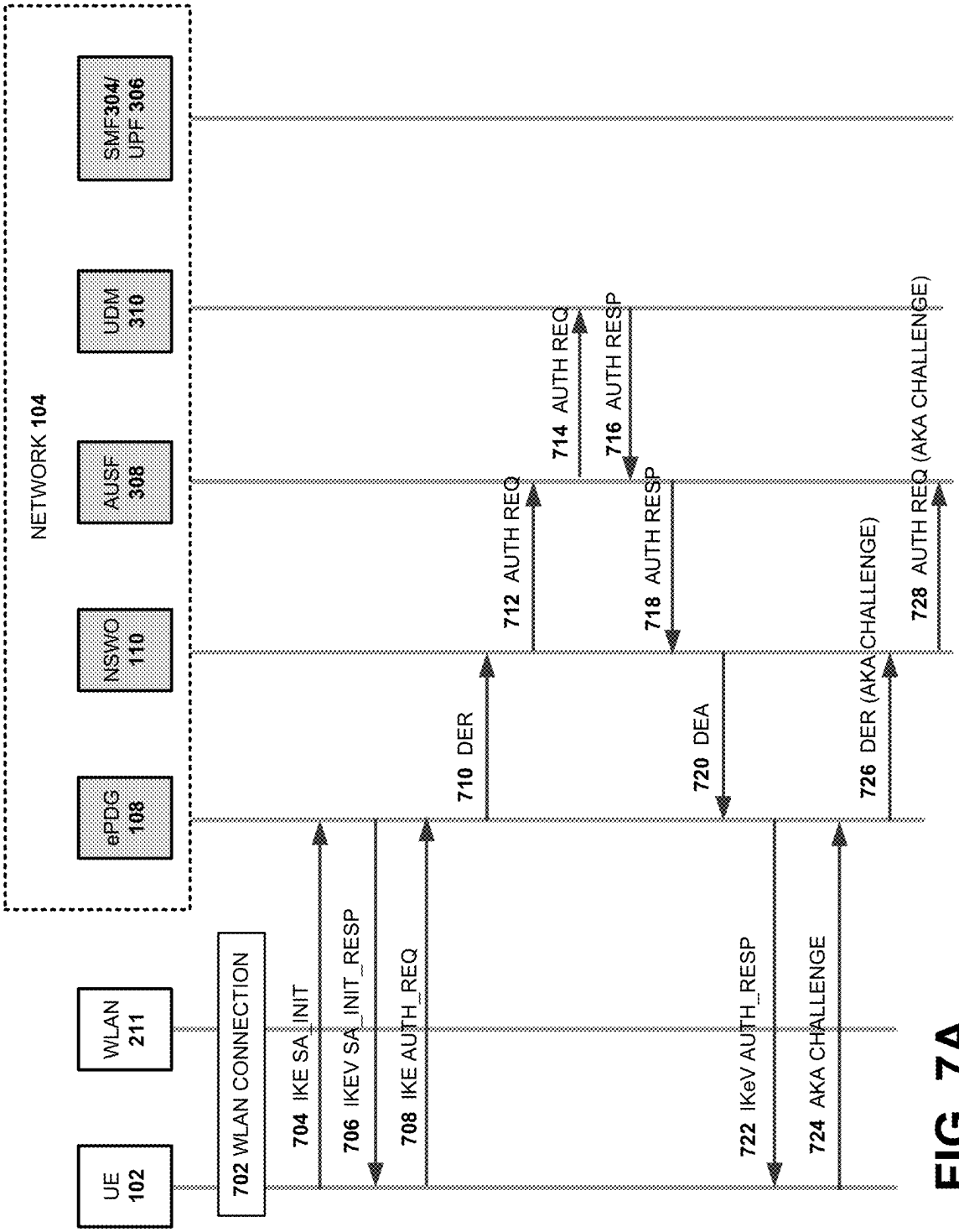

UE 102
WLAN 211
NETWORK 104
ePDG 108
NSWO 110
AUSF 308
UDM 310
SMF304/ UPF 306
702 WLAN CONNECTION
704 IKE SA_INIT
706 IKEV SA_INIT_RESP
708 IKE AUTH_REQ
710 DER
712 AUTH REQ
714 AUTH REQ
716 AUTH RESP
718 AUTH RESP
720 DEA
722 IKeV AUTH_RESP
724 AKA CHALLENGE
726 DER (AKA CHALLENGE)
728 AUTH REQ (AKA CHALLENGE)

FIG. 7A

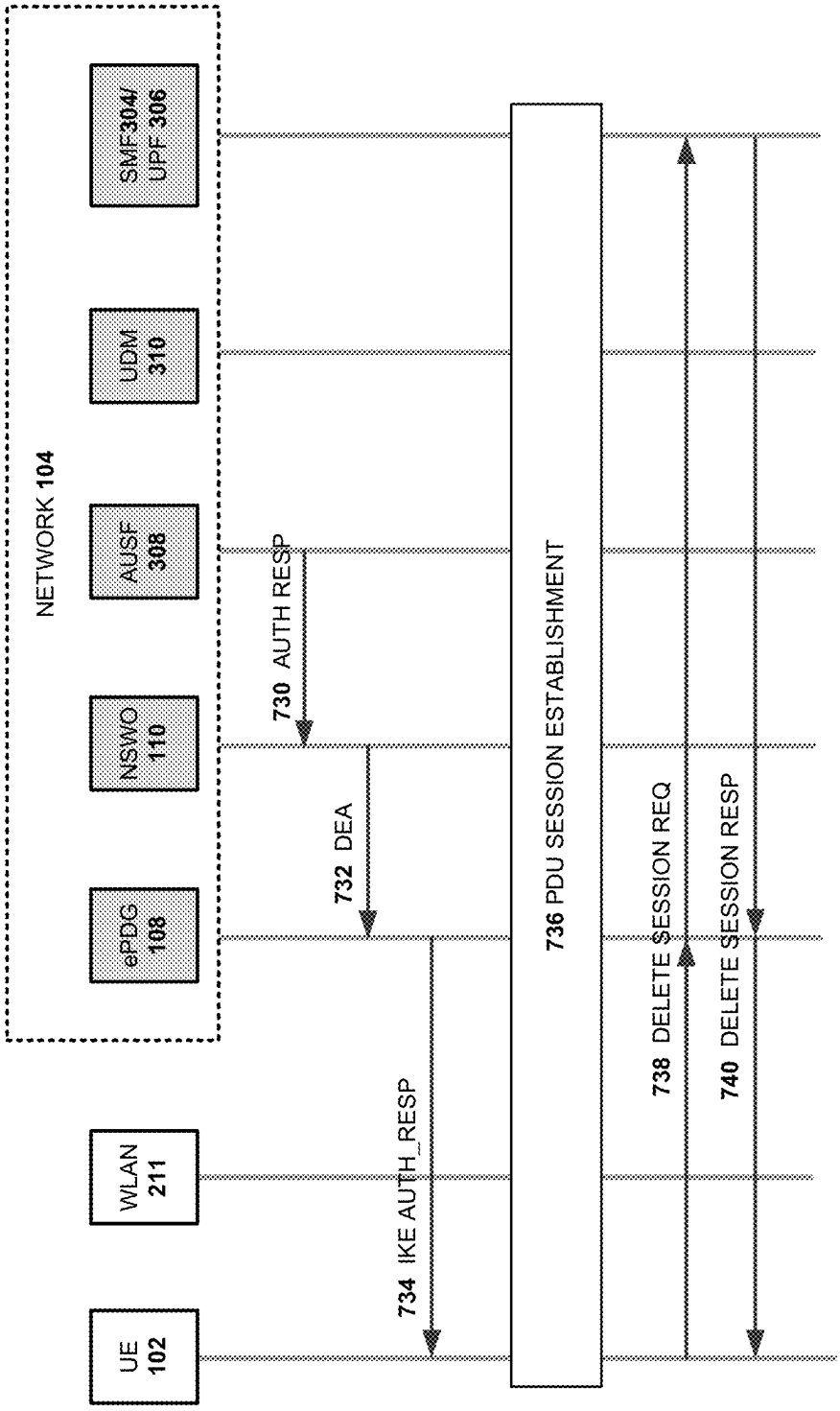
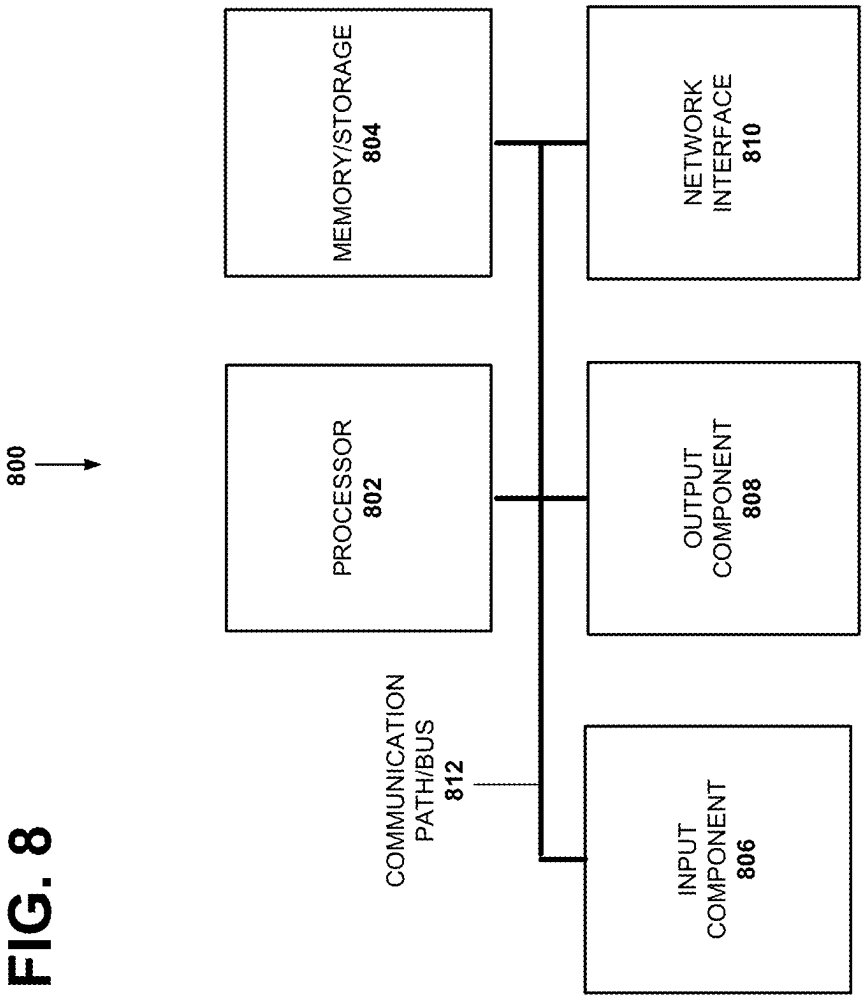

NETWORK 104
UE 102
WLAN 211
ePDG 108
NSWO 110
AUSF 308
UDM 310
SMF304/ UPF 306
730 AUTH RESP
732 DEA
734 IKE AUTH_RESP
736 PDU SESSION ESTABLISHMENT
738 DELETE SESSION REQ
740 DELETE SESSION RESP

FIG. 7B

FIG. 8


800
PROCESSOR
802
MEMORY/STORAGE
804
NETWORK
INTERFACE
810
OUTPUT
COMPONENT
808
INPUT
COMPONENT
806
COMMUNICATION
PATH/BUS
812

SYSTEMS AND METHODS FOR ACCESSING CELLULAR NETWORK VIA WIRELESS LOCAL AREA NETWORK

BACKGROUND INFORMATION

[0001] During initial deployment of Fifth Generation (5G) New Radio (NR) networks, many mobile network operators (MNOs) built their 5G networks using a combination of Fourth Generation (4G) network equipment and 5G network equipment based on a 5G non-standalone (NSA) network architecture. In a 5G non-standalone network architecture, a 5G radio access network (RAN) interoperates with 4G Long Term Evolution (LTE) RAN, a 4G core network, and/or a 5G core network. Many of today's mobile devices (e.g., a smart phone) may include 5G SA devices (e.g., devices capable of connecting to and receiving services from a 5G SA network) or 5G NSA devices (e.g., devices capable of communicating to and receiving services from a 5G NSA network).

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** illustrates an overview of an exemplary system for accessing a cellular network via a wireless local area network (WLAN).

[0003] FIG. **2** illustrates an exemplary network environment in which systems and methods described herein may be implemented, according to an implementation.

[0004] FIG. **3** depicts exemplary components, of a system, which are included in a core network and a network environment, according to an implementation.

[0005] FIG. **4** shows exemplary signaling paths through different components of a system for accessing a cellular network via a WLAN, according to an implementation.

[0006] FIGS. **5**A and **5**B show exemplary data paths through different components of a system for accessing a cellular network via a WLAN, according to an implementation.

[0007] FIG. **6** shows a flow diagram of an exemplary process that is associated with accessing a cellular network via a WLAN, according to an implementation.

[0008] FIGS. **7**A and **7**B show exemplary messages that are exchanged by network components during a process for accessing a cellular network via a WLAN, according to an implementation.

[0009] FIG. **8** depicts exemplary components of an exemplary network device according to an implementation.

DETAILED DESCRIPTION

[0010] The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements. As used herein, the terms "service provider" and "provider network" may refer to, respectively, a provider of communication services and a network operated by the service provider. The network may be a cellular network. A cellular network may be uniquely identified by a Public Land Mobile Network (PLMN) Identifier (ID).

[0011] The systems and methods described herein relate to accessing a cellular network via a wireless local area network (WLAN). More specifically, the systems and methods permit both Fifth Generation (5G) Standalone (SA) devices and 5G Non-Standalone (NSA) devices that are wirelessly attached a WLAN to access a cellular network via the WLAN. Currently, 5G NSA devices and 5G SA devices may use different mechanisms to access a 5G NSA network and a 5G SA network, respectively. For example, when a 5G NSA device attaches to a WLAN, the 5G NSA device may access a cellular network through an evolved Packet Data Gateway (ePDG) within the cellular network. In contrast, when a 5G SA device attaches to a WLAN, the 5G SA device may access a cellular network through a Non-Seamless Wireless Offload (NSWO) device. To render services to both 5G NSA and SA devices, therefore, the systems described herein include ePDGs and NSWOs, both modified to permit the ePDGs and the NSWOs to interoperate.

[0012] FIG. **1** illustrates an overview of an exemplary system **100** for accessing a cellular network via a WLAN. As shown, system **100** may include User Equipment devices (UE) **102-1** and **102-2** (e.g., mobile devices such as smart phones), a cellular network **104** (or simply referred to as network **104**), a wireless access point device **106** included in a WLAN (not shown in FIG. **1**), and a NSWO device (NSWO) **110**. These components are described below in greater detail with reference to FIGS. **2-6**, **7**A, and **7**B. Assume that UE **102-1** includes a 5G NSA device and that UE **102-2** includes a 5G SA device. UE **102-1** may or may not include the capability to notify ePDG **108** that UE **102-1** is a 5G NSA device. UE **102-2** includes the capability to notify ePDG **108** that UE **102-2** is a 5G SA device.

[0013] When UE **102-1** attaches to the WLAN via access point device **106** (e.g., a WI-FI access point device), UE **102-1** may send a message to ePDG **108**, requesting a connection to network **104**. If UE **102-1** does not identify itself as a 5G NSA device, ePDG **108** may assume that UE **102-1** includes a 5G NSA device and may follow a Fourth Generation (4G) or Long-Term Evolution (LTE) authentication procedure that involves 4G or LTE core network components of system **100**. If the authentication is successful, UE **102-1** may then establish an IPSec tunnel with ePDG **108** and a session with another endpoint in network **104**. Thus, system **100** may permit UE **102-1** (e.g., 5G NSA device) to access cellular network **104** and its services via the WLAN.

[0014] Similarly, when UE **102-2** attaches to the WLAN via access point device **106**, UE **102-2** may send a message to ePDG **108**, requesting a connection to network **104**. In contrast to UE **102-1**, however, UE **102-2** indicates that UE **102-2** includes a 5G SA device. Upon receipt of the 5G SA device indication from UE **102-2**, ePDG **108** may request an NSWO **110** to 5G authenticate UE **102-2**. Next, NSWO **110** may follow a 5G authentication procedure that involves UE **102-2** and 5G core (5GC) components of system **100**. If the 5G authentication is successful, UE **102-2** may establish an IPSec tunnel with ePDG **108** and a session with another endpoint in network **104**. Thus, system **100** permits UE **102-2** (e.g., 5G SA device), as well as UE **102-1** (e.g., 5G NSA device), to access cellular network **104** via the WLAN.

[0015] FIG. **2** illustrates an exemplary network environment **200** in which system **100** and methods associated with system **100** may be implemented. As shown, network environment **200** may include UEs **102-1** through **102**-L (collectively referred to as UEs **102** and generically as UE **102**), an access network **204**, a core network **206**, and data networks **208-1** through **208**-M (collectively referred to as data networks **208** and generically as data network **208**). Access network **204**, core network **206**, and data networks **208** may be part of cellular network **104**.

[0016] UE **102** may include a wireless communication device. Examples of UE **102** include: a smart phone; a tablet device; a wearable computer device (e.g., a smart watch); a global positioning system (GPS) device; a laptop computer; a media playing device; a portable gaming system; an Internet-of-Things (IoT) device, etc. In some implementations, UE **102** may correspond to a wireless Machine-Type-Communication (MTC) device that communicates with other devices over a machine-to-machine (M2M) interface, such as LTE-M or Category M1 (CAT-M1) devices and Narrow Band (NB)-IoT devices.

[0017] When a UE **102** attaches to a WLAN (e.g., a WLAN **211**), the UE **102** may send a request to ePDG **108** to connect to network **104**. Depending on whether UE **102** includes a 5G NSA device or a 5G SA device, UE **102** may behave differently in requesting ePDG **108** to permit UE **102** to access network **108**. For example, when UE **102** is implemented as a 5G NSA device, UE **102** may or may not provide, in the request, an indication that UE **102** includes a 5G NSA device. In contrast, when UE **102** is implemented as a 5G SA device, UE **102** may provide, in the request, an indication that UE **102** includes a 5G SA device. Whether UE **102** includes a 5G NSA device or a 5G SA device, after sending the request to ePDG **108**, UE **102** may authenticate at network **104** via ePDG **108** and establish a session with an endpoint located in network **104**. If UE **102** includes a 5G NSA device, the endpoint may include another UE **102**, a component in access network **204** (e.g., a Multi-access Edge Computing (MEC) cluster, a component in core network **206**, or a component in data network **208**. If UE **102** includes a 5G SA device, the endpoint may include another UE **102**, a MEC cluster, a component in core network **206**, a component in a network slice **212** (described below), or a component in data network **208**.

[0018] Access network **204** may include a 5G New Radio (NR) network, an LTE radio network, an LTE-Advanced radio network, or another type of radio network. These networks may include many central units (CUs), distributed units (DUs), radio units (RUS), and access stations, which are illustrated in FIG. **2** as access stations **210** for establishing and maintaining over-the-air broadband channels with UEs **102**. Each access station **210** may include a 4G, 5G, or another type of base station (e.g., eNB, gNB, etc.) that comprises one or more radio frequency (RF) transceivers. In some implementations, access station **210** may be part of an evolved Universal Mobile Telecommunications Service (UMTS) Terrestrial Network (eUTRAN).

[0019] Access network **204** may include, in addition to radio access networks (RANs), other networks via which UE **102** may access core network **206**. For example, access network **204** may include various IP networks, such as the Internet, or WLANs, such as a WLAN **211**. WLAN **211** may include a wireless local area network whose components operate in accordance with various Institute of Electrical and Electronics Engineering (IEEE) 802.11 protocols. WLAN **211** may include devices that use radio waves to communicate in, for example, 2.4 GHz band and/or 5 GHz band, as well as other wired network devices, such as Ether net devices. As shown, WLAN **211** may include one or more access point devices, such as a wireless access point device **106**, to which UEs **102** may attach wirelessly. Once UE **102** attaches to WLAN **211** via access point device **106**, UE **102** may forward a request to ePDG **108** via one or more networks (e.g., the Internet) to request a session with network **104**.

[0020] Core network **206** may include one or more devices and network components for providing communication services to UEs **102**. For example, core network **206** may permit UEs **102** to attach to network **104**, establish sessions with devices in network **104**, and/or receive services from network **104** (e.g., receive content, access the Internet, conduct video conferences with other UEs **102** attached to network **104**). To deliver services, core network **206** may interface with other networks, such as data networks **208**. To render these services and to perform the core functions of network **104**, core network **206** may include 5G core network components or 4G core network components. Some of these components, which may include ePDG **108** and NSWO **110** (shown in FIG. **1** but not in FIG. **2**), are described below in greater detail with reference to FIGS. **3**-**7**B.

[0021] As further shown, core network **206** may include one or more of network slice **212** (collectively referred to network slices **212** and generically referred to as network slice **212**). Depending on the implementation, network slice **212** may be implemented within other networks, such as access network **204** and/or data networks **208**. Access network **204**, core network **206**, and data networks **208** may include multiple instances of network slices **212**. Each network slice **212** may be instantiated as a result of network slicing, which involves a form of virtual network architecture that enables multiple logical networks to be implemented on top of a shared physical network infrastructure using software defined networking (SDN) and/or network function virtualization (NFV). Each logical network, referred to as a "network slice," may encompass an end-to-end virtual network with dedicated storage and/or computational resources that include access network components, clouds, transport components, Central Processing Unit (CPU) cycles, memory, etc. Furthermore, each network slice **212** may be configured to meet a different set of requirements and may be associated with a particular Quality-of-Service (QoS) Class Identifier (QCI), 5G QoS Identifier (5Q1), and/or a particular group of enterprise customers associated with communication devices.

[0022] Network slices **212** may be capable of supporting enhanced Mobile Broadband (eMBB) traffic, Ultra Reliable Low Latency Communication (URLLC) traffic, Time Sensitive Network (TSN) traffic, Massive IoT (MIoT) traffic, Vehicle-to-Everything (V2X) traffic, High performance Machine Type Communication (HMTC) traffic, and other customized traffic, for example. Each network slice **212** may be associated with an identifier, herein referred to as a Single Network Slice Selection Assistance Information (S-NSSAI) and/or a network slice instance ID. Many components in core network **206** may manage S-NSSAIs (or simply NSSAI).

[0023] Data networks **208** may include one or more networks connected to core network **206**. In some implementations, a particular data network **208** may be associated with a data network name (DNN) in 5G and/or an Access Point Name (APN) in 4G. UE **102** may request a connection to data network **208** using a DNN or APN. Each data network **208** may include and/or be connected to a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), an autonomous system on the Internet, an

optical network, a cable television network, a satellite network, another wireless network (e.g., a Code Division Multiple Access (CDMA) network, a general packet radio service (GPRS) network, and/or an LTE network), a telephone network (e.g., the Public Switched Telephone Network (PSTN) or a cellular network), an intranet, an ad hoc network, or a combination of networks.

[0024] For clarity, FIG. **2** does not show all components that may be included in network environment **200** (e.g., routers, bridges, additional networks, additional access stations **210**, access point devices **106**, WLANs **211**, data centers, portals, etc.). Depending on the implementation, network environment **200** may include additional, fewer, different, or a different arrangement of components than those illustrated in FIG. **2**. Furthermore, in different implementations, the configuration of network environment **200** may be different.

[0025] FIG. **3** depicts exemplary components, of system **100**, which are included in core network **206** and network environment **200**, according to an implementation. As shown, core network **206** may include ePDG **108**, NSWO **110**, a Session Management Function (SMF) **304**, a User Plane Function (UPF) **306**, an Authentication Server Function (AUSF) **308**, a Unified Data Management (UDM) **310**, and a Unified Data Repository (UDR) **312**, a Packet data network Gateway-Control Plane (PGW-C) **324**, a PGW-User Plane (PGW-U) **326**, an Authentication Authorization and Accounting server (AAA) **328**, and a Home Subscriber Server **330**. In some implementations, NSWO **110**, SMF **304**, UPF **306**, AUSF **308**, UDM **310**, and UDR **312** may be part of and be included in a 5G core (5GC); and ePDG **108**, PGW-C **324**, PGW-U **326**, AAA **328**, and HSS **330** may be part of and be included in a 4G core (e.g., Evolved Packet Core (EPC)). FIG. **3** also shows UEs **102-1** and **102-2**, access network **204**, and WLAN **211**, which have been described above with reference to FIGS. **1** and **2**. Depending on the implementation, core network **206** may include additional, fewer, or different components than those illustrated in FIG. **3**.

[0026] ePDG **108** may provide access to network **104** to UEs **102** attached to WLAN **211**. ePDG **108** may be capable of setting up an IPSec tunnel between UE **102** and ePDG **108**. To set up an IPSec tunnel, ePDG **208** may apply, within the framework of Extensible Authentication Protocol (EAP), the Internet Key Exchange protocol version 2 (IKEv2), and Authentication and Key Agreement protocols (EAP-AKA and EAP-AKA'). EAP-AKA and EAP-AKA' may provide mechanisms for exchanging keys and establishing secure communication channels between UEs **102** and network **104**. ePDG **108** may provide communications from UE **102** (e.g., via an IPSec tunnel) to other components in core network **206** using interfaces specific to the components of core network **206**.

[0027] NSWO **110** may include capability to authenticate UE **102** attached to WLAN **108** using 5G credentials. NSWO **110** may apply EAP-AKA' to UE-provided credentials and subscriber data from UDM **310** and/or UDR **312**. ePDG **108** and NSWO **110** may provide the above-described capabilities via modifications to standard interfaces and/or addition of new interfaces. These capabilities for enabling UE **102** to access cellular network **104** via WLAN **211** are described below in greater detail with reference to FIGS. **4-7**B.

[0028] SMF **304** may: perform session establishment, modification and/or release; perform IP address allocation and management; perform Dynamic Host Configuration Protocol (DHCP) functions; perform selection and control of UPF **306**; configure traffic steering at UPF **306** to guide traffic to the correct destination; terminate interfaces toward a Policy Control Function (PCF); perform lawful intercepts; charge data collection; support charging interfaces; control and coordinate charging data collection; terminate session management parts of Non-Access Stratum (NAS) messages; perform downlink data notification; manage roaming functionality; and/or perform other types of control plane processes for managing user plane data.

[0029] UPF **306** may perform the following: maintain an anchor point for intra/inter-Radio Access Technology (RAT) mobility (e.g., mobility across different radio access technologies); maintain an external Packet Data Unit (PDU) point of interconnect to a data network (e.g., an IP network, etc.); perform packet routing and forwarding; perform the user plane part of policy rule enforcement; perform packet inspection; perform lawful intercept; perform traffic usage reporting; perform Quality-of-Service (QoS) handling in the user plane; perform uplink traffic verification; perform transport level packet marking; perform downlink packet buffering; send an "end marker" to a Radio Access Network node (e.g., access station **210**) or ePDG **108**; and/or perform other types of user plane processes.

[0030] AUSF **308** may provide authentication and authorization services to 5GC components of core network **206**. For authentication, AUSF **308** may verify the subscriber's identity and determine whether UE **102** has provided the correct credentials to access network **104**. For authorization, AUSF **308** may determine whether UE **102** has the authority to access specific network functions or services. According to an embodiment, AUSF **3308** may support Authentication and key agreement (AKA) protocol (e.g., EAP-AKA and/or EAP-AKA').

[0031] UDM **310** may: maintain subscription information for UE **102**; manage subscriptions; generate authentication credentials; handle user identification; perform access authorization based on subscription data; perform network function registration management; maintain service and/or session continuity by maintaining assignment of SMF **304** for ongoing sessions; support Short Messaging Service (SMS) message delivery; support lawful intercept functionality; and/or perform other processes associated with managing user data. For example, UDM **310** may store subscription profiles that include authentication, access, and/or authorization information. Each subscription profile may include: information identifying UE **102**; authentication and/or authorization information for UE **102**; information identifying services enabled and/or authorized for UE **102**; device group membership information for UE **102**; and/or other types of information associated with UE **102**. Furthermore, the subscription profile may include mobility category information associated with UE **102**. UDR **312** may store subscriber/subscription data (e.g., subscriber/subscription profile) associated with UEs **102**, retrieve subscriber data, modify subscriber data, and/or delete subscriber data.

[0032] PGW-C **324** may provide control plane operations for UE traffic in network **104**. The functionalities of PGW-C **324** may include, for example, UE **102** authentication, mobility management for UEs **102**, management of QoS policy enforcement, management of enforcement of charg-

ing and policy rules; and management of Packet Data Network (PDN) sessions between PGW-U **326** and UEs **102**.

[0033] PGW-U **326** may act as a gateway from core network **206** into data network **208**. The functionalities of PGW-U **326** may include, for example, managing uplink/downlink UE data; allocating Internet Protocol (IP) addresses; to UEs **102**; enforcing QoS policies for UE traffic of various types (e.g., video, audio, etc.); performing deep packet inspections to take appropriate security measure (e.g., block traffic from a particular UE **102**); facilitating mobility management of UE **102**; maintaining data connection to UEs **102** and redirecting UE **102** traffic during UE **102** transit; and aiding Policy and Charging Rules Function (PCRF) in enforcing policy rules and charging rules. The role of PGW-U **326** among EPC components of system **100** may be similar to that of UPF **306** among 5GC components of system **100**.

[0034] AAA **328** may perform authentication of UEs **102**, authorization of UEs **102** to receive services or access resources, and accounting for the use of services and resources by UEs **102**. For UE **102** authentication, AAA **328** may verify the identity of UE **102** (or the user of UE **102**) attempting to access network **104** based on the security credentials provided by UE **102** and checked against information stored at HSS **330** or UDR **312**. For authorization of UE **102**, AAA **328** may determine whether UE **102** has the permission to access the particular service or resource (e.g., identified by UE **102** or by network **104**) based on information from UE **102** and HSS **330**. For accounting, AAA **328** may record UE activities (e.g., data usage, service usage, etc.). Accounting records may be used for billing, troubleshooting, maintenance, etc. AAA **328** may support EAP-AKA'. HSS **330** may store and retrieve UE subscription information for EPC components in system **100**, such as AAA **328** and PGW-C **324**. For EPC components of system **100**, HSS **330** may provide functionalities that are similar to those performed by UDM **308** and UDR **310** for 5GC components of system **100**.

[0035] FIG. **4** shows exemplary signaling paths through different components, of system **100** illustrated in FIG. **3**, for accessing a cellular network **104** via WLAN **211**. Assume that UE **102-1** includes a 5G NSA device and UE **102-2** includes a 5G SA device. Components of system **100** may exchange various messages over the signaling paths when UEs **102-1** and **102-2** attempt to access network **104**.

[0036] When UE **102-1** attempts to receive services from network **104**, UE **102-1** may send, to ePDG **108**, a request to establish a session (arrows **402-1** and **404**). In one implementation, the request may include an Information Element (IE) that indicates whether UE **102-1** includes a 5G NSA device. When ePDG **108** receives the request, ePDG **108** may conclude that UE **102-1** includes a 5G NSA device based on either the IE or the absence of the IE in the request. Upon determining that UE **102-1** includes a 5G NSA device, ePDG **108** may initiate a 4G or LTE authentication of UE **102**, by forwarding an authentication request for UE **102-1** to AAA **328** and receiving authentication reply for UE **102-1** from AAA **328** via an SWm interface between ePDG **108** and AAA **328** (arrow **406**). In order for AAA **328** to respond to the request from ePDG **108** and to authenticate and/or authorize UE **102-1**, AAA **328** may obtain security credentials for UE **102-1** and subscriber information from HSS **330** via an SWx interface between AAA **328** and HSS **330** (arrow **408**). When ePDG **108** receives the result of the authentication from AAA **328**, ePDG **108** and UE **102-1** may exchange additional messages (e.g., IKEv2-AKA challenge messages) to create an IPSec tunnel between UE **102-1** and ePDG **108** and then to establish the PDN session requested by UE **102**. The PDN session may be established over a data path between UE **102-1** and an endpoint in network **104** (e.g., data network **208**) for UE **102-1** to access cellular network **104** via WLAN **211**.

[0037] FIG. **5**A shows an exemplary data path through EPC components of system **100** for UE **102-1** to access cellular network **104** via WLAN **211**. As noted above, after exchanging messages, ePDG **108** and UE **102-1** may construct an IPSec tunnel. The IPsec tunnel may be established over path segments **502** and **504** between UE **102-1** and ePDG **108**. Next, ePDG **108** may send PDN session establishment request messages to PGW-C **324** (**506**). In turn, PGW-C **324** may configure PGW-U **326**, via messages (**508**), to establish a PDN session that extends from UE **102-1** to data network **208** through PGW-U **326**, over paths **502**, **504**, **510**, and **512**. After the session establishment, UE **102-1** may receive services from network **104** via WLAN **211**.

[0038] Referring back to FIG. **4**, when UE **102-2** attempts to receive services from network **104**, UE **102-2** may send, to ePDG **108**, a request to establish a session (arrows **402-2** and **404**). In one implementation, the request may include an IE that indicates whether UE **102-1** includes a 5G SA device. When ePDG **108** receives the request, ePDG **108** may conclude that UE **102-2** includes a 5G SA device based on the IE. Upon determining that UE **102-2** includes a 5G SA device, ePDG **108** may initiate a 5G authentication, by forwarding an authentication request for UE **102-2** to NSWO **110** (arrow **410**). The request may include a UE identifier, such as a Subscription Concealed Identifier (SUCI).

[0039] In one implementation, ePDG **108** may make the request to NSWO **110** via an interface designed for ePDG **108** and NSWO **110** to exchange UE authentication-related messages. In particular, ePDG **108** may send a Diameter EAP-Request (DER) by using the interface. When NSWO **110** receives the DER, NSWO **110** may use an Nausf interface of AUSF **308** (arrow **412**) to request AUSF **308** to authenticate UE **102-2**. Like the DER, the request may include a UE identifier. Next, in response to the request, AUSF **308** may query UDM **310** via an Nudm interface to obtain UE credentials-related data and subscription profile data (arrow **414**). When AUSF **308** obtains the information, AUSF **308** may verify the identity of UE **102-2** and return the result of the verification to NSWO **110**, which in turn may relay the result to ePDG **108**. ePDG **108** and UE **102-2** may exchange additional messages (IKE-AKA' challenge messages) to establish an IPSec tunnel between UE **102-2** and ePDG **108** and then to establish a PDU session requested by UE **102**. The PDU session may be established over a data path between UE **102-1** and an endpoint in network **104** (e.g., data network **208** or network slice **212**) for UE **102-2** to access cellular network **104** via WLAN **211**.

[0040] FIG. **5**B shows an exemplary data path through 5GC components of system **100** for UE **102-2** to access cellular network **104** via WLAN **211**. As noted above, after exchanging IKE-AKA' messages, ePDG **108** and UE **102-2** may construct an IPSec tunnel. The IPsec tunnel may be established over path segments **522** and **524** between UE

102-2 and ePDG **108**. Next, ePDG **108** may send session establishment request messages to SMF **304** (Sb2 interface on segment **526**). In turn, SMF **304** may instruct UPF **308** via messages over a segment **528** (N4 interface), to establish a PDU session that extends from UE **102-2** to data network **208** or network slice **212** via UPF **306**, over a data path that comprises segments **522**, **524**, **530**, and **532**. After the establishment, UE **102-2** may receive services from network **104** via WLAN **211**.

[0041] FIG. **6** shows a flow diagram of an exemplary process **600** that is associated with accessing a cellular network **104** via WLAN **211**, according to an implementation. Process **600** may be performed by various network components illustrated in FIGS. **1-3**, such as UE **102**, access network **204**, core network **206**, data network **208**, network slice **212**, access point device **106**, ePDG **108**, NSWO **110**, SMF **304**, UPF **306**, AUSF **308**, UDM **310**, UDR **312**, PGW-C **324**, PGW-U **326**, AAA **328**, and HSS **330**.

[0042] As shown, process **600** may include ePDG **108** receiving a request for network connection from UE **102** via WLAN **211** in access network **204** (block **602**). In response to the request, ePDG **108** may determine whether the request includes an IE that indicates whether UE **102** is a 5G SA device (block **604**). If there is an IE, in the request, that indicates UE **102** is a 5G SA device (block **604**: YES), ePDG **108** may perform 5G authentication of UE **102** via NSWO **110**, as described above with reference to FIG. **4** (block **606**). Process **600** may then proceed to block **610**.

[0043] At block **604**, if the request for connection does not include an IE which indicates that UE **102** is a 5G SA device or includes an IE which indicates that UE **102** is a 5G NSA device (block **604**: NO), ePDG **108** may perform LTE authentication of UE **102** via AAA **328**, as described above with reference to FIG. **4** (block **608**). Process **600** may proceed to block **610**.

[0044] At block **610**, ePDG **108** may obtain the result of authenticating UE **102**. If ePDG **108** determines that UE **102** is successfully authenticated (block **612**: YES), ePDG **108** may send an acknowledgement to UE **102** and construct an IPSec tunnel between UE **102** and ePDG **108** (block **614**). Furthermore, if UE **102** includes a 5G NSA device, ePDG may establish a PDN session between UE **102** and an endpoint in network **104** (e.g., a component in data network **208**), as described above with reference to FIG. **5**A. If UE **102** includes a 5G SA device, ePDG **108** may establish a PDU session between UE **102** and an endpoint in network **104** (e.g., a component on network slice **212** or in data network **208**). At block **612**, if UE **102** is not successfully authenticated (block **612**: NO), ePDG **108** may block UE **102** from connecting to network **104** (block **616**).

[0045] FIGS. **7**A and **7**B show exemplary messages that are exchanged by network components of system **100** during process **600**, according to an implementation. As shown, UE **102** may establish a connection with WLAN **211** (block **702**). After UE **102** attaches to WLAN **211**, UE **102** may send a request to ePDG **108** to connect to network **104**. The request may include, for example, an IE with an IKE_SA_INIT flag, to indicate that UE **102** includes a 5G SA device (arrow **704**). When ePDG **108** receives the IE, ePDG **108** may determine that the UE **102** requesting the connection includes a 5G SA device, and accordingly, may send a reply with an indication, such as IKE_SA_INIT_RESP flag (arrow **706**). The IKE_SA_INIT_RESP flag may acknowledge that ePDG **108** received the IKE_SA_INIT flag.

[0046] When UE **102** receives response **706** from ePDG **108**, UE **108** may request ePDG **108** to authenticate UE **102**, with IKE authentication request (arrow **708**). The request may include an ID of the UE, such as a SUCI. In response, having already determined that UE **102** includes a 5G SA device, ePDG **108** may issue a Diameter EAP Request (DER) to NSWO **110**, along with the UE ID (arrow **710**). In turn, NSWO **110** may send an authentication request (along with the UE ID, such as the SUCI) to AUSF **308** via an Nausf interface (e.g., Nausf_UEAuthentication Authentication_Request (SUCI, NSWO_Indication), where NSWO_Indication signifies that NSWO **110** is requesting the authentication) (arrow **712**). To authenticate the UE **102**, AUSF **308** may request a transformed UE authentication vector from UDM **310** via an Nudm interface (e.g., an Nudm_UEAuthentication Get_Request (SUCI, NSWO_Indication) interface) (arrow **714**). UDM **310** may then access UDR **312** to retrieve any information it needs and perform processing to obtain a transformed authentication vector-EAP AKA' and a Subscriber Permanent Identity (SUPI). Next, UDM **310** may pass the transformed authentication vector to AUSF **308** via am Nudm interface (e.g., Nudm_UEAuthentication Get_Response (SUPI, EAP_AKA') (arrow **716**).

[0047] When AUSF **308** receives the transformed authentication vector, AUSF **308** may pass the transformed vector to NSWO **110** (arrow **718**), via an Nausf interface (e.g., Nausf_UEAuthentication Authentication_Response (SUPI, EAP-AKA')). In response, NSWO **110** may pass EAP_AKA' to ePDG **108** as a Diameter EAP Answer (DEA) (arrow **720**). ePDG **108** may relay the authentication response to UE **102** (arrow **722**), along with IKE AKA'.

[0048] Upon receiving IKE_AKA', UE **102** may respond to an authentication challenge, sending an additional credentials and AKA' challenge to ePDG **108** (arrow **724**). ePDG **108** may send a DER with AKA' challenge to NSWO **110** (arrow **726**), which in turn may send an authentication challenge response to AUSF **110** via the Nausf interface (e.g., Nausf UEAuthentication Authentication_Request (AKA' challenge) (arrow **728**). AUSF **308** may then evaluate the response to the challenge and return the result of the evaluation to NSWO **110** via Nausf_UEAuthentication Authentcation_Response (arrow **730**, FIG. **7**B). If the challenge was met successfully, the response may include a master session key (MSK). NSWO **110** may relay the result of the challenge to ePDG **108** via DEA (arrow **732**), passing the MSK. ePDG **108** may then notify UE **102** with an IKE challenge response that includes the MSK (arrow **734**). Having successfully met the challenge, UE **102** then may establish a session with network **104** via ePDG **108**, core network components, and the endpoint (not shown) (bock **736**). When UE **102** is done with the session, UE **102** may terminate the session by sending a request to delete the session to ePDG **108**, which may then satisfy the request in coordination with core network components and the endpoint (arrows **738**). Once the session is terminated, ePDG **108** may send a response message to UE **102** (arrow **740**).

[0049] FIG. **8** depicts exemplary components of an exemplary network device **800**. Network device **800** may correspond to or be included in any of the devices and/or components illustrated in FIGS. **1-5**, **7**A, and **7**B (e.g., UE **102**, access network **204**, core network **206**, data network **208**, ePDG **108**, NSWO **110**, SMF **304**, UPF **306**, AUSF **308**, UDM **310**, UDR **312**, PGW-C **324**, PGW-U **326**, AAA **328**, HSS **330**, etc.). In some implementations, network

devices **800** may be part of a hardware network layer on top of which other network layers and NFs may be implemented. As shown, network device **800** may include a processor **802**, memory/storage **804**, input component **806**, output component **808**, network interface **810**, and communication path **812**. In different implementations, network device **800** may include additional, fewer, different, or different arrangement of components than the ones illustrated in FIG. **8**. For example, network device **800** may include line cards, switch fabrics, modems, etc.

[0050] Processor **802** may include a processor, a microprocessor, an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), programmable logic device, chipset, application specific instruction-set processor (ASIP), system-on-chip (SoC), central processing unit (CPU) (e.g., one or multiple cores), microcontrollers, and/or other processing logic (e.g., embedded devices) capable of controlling network device **800** and/or executing programs/instructions.

[0051] Memory/storage **804** may include static memory, such as read only memory (ROM), and/or dynamic memory, such as random access memory (RAM), or onboard cache, for storing data and machine-readable instructions (e.g., programs, scripts, etc.).

[0052] Memory/storage **804** may also include an optical disk, magnetic disk, solid state disk, holographic versatile disk (HVD), digital versatile disk (DVD), and/or flash memory, as well as other types of storage device (e.g., Micro-Electromechanical system (MEMS)-based storage medium) for storing data and/or machine-readable instructions (e.g., a program, script, etc.). Memory/storage **804** may be external to and/or removable from network device **800**.

[0053] Memory/storage **804** may include, for example, a Universal Serial Bus (USB) memory stick, a dongle, a hard disk, off-line storage, a Blu-Ray® disk (BD), etc. Memory/storage **804** may also include devices that can function both as a RAM-like component or persistent storage, such as Intel® Optane memories.

[0054] Depending on the context, the term "memory," "storage," "storage device," "storage unit," and/or "medium" may be used interchangeably. For example, a "computer-readable storage device" or "computer-readable medium" may refer to both a memory and/or storage device.

[0055] Input component **806** and output component **808** may provide input and output from/to a user to/from network device **800**. Input/output components **806** and **808** may include a display screen, a keyboard, a mouse, a speaker, a microphone, a camera, a DVD reader, USB lines, and/or other types of components for obtaining, from physical events or phenomena, to and/or from signals that pertain to network device **800**.

[0056] Network interface **810** may include a transceiver (e.g., a transmitter and a receiver) for network device **800** to communicate with other devices and/or systems. For example, via network interface **810**, network device **800** may communicate over a network, such as the Internet, an intranet, a terrestrial wireless network (e.g., a WLAN, WI-FI, WI-MAX, etc.), a satellite-based network, optical network, etc. Network interface **810** may include a modem, an Ethernet interface to a LAN, and/or an interface/connection for connecting network device **800** to other devices (e.g., a Bluetooth interface).

[0057] Communication path **812** may provide an interface through which components of network device **800** can communicate with one another.

[0058] Network device **800** may perform the operations described herein in response to processor **802** executing software instructions stored in a non-transient computer-readable medium, such as memory/storage **804**. The software instructions may be read into memory/storage **804** from another computer-readable medium or from another device via network interface **810**. The software instructions stored in memory/storage **804**, when executed by processor **802**, may cause processor **802** to perform processes that are described herein.

[0059] In this specification, various preferred embodiments have been described with reference to the accompanying drawings. It will be evident that modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the broader scope of the invention as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

[0060] In the above, while a series of blocks, messages, and signals have been described with regard to the processes and messages illustrated in FIGS. **6**, **7**A, and **7**B, the order of the blocks and messages may be modified in other implementations. In addition, non-dependent blocks and messages may represent actions and messages that can be performed or sent in parallel and in different order.

[0061] As used above, the term "session" may refer to a series of communications, of a limited duration, between two endpoints (e.g., two applications). When a session is established between an application and a network or a network slice, the session is established between the application and another application/server hosted by the network or the network slice. Similarly, if a session is established between a device and a network slice or a network, the session is established between an application on the device and another application on either the network slice or the network.

[0062] In addition, the term "Protocol Data Unit (PDU) session" or "Packet Data Network (PDN) session" may refer to communications between a mobile device and another endpoint (e.g., a data network, a network slice, etc.). Depending on the context, the term "session" may refer to a PDU session, a PDN session, or a session between applications. Additionally, depending on the context, the term "connection" may refer to a session, a PDU session, a PDU session, or another type of connection (e.g., a radio frequency link between a device and a base station).

[0063] It will be apparent that aspects described herein may be implemented in many different forms of software, firmware, and hardware in the implementations illustrated in the figures. The actual software code or specialized control hardware used to implement aspects does not limit the invention. Thus, the operation and behavior of the aspects were described without reference to the specific software code—it being understood that software and control hardware can be designed to implement the aspects based on the description herein.

[0064] Further, certain portions of the implementations have been described as "logic" that performs one or more functions. This logic may include hardware, such as a processor, a microprocessor, an application specific inte-

grated circuit, or a field programmable gate array, software, or a combination of hardware and software.

[0065] To the extent the aforementioned embodiments collect, store or employ personal information provided by individuals, it should be understood that such information shall be collected, stored, and used in accordance with all applicable laws concerning protection of personal information. The collection, storage and use of such information may be subject to consent of the individual to such activity, for example, through well known "opt-in" or "opt-out" processes as may be appropriate for the situation and type of information. Storage and use of personal information may be in an appropriately secure manner reflective of the type of information, for example, through various encryption and anonymization techniques for particularly sensitive information.

[0066] No element, block, or instruction used in the present application should be construed as critical or essential to the implementations described herein unless explicitly described as such. Also, as used herein, the articles "a," "an," and "the" are intended to include one or more items. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A device included in a cellular network, comprising:

a processor configured to:

receive a request from a User Equipment device (UE) to connect to the cellular network;

determine whether the UE includes a Fifth Generation (5G) Non-Standalone (NSA) device or a 5G Standalone (SA) device;

if the UE is determined to include a 5G NSA device, perform a Fourth Generation (4G) authentication via 4G core network components included in the cellular network;

if the UE is determined to include a 5G SA device, perform a 5G authentication via 5G core network components included in the cellular network; and

when the 4G authentication or the 5G authentication is successful, establish a session with an endpoint in the cellular network.

2. The device of claim **1**, wherein the request includes an information element that indicates that the UE includes a 5G SA device.

3. The device of claim **1**, wherein when determining, the processor is configured to:

determine that the UE includes a 5G NSA device if the device does not receive, from the UE, an information element which indicates that the UE includes a 5G SA device.

4. The device of claim **1**, wherein when performing the 4G authentication, the processor is configured to:

perform the 4G authentication via an Authentication Authorization and Accounting server (AAA) and a Home Subscriber Server (HSS).

5. The device of claim **1**, wherein when performing the 5G authentication, the processor is configured to:

perform the 5G authentication via a Non-seamless Wireless Local Area Network Offload device (NSWO), an Authentication Server Function (AUSF), and a United Data Management device (UDM).

6. The device of claim **5**, wherein when performing the 5G authentication via the NSWO, the AUSF, and the UDM, the processor is configured to:

send a Diameter Extensible Authentication Protocol Request (DER) to the NSWO.

7. The device of claim **6**, wherein the DER includes a Subscriber Concealed Identifier (SUCI).

8. The device of claim **1**, wherein when establishing the session, the processor is configured to:

establish a session between the UE and a network slice included in the cellular network.

9. The device of claim **1**, wherein when establishing the session, the processor is configured to:

establish an Internet Protocol security (IPsec) tunnel between the UE and the device; and

establish a Protocol Data Unit (PDU) session between the UE and the endpoint or a Packet Data Network (PDN) session between the UE and the endpoint.

10. A method comprising:

receiving, by a device included in a cellular network, a request from a User Equipment device (UE) to connect to the cellular network;

determining whether the UE includes a Fifth Generation (5G) Non-Standalone (NSA) device or a 5G Standalone (SA) device;

if the UE is determined to include a 5G NSA device, performing a Fourth Generation (4G) authentication via 4G core network components included in the cellular network;

if the UE is determined to include a 5G SA device, performing a 5G authentication via 5G core network components included in the cellular network; and

when the 4G authentication or the 5G authentication is successful, establishing a session with an endpoint in the cellular network.

11. The method of claim **10**, wherein the request includes an information element that indicates that the UE includes a 5G SA device.

12. The method of claim **10**, when determining includes:

determining that the UE includes a 5G NSA device if an information element, which indicates the UE includes a 5G SA device, is not received from the UE.

13. The method of claim **10**, wherein performing the 4G authentication includes:

performing the 4G authentication via an Authentication Authorization and Accounting server (AAA) and a Home Subscriber Server (HSS).

14. The method of claim **10**, wherein performing the 5G authentication includes:

performing the 5G authentication via a Non-seamless Wireless Local Area Network Offload device (NSWO), an Authentication Server Function (AUSF), and a United Data Management device (UDM).

15. The method of claim **14**, wherein performing the 5G authentication via the NSWO, the AUSF, and the UDM includes:

sending a Diameter Extensible Authentication Protocol Request (DER) to the NSWO.

16. The method of claim **15**, wherein the DER includes a Subscriber Concealed Identifier (SUCI).

17. The method of claim **10**, wherein establishing the session includes:

establishing a session between the UE and a network slice included in the cellular network.

18. The method of claim **10**, wherein establishing the session includes:

establishing an Internet Protocol security (IPsec) tunnel between the UE and the device; and

establishing a Protocol Data Unit (PDU) session between the UE and the endpoint or a Packet Data Network (PDN) session between the UE and the endpoint.

19. A non-transitory computer-readable medium comprising processor-executable instruction, which when executed by a processor of a device included in a cellular network, cause the processor to:

receive a request from a User Equipment device (UE) to connect to the cellular network;

determine whether the UE includes a Fifth Generation (5G) Non-Standalone (NSA) device or a 5G Standalone (SA) device;

if the UE is determined to include a 5G NSA device, perform a Fourth Generation (4G) authentication via 4G core network components included in the cellular network;

if the UE is determined to include a 5G SA device, perform a 5G authentication via 5G core network components included in the cellular network; and

when the 4G authentication or the 5G authentication is successful, establish a session with an endpoint in the cellular network.

20. The non-transitory computer-readable medium of claim **1**, wherein the request includes an information element that indicates that the UE includes a 5G SA device.

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