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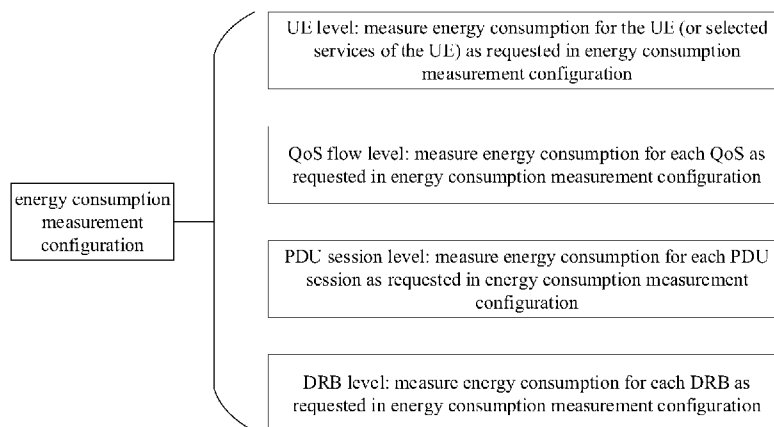


FIG. 4B

(57) Abstract: This disclosure relates generally to a method, device, and system for energy consumption measurement and management in a wireless network. One method performed by a first network element may include receiving, from a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a UE; obtaining energy consumption information for the energy consumption associated with serving the UE based on the energy consumption measurement configuration; and transmitting, to a third network element, a second message carrying the energy consumption information associated with serving the UE.

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METHOD, DEVICE, AND SYSTEM FOR ENERGY CONSUMPTION MANAGEMENT IN WIRELESS NETWORKS

TECHNICAL FIELD

This disclosure is directed generally to wireless communications, and particularly to a method, device, and system for energy consumption measurement and management in a wireless network.

BACKGROUND

To satisfy the demands of the unprecedented growth of mobile subscribers and large number of novel services, the wireless communication networks require continuous expansion, which leads to the continuous growth in the energy consumption. Controlling power consumption and reducing energy cost, and yet still being able to meet performance requirement are critical for developing and deploying a cost effective wireless communication network.

SUMMARY

This disclosure is directed to a method, device, and system for energy consumption management in a wireless network, such as 3G, 4G, 5G, or 6G wireless network. More specifically, the energy consumption management includes power consumption measurement configuration, power consumption measuring and reporting.

In some embodiments, a method performed by a first network element is disclosed. The method may include: receiving, from a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a User Equipment (UE); obtaining energy consumption information for the energy consumption associated with serving the UE based on the energy consumption measurement configuration; and transmitting, to a third network element, a second message carrying the energy consumption information associated with serving the UE.

In some embodiments, a method performed by a first network element is disclosed. The method may include: transmitting, to a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a User Equipment (UE); and receiving, from a third network element, a second message carrying energy consumption information

associated with serving the UE, wherein the energy consumption information is collected based on the energy consumption measurement configuration. In some example implementations, the second network element is the same as the third network element.

In some embodiments, there is a network element or a network node comprising a processor and a memory, wherein the processor is configured to read code from the memory and implement any methods recited in any of the embodiments.

In some embodiments, a computer program product comprising a computer-readable program medium code stored thereupon, the code, when executed by a processor, causing the processor to implement any method recited in any of the embodiments.

The above embodiments and other aspects and alternatives of their implementations are described in greater detail in the drawings, the descriptions, and the claims below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an example wireless communication network.

FIG. 2 shows an example wireless network node.

FIG. 3 shows an example user equipment.

FIG. 4A shows a high level exemplary flow chart for power consumption measurement configuration and reporting.

FIG. 4B shows exemplary energy consumption measurement levels (or granularities).

FIGs. 5-7, 8A, 8B, and 9-10 show exemplary message flows in various network deployment scenarios for power consumption measurement configuration and reporting.

DETAILED DESCRIPTION

Wireless Communication Network

FIG. 1 shows an exemplary wireless communication network 100 that includes a core network 110 and a radio access network (RAN) 120. The core network 110 further includes at least one Mobility Management Entity (MME) 112 and/or at least one Access and Mobility Management Function (AMF). Other functions that may be included in the core network 110 are not shown in FIG. 1. The RAN 120 further includes multiple base stations, for example, base stations 122 and 124. The base stations may include at least one

evolved NodeB (eNB) for 4G LTE, an enhanced LTE eNB (ng-eNB), or a Next generation NodeB (gNB) for 5G New Radio (NR), or any other type of signal transmitting/receiving device such as a UMTS NodeB. The eNB 122 communicates with the MME 112 via an S1 interface. Both the eNB 122 and gNB 124 may connect to the AMF 114 via an Ng interface. Each base station manages and supports at least one cell. For example, the base station gNB 124 may be configured to manage and support cell 1, cell 2, and cell 3.

The gNB 124 may include a central unit (CU) and at least one distributed unit (DU). The CU and the DU may be co-located in a same location, or they may be split in different locations. The CU and the DU may be connected via an F1 interface. Alternatively, for an eNB which is capable of connecting to the 5G network, it may also be similarly divided into a CU and at least one DU, referred to as ng-eNB-CU and ng-eNB-DU, respectively. The ng-eNB-CU and the ng-eNB-DU may be connected via a W1 interface.

The wireless communication network 100 may include one or more tracking areas. A tracking area may include a set of cells managed by at least one base station. For example, tracking area 1 labeled as 140 includes cell 1, cell 2, and cell 3, and may further include more cells that may be managed by other base stations and not shown in FIG. 1. The wireless communication network 100 may also include at least one UE 160. The UE may select a cell among multiple cells supported by a base station to communicate with the base station through Over the Air (OTA) radio communication interfaces and resources, and when the UE 160 travels in the wireless communication network 100, it may reselect a cell for communications. For example, the UE 160 may initially select cell 1 to communicate with base station 124, and it may then reselect cell 2 at certain later time point. The cell selection or reselection by the UE 160 may be based on wireless signal strength/quality in the various cells and other factors.

The wireless communication network 100 may be implemented as, for example, a 2G, 3G, 4G/LTE, or 5G cellular communication network. Correspondingly, the base stations 122 and 124 may be implemented as a 2G base station, a 3G NodeB, an LTE eNB, or a 5G NR gNB. The UE 160 may be implemented as mobile or fixed communication devices which are capable of accessing the wireless communication network 100. The UE 160 may include but is not limited to mobile phones, laptop computers, tablets, personal digital assistants, wearable devices, Internet of Things (IoT) devices, MTC/eMTC devices, distributed remote sensor devices, roadside assistant equipment, XR devices, and desktop computers. The UE 160 may also be generally referred to as a wireless communication device, or a wireless terminal. The UE 160 may support sidelink communication to another UE via a PC5 interface.

While the description below focuses on cellular wireless communication systems as shown in FIG.

1, the underlying principles are applicable to other types of wireless communication systems for paging wireless devices. These other wireless systems may include but are not limited to Wi-Fi, Bluetooth, ZigBee, and WiMax networks.

FIG. 2 shows an example of electronic device 200 to implement a network base station (e.g., a radio access network node), a core network (CN), and/or an operation and maintenance (OAM). Optionally in one implementation, the example electronic device 200 may include radio transmitting/receiving (Tx/Rx) circuitry 208 to transmit/receive communication with UEs and/or other base stations. Optionally in one implementation, the electronic device 200 may also include network interface circuitry 209 to communicate the base station with other base stations and/or a core network, e.g., optical or wireline interconnects, Ethernet, and/or other data transmission mediums/protocols. The electronic device 200 may optionally include an input/output (I/O) interface 206 to communicate with an operator or the like.

The electronic device 200 may also include system circuitry 204. System circuitry 204 may include processor(s) 221 and/or memory 222. Memory 222 may include an operating system 224, instructions 226, and parameters 228. Instructions 226 may be configured for the one or more of the processors 221 to perform the functions of the network node. The parameters 228 may include parameters to support execution of the instructions 226. For example, parameters may include network protocol settings, bandwidth parameters, radio frequency mapping assignments, and/or other parameters.

FIG. 3 shows an example of an electronic device to implement a terminal device 300 (for example, a user equipment (UE)). The UE 300 may be a mobile device, for example, a smart phone or a mobile communication module disposed in a vehicle. The UE 300 may include a portion or all of the following: communication interfaces 302, a system circuitry 304, an input/output interfaces (I/O) 306, a display circuitry 308, and a storage 309. The display circuitry may include a user interface 310. The system circuitry 304 may include any combination of hardware, software, firmware, or other logic/circuitry. The system circuitry 304 may be implemented, for example, with one or more systems on a chip (SoC), application specific integrated circuits (ASIC), discrete analog and digital circuits, and other circuitry. The system circuitry 304 may be a part of the implementation of any desired functionality in the UE 300. In that regard, the system circuitry 304 may include logic that facilitates, as examples, decoding and playing music and video, e.g., MP3, MP4, MPEG, AVI, FLAC, AC3, or WAV decoding and playback; running applications; accepting user inputs; saving and retrieving application data; establishing, maintaining, and terminating cellular phone calls or data connections for, as one example, internet connectivity; establishing, maintaining, and terminating wireless network connections,

Bluetooth connections, or other connections; and displaying relevant information on the user interface 310. The user interface 310 and the inputs/output (I/O) interfaces 306 may include a graphical user interface, touch sensitive display, haptic feedback or other haptic output, voice or facial recognition inputs, buttons, switches, speakers and other user interface elements. Additional examples of the I/O interfaces 306 may include microphones, video and still image cameras, temperature sensors, vibration sensors, rotation and orientation sensors, headset and microphone input / output jacks, Universal Serial Bus (USB) connectors, memory card slots, radiation sensors (e.g., IR sensors), and other types of inputs.

Referring to FIG. 3, the communication interfaces 302 may include a Radio Frequency (RF) transmit (Tx) and receive (Rx) circuitry 316 which handles transmission and reception of signals through one or more antennas 314. The communication interface 302 may include one or more transceivers. The transceivers may be wireless transceivers that include modulation / demodulation circuitry, digital to analog converters (DACs), shaping tables, analog to digital converters (ADCs), filters, waveform shapers, filters, pre-amplifiers, power amplifiers and/or other logic for transmitting and receiving through one or more antennas, or (for some devices) through a physical (e.g., wireline) medium. The transmitted and received signals may adhere to any of a diverse array of formats, protocols, modulations (e.g., QPSK, 16-QAM, 64-QAM, or 256-QAM), frequency channels, bit rates, and encodings. As one specific example, the communication interfaces 302 may include transceivers that support transmission and reception under the 2G, 3G, BT, WiFi, Universal Mobile Telecommunications System (UMTS), High Speed Packet Access (HSPA)+, 4G / Long Term Evolution (LTE), 5G (also referred to as New Radio, or 5G NR), and 6G standards. The techniques described below, however, are applicable to other wireless communications technologies whether arising from the 3rd Generation Partnership Project (3GPP), GSM Association, 3GPP2, IEEE, or other partnerships or standards bodies.

Referring to FIG. 3, the system circuitry 304 may include one or more processors 321 and memories 322. The memory 322 stores, for example, an operating system 324, instructions 326, and parameters 328. The processor 321 is configured to execute the instructions 326 to carry out desired functionality for the UE 300. The parameters 328 may provide and specify configuration and operating options for the instructions 326. The memory 322 may also store any BT, WiFi, 3G, 4G, 5G, 6G or other data that the UE 300 will send, or has received, through the communication interfaces 302. In various implementations, a system power for the UE 300 may be supplied by a power storage device, such as a battery or a transformer.

Power Management in Wireless Network

To satisfy the demands of the unprecedented growth of mobile subscribers and large number of

novel services, the wireless communication networks require continuous expansion, which also leads to the continuous growth in energy consumption. To develop a greener wireless communication network and satisfy the service quality requirement at the same time, the energy consumption is a critical factor to consider.

In order to reduce the energy consumption of the network, various approaches may be taken, subject to, for example, operator's policy. For example, the wireless system may define a "maximum energy consumption limitation" policy for the user, and/or selected services provided to user. The maximum energy consumption limitation may be a limit to the total amount of energy consumed by various network element(s), and/or various network resources (e.g., hardware resource, software resource), for serving a specific UE(s), or a specific service(s) of the UE. The maximum energy consumption limitation may also apply to a given duration of time, such as per day, per week, or per month. In some example implementations, the limitation may have several tiers. For example, the core network of the wireless network may set different limitations and corresponding different levels of charging rates. A higher charging rate may be applied to a higher limitation or when the specified limitation is exceeded. In this way, different charging rate may help reduce network energy consumption, as users may wish to lower cost by subscribing to plans or services that cost lower energy. Therefore, it is beneficial for a core network to be able to identify how much energy is used by a Radio Access Network (RAN), and whether the energy used by the RAN to serve a specific UE, or a specific service of the UE exceeds the "maximum energy consumption limitation".

It is overserved, however, at present, that the core network is not able to identify the energy consumption on the RAN side for serving a UE or a certain service of the UE, which leads to the inability to apply a charging strategy based on total/ maximum energy consumption limitation. Additionally, a UE may move frequently in the RAN network, and there may be multiple base stations serving the UE. Currently, the core network does not have an efficient and robust method to obtain the total energy consumed by these base stations for serving the UE (or a specific service of the UE). This document provides the method enabling the RAN to report the total amount of energy consumed of the network resources used for a specific UE, or a specific service of the UE, e.g., energy consumed in UE level, PDU session level, or QoS flow level, to the core network. This method can also be applied in scenario where UE moves and handovers between different base stations.

In this disclosure, various methods for enabling energy management in the wireless network are described. The energy management may include, for example, energy consumption measurement configuration and energy consumption reporting. The RAN (or one or more nodes, elements, entities in the RAN) may be configured with energy consumption measurement requirement. The measurement may be

configured to be performed at different levels. For example, these measurement levels may include a UE level, a Quality of Service (QoS) flow level, a Packet Data Unit (PDU) session level, a Data Radio Bearer (DRB) level.

FIG. 4A illustrates a high level exemplary energy consumption measurement configuration and energy consumption reporting framework. In this framework, the core network (or a network element in core network, such as AMF) is in charge of configuring the energy consumption measurement. The measurement may be configured at various levels, as shown in FIG. 4B. Table 1 below shows some example energy consumption measurement configurations.

Table 1: Example Measurement Levels

Energy consumption measurement configuration	Note
UE 1	Perform energy consumption measurement at UE level, for UE 1.
UE 2, QoS flows 1-3	Perform energy consumption measurement at QoS flow level, for UE 2, QoS flows 1-3
UE 3, PDU sessions 2-5	Perform energy consumption measurement at PDU session level, for UE 3, PDU sessions 2-5
UE 4, DRBs 1-6	Perform energy consumption measurement at DRB level, for UE 4, DRBs 1-6

Note that the energy consumption measurement configuration may include one or more entries, at different levels. For example, one or more rows in table 1 may be configured.

In this disclosure, the energy consumption may include the total amount of energy consumed by the network resource (e.g., network node, network entities, and network elements, which may be hardware, software, and a mixture thereof) used for providing services to a UE, PDU session(s), QoS flow(s), or DRB(s). The energy efficiency may be defined as the ratio between the produced performance of service (e.g., data volume, data rate, delay, etc.) by the network and the energy consumed by the network resources. For example, the network energy efficiency may be defined as a ratio between data volume served and energy consumed for serving the data volume, with a unit of [bit/Joule]. Note that energy consumption in this disclosure refers to the energy consumed by the RAN for serving the UE, or one or more services (e.g., QoS flows, PDU sessions, DRBs) of the UE.

In embodiments described below, a gNB may be used for illustration purpose. The same underlying principle applies to all types of base stations, unless otherwise specified. An AMF is used as an example core network element. Other core network elements may also be used.

In this disclosure, various embodiments are disclosed, aiming for providing mechanisms for energy consumption measurement configuration and energy consumption reporting. Details on these embodiments are described below.

Embodiment 1: RAN Energy Consumption Reporting

In this embodiment, the measurement and reporting of RAN energy consumption are described in a base station (e.g., a gNB) level, or a RAN level (note that the gNB is part of the RAN). The base station may include, for example, a gNB with non-split architecture. A core network element, such as an AMF, is in charge of requesting and configuring RAN side energy consumption measurement. The AMF may send a message which carries the energy consumption measurement configuration to the base station. The message may be a Next Generation Application Protocol (NGAP) message, which may include, for example, an INITIAL CONTEXT SETUP REQUEST message. The base station may then start measuring/collecting the RAN energy consumption for serving the UE as requested/configured in the message, until the AMF sends another message that triggers the RAN to stop energy consumption measurement. For example, the AMF may send a UE CONTEXT RELEASE COMMAND message to release the UE and stop energy consumption measurement for the UE. The base station may then report the total measured energy consumption for serving the UE to the AMF via, for example, a UE CONTEXT RELEASE COMPLETE message. Therefore, the Core Network (CN) may be aware of the RAN energy consumption for serving the UE during this particular connection (e.g., from UE context setup to UE context release, or from the UE context being successfully established), and may use such reported RAN energy consumption to formulate certain strategies/policies, such as a charging strategy based on the energy consumption limitation control.

FIG. 5 illustrates an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The UE initiates PDU session setup procedure among UE, gNB and CN.

Step 2: The AMF sends a message, such as an INITIAL CONTEXT SETUP REQUEST message to the gNB. The message may include the energy consumption measurement configuration to request the gNB (or the RAN) to measure the energy consumption for serving the UE. Specifically, the energy consumption measurement configuration may indicate or instruct various energy measurement levels, which may include at least one of:

- UE level: when the indication is for UE level, it instructs RAN to measure/report the RAN energy consumption measurement for serving the UE. For example, all services (e.g., multiple PDU sessions,

multiple QoS flows, multiple DRBs, etc.) associated with the UE consumed by the RAN count.

- QoS flow level: when the indication is for QoS flow level, it instructs RAN to measure/report RAN energy consumption for serving each QoS flow in a list of QoS flows. The list of QoS flows may be indicated in the message, or may be predefined/preconfigured.
- PDU session level: when the indication is for PDU session level, it instructs RAN to measure/report RAN energy consumption for serving each PDU session in a list of PDU sessions. The list of PDU sessions may be indicated in the message, or may be predefined/preconfigured.

In some example implementations, the measurement may be performed individually, for example, for each QoS flow, for each PDU session. In some example implementations, the measurement may be performed as an aggregation for multiple services. For example, measurement may be performed for a sub-list of services together.

Note that the energy consumption measurement applies to a particular duration. The duration may be, for example, a lifecycle of a service (e.g., from service started/initiated to service released/terminated).

Note that in this Embodiment, if UE level energy consumption report is requested by the AMF, only UE level energy consumption indication will present in the energy consumption measurement configuration.

Step 3: The gNB performs the resource setup for the connection between the UE and gNB.

Step 4: The gNB sends an INITIAL CONTEXT SETUP RESPONSE message to the AMF to inform the successful setup of the UE context at the gNB.

Step 5: In the duration that gNB provides the service to the UE (i.e., the lifecycle of the service for the UE), the gNB measures the energy consumption by the network resource(s) in the RAN consumed for serving the UE as requested by the AMF. Note that the network resources include and are not limited to, network nodes, network elements, and network entities in the RAN, which may be in the form of hardware, software, and a mixture thereof.

Step 6: The data transmission between the core network (e.g., AMF) and the UE is completed and the AMF decides to release the UE-associated logical NG-connection.

Step 7: The AMF sends a message, such as a UE CONTEXT RELEASE COMMAND message to the gNB to release all the resources associated to the UE.

Step 8: The gNB sends a message, such as a UE CONTEXT RELEASE COMPLETE message to the AMF.

This message may carry the measured energy consumption as requested/configured in step 2. The measured energy consumption may include at least one of following:

- Total amount of energy consumed by the network resource in the RAN for serving the UE.
- Total amount of energy consumed by the network resource in the RAN for serving the list of QoS flows of the UE.
- Total amount of energy consumed by the network resource in the RAN for serving the list of PDU sessions of the UE.
- Total amount of energy consumed by the network resource in the RAN for serving the list of DRBs of the UE.

In this disclosure, when reporting energy consumption for a service, an identifier for the service may be indicated in the reporting message. For example, referring to FIG. 4B, if energy consumption measurement is for QoS flow(s), then the reporting message may be in the form of “QoS flow 1: energy consumption information X; QoS flow 2: energy consumption information Y”.

The energy consumption measurement result sent to the core network may be based on the measurement configuration setting in step 2. Alternatively, the content to be reported may be separately configured by, for example, another message from the core network. Alternatively, the content to be reported may be predefined or preconfigured.

As an example, in step 2, AMF may send an INITIAL CONTEXT SETUP REQUEST message to the gNB, to configure or instruct energy consumption measurement to be performed at UE level. Then in step 8, gNB may send energy consumption information to the AMF, the energy consumption information is the total amount of energy consumed by the network resource in the RAN for serving the UE.

This embodiment applies to, and is not limited to UE level energy consumption configuration and reporting.

Embodiment 2: RAN Energy Consumption Reporting

In this embodiment, the AMF requests and configures the energy consumption measurement at RAN side by including the energy consumption measurement configuration in an NGAP request message sent to the gNB for PDU session or QoS flow setup. The NGAP request message may include, for example, INITIAL UE CONTEXT SETUP REQUEST message, PDU SESSION RESOURCE SETUP REQUEST message, PDU SESSION RESOURCE MODIFICATION REQUEST message, etc. The gNB starts measuring the RAN

energy consumption of the PDU sessions or QoS flows as requested, until the AMF sends an NGAP messages to release the PDU sessions or QoS flows, e.g., UE CONTEXT RELEASE COMMAND message, PDU SESSION RESOURCE RELEASE COMMAND message, PDU SESSION RESOURCE MODIFY REQUEST message, etc. The gNB reports the total measured energy consumption of the PDU sessions or QoS flows to the AMF via a corresponding NGAP response message sent to the AMF, e.g., UE CONTEXT RELEASE COMPLETE message, PDU SESSION RESOURCE RELEASE RESPONSE message, PDU SESSION RESOURCE MODIFY RESPONSE message. Then the CN may be aware of the RAN energy consumption for specific QoS flow(s) or PDU session(s) of the UE, and use such reported RAN energy consumption for formulating some strategies, e.g., by applying a charging strategy based on the energy consumption limitation control.

FIG. 6 illustrates an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The UE initiates PDU session setup procedure among UE, gNB and CN.

Step 2: The AMF sends a message, such as an NGAP message to the gNB. The message may carry the energy consumption measurement configuration to request the gNB (or the RAN) to measure the energy consumption for serving the UE. Specifically, the energy consumption measurement configuration may indicate or instruct various energy measurement levels, which may include at least one of:

- UE level: when the indication is for UE level, it instructs RAN to measure/report the RAN energy consumption measurement for serving the UE. For example, all services (e.g., multiple PDU sessions, multiple QoS flows, multiple DRBs, etc.) associated with the UE consumed by the RAN count.
- QoS flow level: when the indication is for QoS flow level, it instructs RAN to measure/report RAN energy consumption for serving a list of QoS flow. The list of QoS flow may be indicated by the message, or may be predefined/preconfigured.
- PDU session level: when the indication is for PDU session level, it instructs RAN to measure/report RAN energy consumption for serving a list of PDU session. The list of PDU session may be indicated by the message, or may be predefined/preconfigured.

Note that in this Embodiment, if QoS flow and/or PDU session level energy consumption report is requested by the AMF, then QoS flow level and/or PDU session level energy consumption indication is present in the energy consumption measurement configuration.

Step 3: The gNB performs the resource setup for the connection between the UE and gNB.

Step 4: The gNB sends a response message as a response to the NGAP message in step 2. Depending on the specific NGAP message sent in step 2, a corresponding response message is sent.

Table 2 below shows example messages when the requested energy consumption measurement is at a PDU session level.

Table 2

NGAP message in step 2	NGAP response message in step 4
INITIAL CONTEXT SETUP REQUEST	INITIAL CONTEXT SETUP RESPONSE
PDU SESSION RESOURCE SETUP REQUEST	PDU SESSION RESOURCE SETUP RESPONSE

Table 3 below shows example messages when the requested energy consumption measurement is at a QoS flow level.

Table 3

NGAP message in step 2	NGAP response message in step 4
INITIAL CONTEXT SETUP REQUEST	INITIAL CONTEXT SETUP RESPONSE
PDU SESSION RESOURCE SETUP REQUEST	PDU SESSION RESOURCE SETUP RESPONSE
PDU SESSION RESOURCE MODIFY	PDU SESSION RESOURCE MODIFY

Step 5: In the duration that gNB provides the service to the UE (e.g., the lifecycle of the service for the UE), the gNB measures the energy consumption by the network resource(s) used for the indicated QoS flow(s) and/or PDU session(s) of the UE as requested by the AMF. Note that the network resources include and are not limited to, network nodes, network elements, and network entities in the RAN. For example, the energy consumption measurement may be at a QoS flow level, or a PDU session level, as requested in step 2.

Step 6: The AMF decides to release the resources that have been established for one or more PDU sessions; one or more QoS flows; or one or more DRBs for the UE.

Step 7: The AMF sends an NGAP message to the gNB, to release the PDU sessions or QoS flows for the UE.

Step 8: The gNB sends a response message to the NGAP message in step 7. This message may carry the measured energy consumption as requested/configured in step 2. The measured energy consumption may include at least one of following:

- Total amount of energy consumed by the network resource in the RAN for serving the UE.
- Total amount of energy consumed by the network resource in the RAN for serving the list of QoS flows of

- Total amount of energy consumed by the network resource in the RAN for serving the list of PDU sessions of the UE.
- Total amount of energy consumed by the network resource in the RAN for serving the list of DRBs of the UE.

Table 4 below shows example messages in step 7 and step 8, when the requested energy consumption measurement is at a PDU session level.

Table 4

NGAP message in step 7	NGAP response message in step 8
UE CONTEXT RELEASE COMMAND	UE CONTEXT RELEASE COMPLETE
PDU SESSION RESOURCE RELEASE COMMAND	PDU SESSION RESOURCE RELEASE RESPONSE

Table 5 below shows example messages in step 7 and step 8, when the requested energy consumption measurement is at a QoS flow level.

Table 5

NGAP message in step 7	NGAP response message in step 8
UE CONTEXT RELEASE COMMAND	UE CONTEXT RELEASE COMPLETE
PDU SESSION RESOURCE RELEASE COMMAND	PDU SESSION RESOURCE RELEASE RESPONSE
PDU SESSION RESOURCE MODIFY REQUEST	PDU SESSION RESOURCE MODIFY RESPONSE

This embodiment may apply to, and is not limited to PDU session level, QoS flow level energy consumption configuration and reporting.

Embodiment 3: RAN Energy Consumption Reporting: CU-DU Split Base Station

In this embodiment, the base station is implemented under a distributed architecture and can be divided into two entities named Centralized Unit (CU) and Distributed Unit (DU). From a protocol stack point of view, CU provides support for higher layers of the protocol stack such as SDAP, PDCP and RRC, whereas DU provides support for lower layers of the protocol stack such as RLC, MAC and Physical layer. A base station, such as a gNB, may include one CU and multiple DUs. A CU may be further divided into a control plane (CUCP, or gNB-CU-CP) and a user plane (CUUP, or gNB-CU-UP). CUCP and CUUP may be implemented as different hardware or software entities, or they may share a same hardware entity and be implemented as different logical entities. Therefore, due to the split architecture, when performing energy

consumption measurement and reporting, the measurement task may be distributed to various entities in the base station. For example, CU and DU may each measure its own energy consumption for serving a UE (or a service of a UE). Further, in the CU, CUCP and CUUP may be in charge of measuring energy consumption in the control plane, and the user plane, respectively.

In some example implementations, the CU may serve as a gateway to receive energy consumption measurement configuration from, for example, the core network, and distribute the configuration to DU(s).

In some example implementations, the CUCP may serve as a gateway to receive energy consumption measurement configuration from, for example, the core network, and distribute the configuration to CUUP and DU(s).

FIG. 7 illustrates an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The UE initiates PDU session setup procedure among UE, gNB and CN (e.g., AMF).

Step 2: The AMF sends a message, such as an INITIAL CONTEXT SETUP REQUEST message to the gNB-CU-CP (hereinafter also referred to as CUCP). The message may carry the energy consumption measurement configuration to request the gNB (or the RAN) to measure the energy consumption for serving the UE. Specifically, the energy consumption measurement configuration may indicate or instruct various energy measurement levels, which may include at least one of:

- UE level;
- QoS flow level;
- PDU session level; or
- DRB level.

Details for these levels may be found in previous embodiments and are skipped here.

Step 3: The CUCP, acting as a gateway, may forward energy consumption measurement configuration to gNB-CU-UP (gNB Control Unit – User Plane, hereinafter also referred to as CUUP). Specifically, CUCP may send a message, such as a BEARER CONTEXT SETUP REQUEST message to the CUUP. The message may carry the energy consumption measurement configuration, to request the CUUP to measure the energy consumed by CUUP for serving the UE (at requested level). The energy consumption measurement configuration may indicate or instruct various energy measurement levels on the CUUP side, which may include at least one of: a UE level; a QoS flow level; a PDU session level; or a DRB level. Details for these levels may be found in

previous embodiments and are skipped here.

Step 4: The CUUP replies the CUCP with, for example, a BEARER CONTEXT SETUP RESPONSE message to inform the successful establishment of the requested resources.

Step 5: The CUCP may further forward energy consumption measurement configuration to the gNB-DU (hereinafter also referred to as DU). Specifically, CUCP may send a message, such as a UE CONTEXT SETUP REQUEST message to the DU. The message may carry the energy consumption measurement configuration, to request the DU to measure the energy consumption at DU for serving the UE (at requested level). The energy consumption measurement configuration may indicate or instruct various energy measurement levels on the DU side, which may include at least one of: a UE level; a QoS flow level; a PDU session level; or a DRB level.

In this disclosure, when performing measurement, energy consumption may be measured. Additionally or alternatively, energy efficiency may be measured. For example, for QoS flow 1, energy consumption needs to be measured; and/or for QoS flow 2, energy efficiency needs to be measured.

Step 6: The DU replies the CUCP with, for example, a UE CONTEXT SETUP RESPONSE message to inform the successful setup of the UE context.

Step 7: The DU performs the resource setup for the connection between the UE and gNB.

Step 8: The gNB-CU-CP may reply to the AMF by sending, for example, an INITIAL CONTEXT SETUP RESPONSE message, to inform the success of the UE context setup at the gNB.

Step 9: In the duration that gNB provides service to the UE, the gNB-CU-CP, CUUP and DU measure their respective energy consumption (or energy efficiency) associated with serving the UE (or services(s) of the UE), and the measurement is performed at requested level.

Step 10: The data transmission between the AMF and the UE is completed and the AMF decides to release the UE.

Step 11: The AMF may send a message, for example, a UE CONTEXT RELEASE COMMAND message to the gNB-CU-CP to release all the resources associated to the UE.

Step 12: The gNB-CU-CP may send a message, for example, a UE CONTEXT RELEASE COMMAND message to the DU to release all the resources associated with the UE (in DU side).

Step 13: The DU may send, for example, a UE CONTEXT RELEASE COMPLETE message to the gNB-CU-CP. The message may carry the energy consumption (or energy efficiency) measured at the DU side. The

measured energy consumption may include the total amount of energy consumed by the network resource at DU side used for serving the UE. The measurement result may follow the same level as indicated in measurement configuration.

Step 14: The gNB-CU-CP may send a BEARER CONTEXT RELEASE COMMAND message to the CUUP to release all the resources associated to the UE (in CUUP side).

Step 15: The CUUP may send, for example, a BEARER CONTEXT RELEASE COMPLETE message to the gNB-CU-CP. The message may carry the measured energy consumption (or energy efficiency) at the CUUP side. The measured energy consumption may include the total amount of energy consumed by the network resource at CUUP side used for serving the UE. The measurement result may follow the same level as indicated in measurement configuration in step 3.

Step 16: The CUCP, after collecting energy consumption (or energy efficiency), calculates the total amount of energy consumption as the sum of the energy consumption at DU, CUUP, and CUCP.

In some example implementations, the energy consumption by the control plane CUCP is relatively much smaller than that of other entities such as CUUP and DU. Therefore, the base station (e.g., gNB) may assume energy consumption of gNB-CU-CP is 0. Alternatively, if the energy consumption by CUCP is less than a preconfigured or predefined threshold, the base station may assume energy consumption of CUCP is 0.

Step 17: The gNB-CU-CP may send a message, such as a UE CONTEXT RELEASE COMPLETE message to the AMF. The message may carry the measured energy consumption as requested. The measured energy consumption is the total amount of energy consumed by the base station (CUCP, CUUP, and DU) for serving the UE, the list of QoS flows of the UE, the list of PDU sessions of the UE, or the list of DRBs of the UE.

This embodiment may apply to, and is not limited to UE level energy consumption configuration and reporting.

Embodiment 4: RAN Energy Consumption Reporting: CU-DU Split Base Station

Similar to embodiment 3, in this embodiment, the base station has a distributed architecture and can be divided into CU and DU.

The AMF requests and configures the energy consumption measurement by including the energy consumption measurement configuration in the NGAP message sent to the gNB-CU for PDU session or QoS flow setup. The NGAP message may include INITIAL UE CONTEXT SETUP REQUEST message, PDU

SESSION RESOURCE SETUP REQUEST message, PDU SESSION RESOURCE MODIFICATION REQUEST message, etc. Upon receiving the request, the gNB-CU-CP will indicate the energy consumption measurement configuration to the gNB-CU-UP and gNB-DU. The gNB-CU-CP, gNB-CU-UP and gNB-DU measure the energy consumption as requested respectively, until the AMF sends an NGAP message to release the PDU sessions or QoS flows. The NGAP message may include, for example, UE CONTEXT RELEASE COMMAND message, PDU SESSION RESOURCE RELEASE COMMAND message, PDU SESSION RESOURCE MODIFY REQUEST message, etc. The gNB-CU-CP sends F1AP and E1AP message respectively to the gNB-DU and gNB-CU-UP to release the corresponding resources, and the gNB-DU and gNB-CU-UP reports their measured energy consumption to the gNB-CU-CP by sending a corresponding F1AP and E1AP response message. The gNB-CU-CP calculates the sum of the energy consumption measured at the gNB-CU-CP, gNB-CU-UP and gNB-DU, and reports the total measured energy consumption of the PDU sessions or QoS flows to the AMF via a corresponding NGAP response message, e.g., UE CONTEXT RELEASE COMPLETE message, PDU SESSION RESOURCE RELEASE RESPONSE message, PDU SESSION RESOURCE MODIFY RESPONSE message.

In some example implementations, the CU may serve as a gateway to receive energy consumption measurement configuration from, for example, the core network, and distribute the configuration to DU(s).

In some example implementations, the CUCP may serve as a gateway to receive energy consumption measurement configuration from, for example, the core network, and distribute the configuration to CUUP and DU(s).

FIGs. 8A and 8B illustrate an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The UE initiates PDU session setup procedure among UE, gNB and CN (e.g., AMF).

Step 2: The AMF sends a message, such as an NGAP message to the gNB-CU-CP, to setup PDU sessions of QoS flows. The message may carry the energy consumption measurement configuration to request the gNB (or the RAN) to measure the energy consumption for serving the UE (or service(s) of the UE). The energy consumption measurement configuration may indicate or instruct various energy measurement levels on the gNB side, which may include at least one of: a UE level; a QoS flow level; a PDU session level; or a DRB level. Details for these levels may be found in previous embodiments and are skipped here.

In some example implementations, when configuring energy consumption measurement at PDU

session level, the request messages may include INITIAL CONTEXT SETUP REQUEST message, PDU SESSION RESOURCE SETUP REQUEST message. When configuring energy consumption measure at QoS flow level, the request messages may include INITIAL CONTEXT SETUP REQUEST message, PDU SESSION RESOURCE SETUP REQUEST message, PDU SESSION RESOURCE MODIFY REQUEST message.

Step 3: The CUCP, acting as a gateway, may forward energy consumption measurement configuration to CUUP. Specifically, CUCP may send an E1 Application Protocol (E1AP) message, such as a BEARER CONTEXT SETUP REQUEST message, or a BEARER CONTEXT MODIFICATION REQUEST message to the CUUP. The message may carry the energy consumption measurement configuration, to request the CUUP to measure the Energy consumed by CUUP for serving the UE (at requested level). The energy consumption measurement configuration may indicate or instruct various energy measurement levels on the CUUP side, which may include at least one of: a UE level; a QoS flow level; a PDU session level; or a DRB level. Details for these levels may be found in previous embodiments and are skipped here.

Step 4: The CUUP replies the CUCP with a corresponding E1AP message, such as a BEARER CONTEXT SETUP RESPONSE message, a BEARER CONTEXT MODIFICATION RESPONSE message, and the like, to inform the successful establishment of the requested resources.

Step 5: The CUCP may further send/forward energy consumption measurement configuration to the DU. Specifically, CUCP may send an F1 Application Protocol (F1AP) message, such as a UE CONTEXT SETUP REQUEST message, a UE CONTEXT MODIFICATION REQUEST message, and the like, to the DU. The message may carry the energy consumption measurement configuration, to request the DU to measure the Energy consumed at DU for serving the UE (at requested level). The energy consumption measurement configuration may indicate or instruct various energy measurement levels on the DU side, which may include at least one of: a UE level; a QoS flow level; a PDU session level; or a DRB level.

In some example implementations, when performing measurement, energy consumption may be measured. Additionally or alternatively, energy efficiency may be measured. For example, for QoS flow 1, energy consumption needs to be measured; and/or for QoS flow 2, energy efficiency needs to be measured.

Step 6: The gNB-DU replies the CUCP with a corresponding F1AP message, for example, a UE CONTEXT SETUP RESPONSE message, or a UE CONTEXT MODIFICATION RESPONSE message, to inform the successful setup of the DRBs.

Step 7: The DU performs the resource setup for the connection between the UE and gNB.

Step 8: The gNB-CU-CP may reply to the AMF by sending, for example, an NGAP response message, to inform the success of the UE context setup at the gNB.

In some example implementations, when energy consumption measurement is at PDU session level, the NGAP response messages may include INITIAL CONTEXT SETUP RESPONSE message, PDU SESSION RESOURCE SETUP RESPONSE message, and the like. When energy consumption measurement is at QoS flow level, the NGAP response messages may include INITIAL CONTEXT SETUP RESPONSE message, PDU SESSION RESOURCE SETUP RESPONSE message, PDU SESSION RESOURCE MODIFY RESPONSE message, and the like.

Step 9 – Step 11: These three steps may be performed in parallel by three entities. In the duration that gNB provides service(s) to the UE, the gNB-CU-CP, CUUP and DU measure their respective energy consumption (or energy efficiency) associated with serving the UE, and the measurement is performed at requested level.

Step 12: The AMF decides to release the resources that have been established for the PDU sessions or the QoS flows associated with the UE.

Step 13: The AMF sends an NGAP message to the gNB-CU-CP to release the resources allocated for the PDU sessions or QoS flows associated with the UE.

In some example implementations, when energy consumption measurement is at PDU session level, the NGAP messages may include UE CONTEXT RELEASE COMMAND message, PDU SESSION RESOURCE RELEASE COMMAND, and the like. When energy consumption measurement is at QoS flow level, the NGAP messages may include UE CONTEXT RELEASE COMMAND message, PDU SESSION RESOURCE RELEASE COMMAND message, PDU SESSION RESOURCE MODIFY REQUEST message, and the like.

Step 14: The gNB-CU-CP may send an F1AP message, such as a UE CONTEXT RELEASE COMMAND message, a UE CONTEXT MODIFICATION REQUEST message, and the like, to the DU, to release DRBs established for the PDU sessions or the QoS flows associated with the UE.

Step 15: The DU may send a corresponding F1AP response message, such as a UE CONTEXT RELEASE COMPLETE message, a UE CONTEXT MODIFICATION RESPONSE message, and the like, to the gNB-CU-CP. The message may carry the measured energy consumption (or energy efficiency) at the DU side. The measured energy consumption may include the total amount of energy consumed by the network resource at DU side used for serving the UE. The measurement result may follow the same level as indicated in measurement

In some example implementations, the response message may carry energy consumption information for a list of QoS flows, and/or a list of DRBs. The energy consumption information may also use QoS flow identifier or DRB identifier to identify the corresponding QoS flow or DRB.

In some example implementations, the response message may carry energy efficiency information for a list of QoS flow, and/or a list of DRBs. The energy efficiency information may also use QoS flow identifier or DRB identifier to identify the corresponding QoS flow or DRB.

Step 16: The CUCP receives energy consumption information or energy efficiency information from DU. In case DU sends DRB level energy consumption information or DRB level energy efficiency information, the CUCP may need to calculate the corresponding energy consumption at QoS flow level.

For example, if DU sends DRB level energy consumption, CUCP may calculate energy consumption for a QoS flow by using equation below:

$$EC_{QoS\ flow1} = \frac{data\ volume_{QoS\ flow1}}{data\ volume_{DRB}} * EC_{DRB}$$

where: $EC_{QoS\ flow1}$ is the energy consumption for QoS flow 1; $data\ volume_{QoS\ flow1}$ is the data volume of QoS flow 1; $data\ volume_{DRB}$ is the data volume of DRB associated with QoS flow 1; and EC_{DRB} is the energy consumption for DRB associated with QoS flow 1.

For another example, if DU sends DRB level energy efficiency, CUCP may calculate energy consumption for a QoS flow by using equation below:

$$EC_{QoS\ flow1} = \frac{1}{EE_{DRB}} * data\ volume_{QoS\ flow1}$$

where: $EC_{QoS\ flow1}$ is the energy consumption for QoS flow 1; $data\ volume_{QoS\ flow1}$ is the data volume of QoS flow 1; and EE_{DRB} is the energy efficiency for DRB associated with QoS flow 1.

Furthermore, for each requested PDU session, the gNB-CU-CP may calculate the sum of energy consumption of all QoS flows belonging to this PDU session, to obtain the PDU session energy consumption.

Step 17: The gNB-CU-CP may send an E1AP message, such as a BEARER CONTEXT RELEASE COMMAND message, a BEARER CONTEXT MODIFICATION REQUEST message, and the like, to the CUUP, to release all the resources established for the PDU sessions or QoS flows (in CUUP side).

Step 18: The CUUP may send a corresponding E1AP response message, such as a BEARER CONTEXT

RELEASE COMPLETE message, a BEARER CONTEXT MODIFICATION RESPONSE message, and the like, to the gNB-CU-CP. The message may carry the measured Energy consumed at the CUUP side for serving the PDU sessions or QoS flows.

In some example implementations, the response message may carry energy consumption information for a list of QoS flow. The energy consumption information may use QoS flow identifier to identify the corresponding QoS flow.

In some example implementations, the response message may carry energy consumption information for a list of PDU sessions. The energy consumption information may use PDU session identifier to identify the corresponding PDU session.

Step 19: The CUCP, after collecting energy consumption from DU and CUUP, calculates the total amount of energy consumption as the sum of the energy consumption at DU, CUUP, and CUCP.

In some example implementations, the energy consumption by the control plane CUCP is relatively much smaller than that of other entities such as CUUP and DU. Therefore, the base station (e.g., gNB) may assume energy consumption of gNB-CU-CP is 0. Alternatively, if the energy consumption of CUCP is less than preconfigured or predefine threshold, the base station may assume energy consumption of CUCP is 0.

Step 20: The gNB-CU-CP sends an NGAP response message to the AMF. The message may carry the measured energy consumption as requested. For example, the measured energy consumption is the total amount of energy consumed by the base station (CUCP, CUUP, and DU) for serving the list of QoS flows of the UE, or the list of PDU sessions of the UE. Similarly, an identifier for each QoS flow or PDU session may be indicated in the measured energy consumption information.

In some example implementations, when the energy consumption measurement is configured in PDU session level, the corresponding NGAP response messages may include a UE CONTEXT RELEASE COMPLETE message, and a PDU SESSION RESOURCE RELEASE RESPONSE message. When the energy consumption measurement is configured in QoS flow level, the NGAP response messages may include a UE CONTEXT RELEASE COMPLETE message, a PDU SESSION RESOURCE RELEASE RESPONSE message, and a PDU SESSION RESOURCE MODIFY RESPONSE message.

This embodiment may apply to, and is not limited to PDU session level, QoS flow level energy consumption configuration and reporting.

Embodiment 5: RAN Energy Consumption Reporting – NG Based Handover

In this embodiment, NG based UE handover scenario is covered.

The measurement and reporting of RAN energy consumption are considered during the NG based handover. After the source gNB receives the energy consumption measurement configuration from AMF (as described in previous embodiments) or from other gNB (e.g. in the case of Xn based handover in next embodiment), the source gNB measures the requested energy consumption and transfers the measured result to the AMF via, for example, a HANDOVER REQUIRED message in the case of NG based handover. The energy consumption measurement configuration is relayed to the target gNB via a HANDOVER REQUEST message sent by the AMF. After the UE is successfully handed over to the target gNB, the target gNB will continue to measure the energy consumption of the UE and/or PDU sessions and/or QoS flows based on the received energy consumption measurement configuration until the AMF releases the corresponding resources, or a new handover occurs. In this way, when multiple base stations have served the UE, the core network is able to track the total energy consumed by these base stations for serving the UE.

FIG. 9 illustrates an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The source gNB has already received energy consumption measurement configuration from AMF during the PDU session/QoS flow setup (e.g., as described in previous embodiments); or the source gNB has received energy consumption measurement configuration from another gNB during a previous Xn based handover (refer to following embodiment). The UE is currently served by the source gNB, and the source gNB measures the energy consumed for serving the UE; and/or PDU sessions; and/or QoS flows as requested (e.g., the measurement is performed following the measurement level that is configured by the core network).

Step 2: Due to UE mobility, a handover is desired and the source gNB determines a target gNB for the handover. If there is no Xn interface between the source gNB and target gNB, an NG based handover may occur. The source gNB sends a message, such as a HANDOVER REQUIRED message to the AMF for resource preparation at the selected target gNB. The message may carry the measured energy consumption information associated with the UE. For example, the measured energy consumption information may include at least one of following:

- The total amount of energy consumed by the network resource in the source gNB used for serving the UE;
- Energy consumption for each QoS flow in a list of QoS flow, with each QoS flow being identified by a QoS flow identifier; or
- Energy consumption for each PDU session in a list of PDU sessions, with each PDU session being identified by a PDU session identifier.

Step 3: The AMF stores the received measured energy consumption, and sends a HANDOVER REQUEST message to the target gNB to request resource preparation. The HANDOVER REQUEST message may carry the energy consumption measurement configuration, to indicate/instruct the target gNB to measure the energy consumption of the UE; and/or PDU sessions; and/or QoS flows. Refer to previous embodiments for details on energy consumption measurement configuration.

Step 4: If the target gNB accepts the handover, it may reply with a HANDOVER REQUEST ACKNOWLEDGE message to the AMF.

Step 5: The UE is handed over from the source gNB to the target gNB.

Step 6: The target gNB continues to measure the energy consumption of the UE and/or PDU sessions and/or QoS flows as requested. The measurement may stop when the target gNB receives instruction from the AMF to release corresponding resources for the UE, or when a new handover occurs.

Step 7: Similar to previous embodiments, the AMF may send a message, such as an NGAP message to the target gNB to release the resources allocated for UE (or PDU session, QoS flows of the UE).

Step 8: Similar to previous embodiments, the target gNB may send a message, such as an NGAP response message to the AMF. The message may carry the measured energy consumption at target gNB as requested. The measured energy consumption may include at least one of the followings:

- The total amount of energy consumed by the network resource in the target gNB used for serving the UE;
- Energy consumption at target gNB for each QoS flow in a list of QoS flow, with each QoS flow being identified by a QoS flow identifier; or
- Energy consumption at target gNB for each PDU session in a list of PDU sessions, with each PDU session being identified by a PDU session identifier.

Note: The CN calculates the final energy consumption of the UE (or service(s) of the UE, such as PDU session(s), QoS flow(s)) by adding result from source gNB and target gNB.

In this embodiment, the source gNB and the target gNB may be in a same radio access network (RAN), or a different RAN.

Embodiment 6: RAN Energy Consumption Reporting – Xn Based Handover

In this embodiment, Xn based UE handover scenario is covered.

The measurement and reporting of RAN energy consumption are considered during the Xn (or Xn

interface) based handover. The energy consumption measured at the source gNB, and/or the energy consumption measurement configuration are transferred to the target gNB in a message, such as a HANDOVER REQUEST message. After the UE is successfully handed over to the target gNB, the target gNB will continue to measure the energy consumption of the UE and/or PDU sessions and/or QoS flows based on the received energy consumption measurement configuration, until the AMF releases the corresponding resources or a new handover occurs. Then, even UE handover occurs, the core network can be aware of the RAN energy consumption of the UE, or the specific QoS flow of the UE, or PDU session of the UE, the core network can use such reported RAN energy consumption to formulate some strategies, e.g., applying charging strategy based on the energy consumption limitation control.

FIG. 10 illustrates an exemplary message flow and network elements interaction according to this embodiment. An exemplary method may include a portion or all of the following steps.

Step 1: The UE is served by the source gNB, and the source gNB performs the energy consumption measurement of the UE and/or PDU sessions and/or QoS flows as requested. Refer to previous embodiments for detail on how gNB energy consumption measurement is configured.

Step 2: Due to UE mobility, a handover is desired and the source gNB determines a target gNB for the handover. If Xn interface exists between the source gNB and target gNB, an Xn based handover may occur. The source gNB sends a message, such as a HANDOVER REQUEST message to the target gNB for resource preparation. The message may carry the measured energy consumption information associated with the UE. For example, the measured energy consumption information may include at least one of following:

- The total amount of energy consumed by the network resource in the source gNB used for serving the UE;
- Energy consumption for each QoS flow in a list of QoS flow, with each QoS flow being identified by a QoS flow identifier; or
- Energy consumption for each PDU session in a list of PDU sessions, with each PDU session being identified by a PDU session identifier.

The message may further carry the energy consumption measurement configuration, to indicate/instruct the target gNB to measure the energy consumption of the UE; and/or PDU sessions; and/or QoS flows. Refer to previous embodiments for details on energy consumption measurement configuration.

Step 3: If the target gNB accepts the handover, it sends the HANDOVER REQUEST ACKNOWLEDGE message to the source gNB.

Step 4: The UE is handed over from the source gNB to the target gNB.

Step 5: The target gNB sends a PATH SWITCH REQUEST message to the AMF declaring itself as the new serving gNB.

Step 6: After UE successfully handed over from the source gNB, the target gNB measures the energy consumption of the UE; and/or PDU sessions of the UE; and/or QoS flows of the UE, based on received energy consumption measurement configuration, until receiving instructions from the AMF to release corresponding resources, or until the next handover occurs.

Step 7: Similar to step 7 in embodiment 5.

Step 8: Similar to step 8 in embodiment 5.

The target gNB calculates the final measured energy consumption of the UE, and/or PDU session(s), and/or QoS flow(s) by using sum of received the measured energy consumption from the source gNB and measured energy consumption at the target gNB, and report it to the core network. For example, target gNB receives energy consumed by source gNB for serving QoS flow 1, and adds the received energy consumption to the energy consumed by itself for serving QoS flow 1.

In this embodiment, the source gNB and the target gNB may be in a same radio access network (RAN), or a different RAN.

A method according to embodiments in this disclosure includes a portion or all of the following steps: step 1: receiving, from a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a User Equipment (UE); step 2: obtaining energy consumption information for the energy consumption associated with serving the UE based on the energy consumption measurement configuration; and step 3: transmitting, to a third network element, a second message carrying the energy consumption information associated with serving the UE.

In any portion or combination of the implementations above, the energy consumption measurement configuration indicates the energy consumption associated with serving the UE is to be measured in at least one of following levels: a UE level; a Quality of Service (QoS) flow level; a Packet Data Unit (PDU) session level; or a Data Radio Bearer (DRB) level.

In any portion or combination of the implementations above, a granularity of the energy consumption information follows a same measurement level as indicated in the energy consumption

measurement configuration.

In any portion or combination of the implementations above, the energy consumption information comprises at least one of: total amount of energy consumed by the first network element for serving the UE; total amount of energy consumed by the first network element for serving each QoS flow in a list of QoS flows of the UE; total amount of energy consumed by the first network element for serving each PDU session in a list of PDU sessions of the UE; or total amount of energy consumed by the first network element for serving each DRB in a list of DRBs of the UE.

In this disclosure, various embodiments are described for configuring energy consumption measurement and/or reporting. The configuration may be sent from a core network to a base station or an element of a base station. The configuration may also be sent from a one element of a base station to another element of the base station. The configuration may also be sent from a source base station to a target base station. Various embodiments may be combined, to form a combined embodiment. For example, the energy consumption measurement configuration may be initially configured by a core network element to a first base station, then the energy consumption measurement configuration may be configured from the first base station to a second base station during a handover procedure, where the handover procedure may include an Xn based (or Xn interface based) handover, and an NG based (or NG interface based) handover. Additionally, the various embodiments in the disclosure are for illustration purpose, and may be split into multiple sub-solutions which include partial features of an embodiment.

The description and accompanying drawings above provide specific example embodiments and implementations. The described subject matter may, however, be embodied in a variety of different forms and, therefore, covered or claimed subject matter is intended to be construed as not being limited to any example embodiments set forth herein. A reasonably broad scope for claimed or covered subject matter is intended. Among other things, for example, subject matter may be embodied as methods, devices, components, systems, or non-transitory computer-readable media for storing computer codes. Accordingly, embodiments may, for example, take the form of hardware, software, firmware, storage media or any combination thereof. For example, the method embodiments described above may be implemented by components, devices, or systems including memory and processors by executing computer codes stored in the memory.

Throughout the specification and claims, terms may have nuanced meanings suggested or implied in context beyond an explicitly stated meaning. Likewise, the phrase “in one embodiment/implementation” as used herein does not necessarily refer to the same embodiment and the phrase “in another

embodiment/implementation” as used herein does not necessarily refer to a different embodiment. It is intended, for example, that claimed subject matter includes combinations of example embodiments in whole or in part.

In general, terminology may be understood at least in part from usage in context. For example, terms, such as “and”, “or”, or “and/or,” as used herein may include a variety of meanings that may depend at least in part on the context in which such terms are used. Typically, “or” if used to associate a list, such as A, B or C, is intended to mean A, B, and C, here used in the inclusive sense, as well as A, B or C, here used in the exclusive sense. In addition, the term “one or more” as used herein, depending at least in part upon context, may be used to describe any feature, structure, or characteristic in a singular sense or may be used to describe combinations of features, structures or characteristics in a plural sense. Similarly, terms, such as “a,” “an,” or “the,” may be understood to convey a singular usage or to convey a plural usage, depending at least in part upon context. In addition, the term “based on” may be understood as not necessarily intended to convey an exclusive set of factors and may, instead, allow for the existence of additional factors not necessarily expressly described, again, depending at least in part on context.

Reference throughout this specification to features, advantages, or similar language does not imply that all of the features and advantages that may be realized with the present solution should be or are included in any single implementation thereof. Rather, language referring to the features and advantages is understood to mean that a specific feature, advantage, or characteristic described in connection with an embodiment is included in at least one embodiment of the present solution. Thus, discussions of the features and advantages, and similar language, throughout the specification may, but do not necessarily, refer to the same embodiment.

Furthermore, the described features, advantages and characteristics of the present solution may be combined in any suitable manner in one or more embodiments. One of ordinary skill in the relevant art will recognize, in light of the description herein, that the present solution may be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the present solution.

C L A I M S

1. A method for wireless communication, performed by a first network element, the method comprising:
receiving, from a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a User Equipment (UE);
obtaining energy consumption information for the energy consumption associated with serving the UE based on the energy consumption measurement configuration; and
transmitting, to a third network element, a second message carrying the energy consumption information associated with serving the UE.
2. The method of claim 1, wherein the energy consumption measurement configuration indicates the energy consumption associated with serving the UE is to be measured in at least one of following levels:
a UE level;
a Quality of Service (QoS) flow level;
a Packet Data Unit (PDU) session level; or
a Data Radio Bearer (DRB) level.
3. The method of claim 1, wherein a granularity of the energy consumption information follows a same measurement level as indicated in the energy consumption measurement configuration.
4. The method of claim 1, wherein the energy consumption information comprises at least one of:
total amount of energy consumed by the first network element for serving the UE;
total amount of energy consumed by the first network element for serving each QoS flow in a list of QoS flows of the UE;
total amount of energy consumed by the first network element for serving each PDU session in a list of PDU sessions of the UE; or
total amount of energy consumed by the first network element for serving each DRB in a list of DRBs of the UE.
5. The method of any one of claims 1-4, wherein receiving the first message comprises:
receiving, from the second network element and during a resource setup procedure for the UE, the first message carrying the energy consumption measurement configuration.
6. The method of claim 5, wherein the first message comprises at least one of:

a Next Generation Application Protocol (NGAP) request message;
an initial context setup request message;
an NG interface based handover request message; or
An Xn Application Protocol (XnAP) handover request message.

7. The method of any one of claims 1-4, wherein transmitting the second message comprises:
transmitting, to the third network element and during a resource release procedure for the UE, the second message carrying the energy consumption information associated with serving the UE; or
transmitting, to the third network element and during a handover procedure for the UE, the second message carrying the energy consumption information associated with serving the UE.
8. The method of claim 7, wherein the second message comprises at least one of:
an NGAP response message for addressing a request of resource release for the UE; or
an NGAP handover required message to request handing over the UE from the first network element to a target base station.
9. The method of any one of claims 1-4, wherein the energy consumption information comprises a total amount of energy consumed by one or more entities for serving the UE at a level indicated by the energy consumption measurement configuration, the one or more entities comprising at least one of:
the first network element;
a first Radio Access Network (RAN) to which the first network element belongs; or
a second RAN which is a target RAN serving the UE after a handover procedure.
10. The method of claim 9, wherein at least one of following condition applies:
when an energy consumption measurement is at a UE level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the UE;
when the energy consumption measurement is at a QoS flow level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the QoS flow;
when the energy consumption measurement is at a PDU session level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the PDU session; or
when the energy consumption measurement is at a DRB level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the DRB.

11. The method of any one of claims 1-4, wherein:
- the first network element comprises at least one of: a base station; a Control Unit (CU) of the base station; or a CU Control Plane (CUCP) of the base station, and the base station comprises at least one of: a gNodeB (gNB); an eNodeB (eNB); an ng-eNodeB (ng-eNB); or a NodeB; and
- the second network element comprises a core network element.
12. The method of claim 11, wherein the first message comprises at least one of:
- an initial context setup request message;
- a PDU session resource setup request message; or
- a PDU session resource modify request NGAP message.
13. The method of claim 11, wherein the second message comprises at least one of:
- a UE context release complete message;
- a PDU session resource release response message; or
- a PDU session resource modify response NGAP message.
14. The method of any one of claims 1-4, wherein:
- the first network element comprises a Control Unit Control Plane (CUCP) of a base station; and
- the second network element comprises a core network element.
15. The method of claim 14, further comprising:
- transmitting, to a CU User Plane (CUUP) of the base station, a third message carrying CUUP energy consumption measurement configuration, the CUUP energy consumption measurement configuration indicates energy consumption associated with serving the UE is to be measured in a measurement level comprising at least one of following:
- a UE level;
- a Quality of Service (QoS) flow level;
- a Packet Data Unit (PDU) session level; or
- a Data Radio Bearer (DRB) level.
16. The method of claim 15, wherein the third message comprises an E1 Application Protocol (E1AP) message.
17. The method of claim 15, further comprising:

receiving, from the CUUP, a fourth message carrying CUUP energy consumption information associated with serving the UE, wherein a granularity of the CUUP energy consumption information follows a same measurement level as indicated in the CUUP energy consumption measurement configuration.

18. The method of claim 17, wherein the fourth message comprises an E1AP message.

19. The method of claim 17, wherein obtaining the energy consumption information comprises:

obtaining the energy consumption information for energy consumption associated with serving the UE in the measurement level based on: 1) the CUUP energy consumption information; and 2) CUUP energy consumption information.

20. The method of claim 14, further comprising:

transmitting, to a Distributed unit (DU) of the base station, a fifth message carrying DU energy consumption measurement configuration, the DU energy consumption measurement configuration indicates energy consumption associated with serving the UE is to be measured in at least one of following levels:

a UE level;

a Quality of Service (QoS) flow level;

a Packet Data Unit (PDU) session level; or

a Data Radio Bearer (DRB) level.

21. The method of claim 20, wherein the fifth message comprises an F1 Application Protocol (F1AP) message.

22. The method of claim 20, further comprising:

receiving, from the DU, a sixth message carrying DU energy consumption information associated with serving the UE, wherein a granularity of the DU energy consumption information follows a same measurement level as indicated in the DU energy consumption measurement configuration.

23. The method of claim 22, wherein obtaining the energy consumption information comprises:

obtaining the energy consumption information for energy consumption associated with serving the UE in the measurement level based on: 1) the DU energy consumption information; and 2) CUUP energy consumption information.

24. The method of any one of claims 1-4, wherein:

the first network element is a source base station;

- the second network element is a core network element;
- the third network element is same as the second network element; and
- the UE is in a handover procedure to be handed over from the source base station to a target base station.
25. The method of claim 24, wherein the second message comprises a handover required message requesting to hand over the UE from the source base station to the target base station.
26. The method of any one of claims 1-4, wherein:
- the first network element comprises a target base station;
- the second network element comprises a source base station;
- the third network element comprises a core network element; and
- the UE is in a handover procedure to be handed over from the source base station to the target base station.
27. The method of claim 26, wherein the first message comprises a handover request message requesting to hand over the UE from the source base station to the target base station.
28. The method of claim 27, wherein the first message further comprises energy consumption information of the second network element for serving the UE at a granularity configured by the third network element.
29. The method of claim 28, wherein obtaining the energy consumption information comprises:
- measuring energy consumed by the first network element for serving the UE following a measurement level as indicated in the energy consumption measurement configuration;
- determining energy consumed by the second network element based on the energy consumption information of the second network element; and
- determining the energy consumption information as a sum of the energy consumed by the first network element and the energy consumed by the second network element.
30. The method of any one of claims 1-4, wherein:
- the first network element comprises a Control Unit User Plane (CUUP) of a base station;
- the second network element comprises a CUCP of the base station; and
- the third network element is same as the second network element.
31. The method of claim 30, wherein:
- the first message comprises at least one of:

- a bearer context setup request message; or
 - a bearer context modification request message; and
- the second message comprises at least one of:
- a bearer context release complete message; or
 - a bearer context modification response message.
32. The method of claim 30, wherein:
- the first message comprises an E1AP message; and
 - the second message comprises an E1AP response message.
33. The method of any one of claims 1-4, wherein:
- the first network element comprises a DU of a base station;
 - the second network element comprises a CU-CP of the base station; and
 - the third network element is same as the second network element.
34. The method of claim 33, wherein:
- the first message comprises at least one of:
 - a UE context setup request message; or
 - a UE context modification request message; and
 - the second message comprises at least one of:
 - a UE context release complete message; or
 - a UE context modification response message.
35. A method for wireless communication, performed by a first network element, the method comprising:
- transmitting, to a second network element, a first message carrying energy consumption measurement configuration for measuring energy consumption associated with serving a User Equipment (UE); and
 - receiving, from a third network element, a second message carrying energy consumption information associated with serving the UE, wherein the energy consumption information is collected based on the energy consumption measurement configuration.
36. The method of claim 35, wherein the energy consumption measurement configuration indicates the energy consumption associated with serving the UE is to be measured in at least one of following levels:
- a UE level;

- a Quality of Service (QoS) flow level;
- a Packet Data Unit (PDU) session level; or
- a Data Radio Bearer (DRB) level.

37. The method of claim 35, wherein a granularity of the energy consumption information follows a same measurement level as indicated in the energy consumption measurement configuration.

38. The method of claim 35, wherein the energy consumption information comprises at least one of:

- total amount of energy consumed by the second network element for serving the UE;
- total amount of energy consumed by the second network element for serving each QoS flow in a list of QoS flows of the UE;
- total amount of energy consumed by the second network element for serving each PDU session in a list of PDU sessions of the UE; or
- total amount of energy consumed by the second network element for serving each DRB in a list of DRBs of the UE.

39. The method of any one of claims 35-38, wherein transmitting the first message comprises:

- transmitting, to the second network element and during a resource setup procedure for the UE, the first message carrying the energy consumption measurement configuration.

40. The method of claim 39, wherein the first message comprises at least one of:

- a Next Generation Application Protocol (NGAP) request message;
- an initial context setup request message;
- an NG interface based handover request message; or
- An Xn Application Protocol (XnAP) handover request message.

41. The method of any one of claims 35-38, wherein receiving the second message comprises:

- receiving, from the third network element and during a resource release procedure for the UE, the second message carrying the energy consumption information associated with serving the UE; or
- receiving, from the third network element and during a handover procedure for the UE, the second message carrying the energy consumption information associated with serving the UE.

42. The method of claim 41, wherein the second message comprises at least one of:

an NGAP response message for addressing a request of resource release for the UE; or

an NGAP handover required message to request handing over the UE from the first network element to a target base station.

43. The method of any one of claims 35-38, wherein the energy consumption information comprises a total amount of energy consumed by one or more entities for serving the UE at a level indicated by the energy consumption measurement configuration, the one or more entities comprising at least one of:

the second network element;

a first Radio Access Network (RAN) to which the second network element belongs; or

a second RAN which is a target RAN serving the UE after a handover procedure.

44. The method of claim 43, wherein at least one of following condition applies:

when an energy consumption measurement is at a UE level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the UE;

when the energy consumption measurement is at a QoS flow level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the QoS flow;

when the energy consumption measurement is at a PDU session level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the PDU session; or

when the energy consumption measurement is at a DRB level, the energy consumption information indicates the total amount of energy consumed by the one or more entities for serving the DRB.

45. The method of any one of claims 35-38, wherein:

the first network element comprises at least one of: a core network element; a Control Unit (CU) of a base station; or a CU Control Plane (CUCP) of the base station, and the base station comprises at least one of: a gNodeB (gNB); an eNodeB (eNB); an ng-eNodeB (ng-eNB); or a NodeB; and

the second network element comprises at least one of: the base station; a CU User Plane (CUUP) of the base station; or a Distributed Unit (DU) of the base station.

46. The method of claim 45, wherein the first message comprises at least one of:

an initial context setup request message;

a PDU session resource setup request message; or

a PDU session resource modify request NGAP message.

47. The method of claim 45, wherein the second message comprises at least one of:
- a UE context release complete message;
 - a PDU session resource release response message; or
 - a PDU session resource modify response NGAP message.
48. The method of any one of claims 35-38, wherein:
- the first network element comprises a core network element; and
 - the second network element comprises at least one of: a base station; or a CUCP of the base station; and
 - the third network element is same as the first network element.
49. The method of any one of claims 35-38, wherein:
- the first network element comprises a CUCP of a base station; and
 - the second network element comprises at least one of: a CUUP of the base station; or a DU of the base station; and
 - the third network element is same as the first network element.
50. The method of any one of claims 35-38, wherein:
- the first network element comprises a source base station in a handover procedure for handing over the UE;
 - the second network element comprises a target base station in the handover procedure for handing over the UE; and
 - the third network element comprises a core network element.
51. A device for wireless communication comprising a memory for storing computer instructions and a processor in communication with the memory, wherein, when the processor executes the computer instructions, the processor is configured to implement a method in any one of claims 1-50.
52. A computer program product comprising a non-transitory computer-readable program medium with computer code stored thereupon, the computer code, when executed by one or more processors, causing the one or more processors to implement a method of any one of claims 1-50.

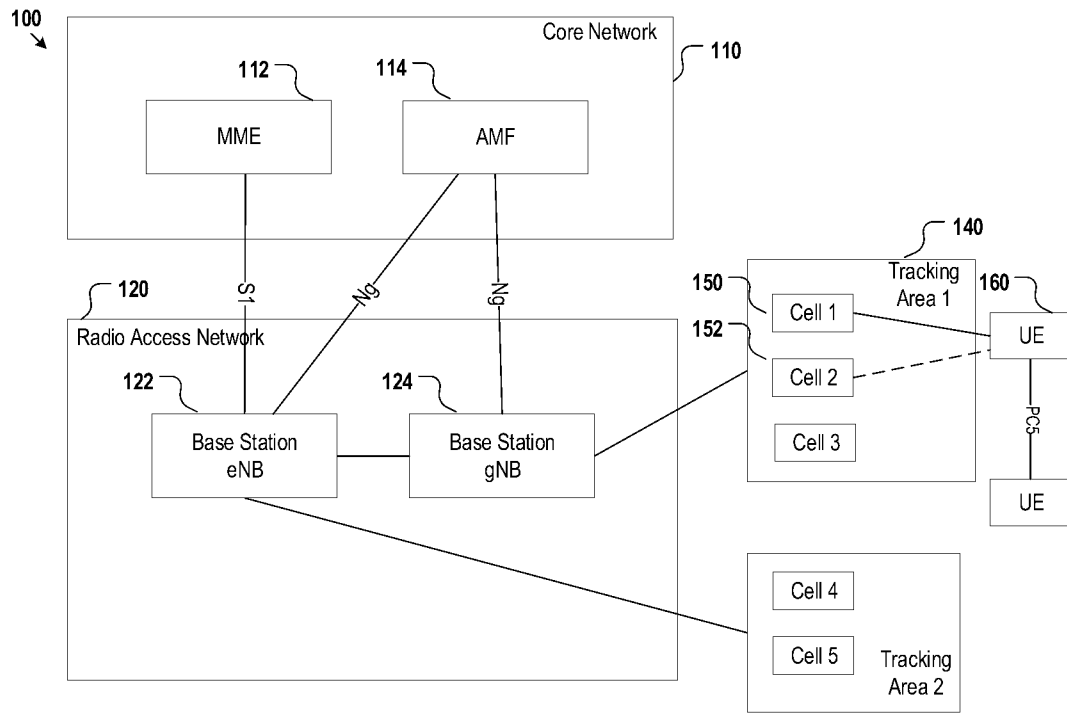


FIG. 1

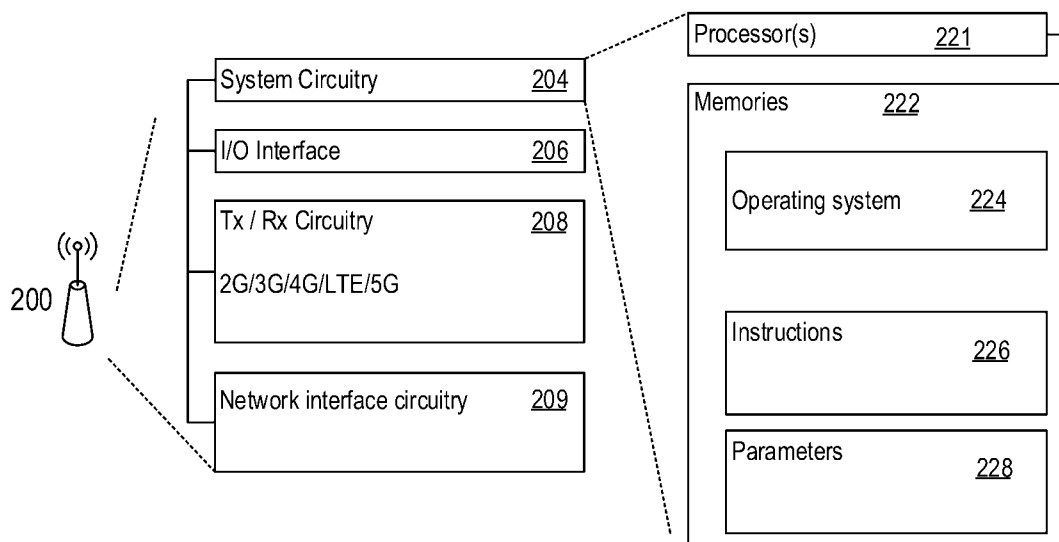


FIG. 2

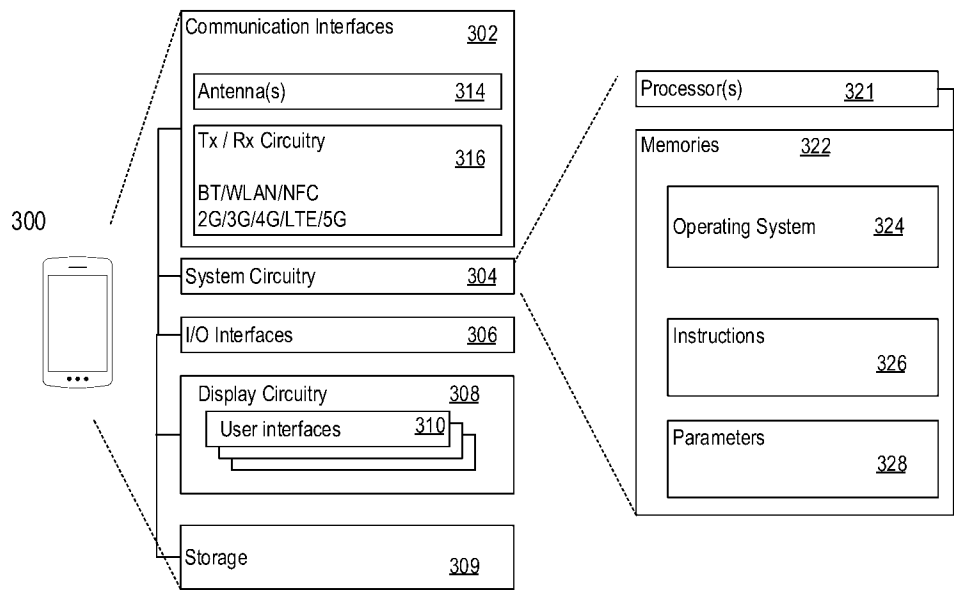


FIG. 3

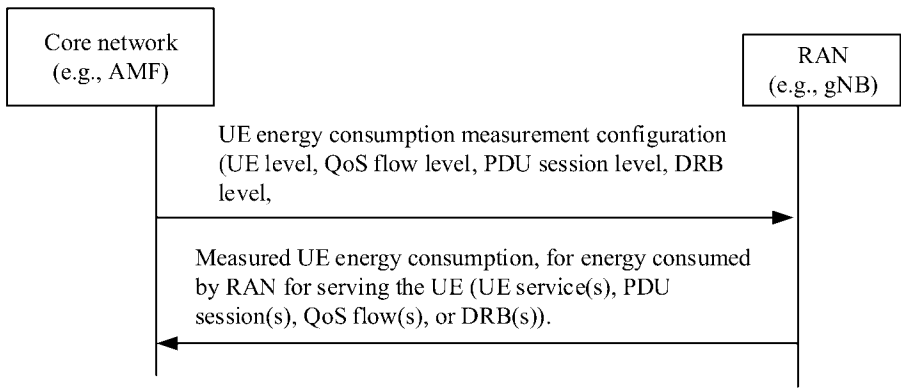


FIG. 4A

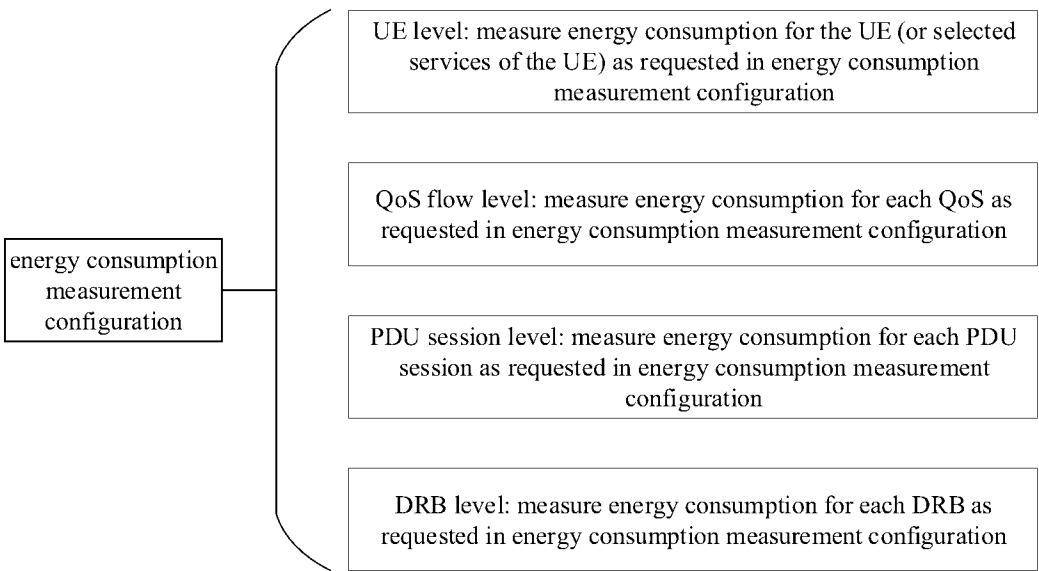


FIG. 4B

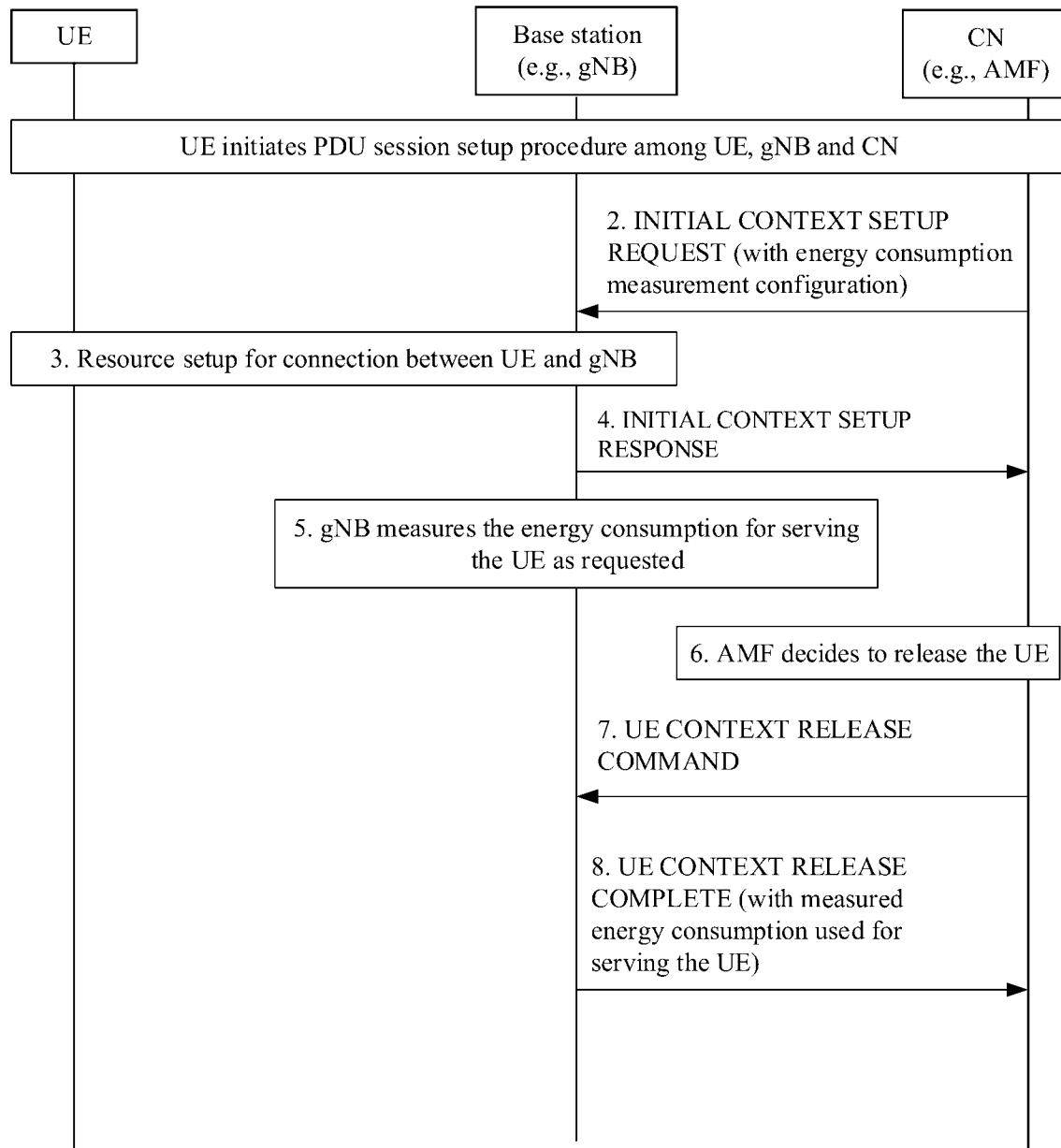


FIG. 5

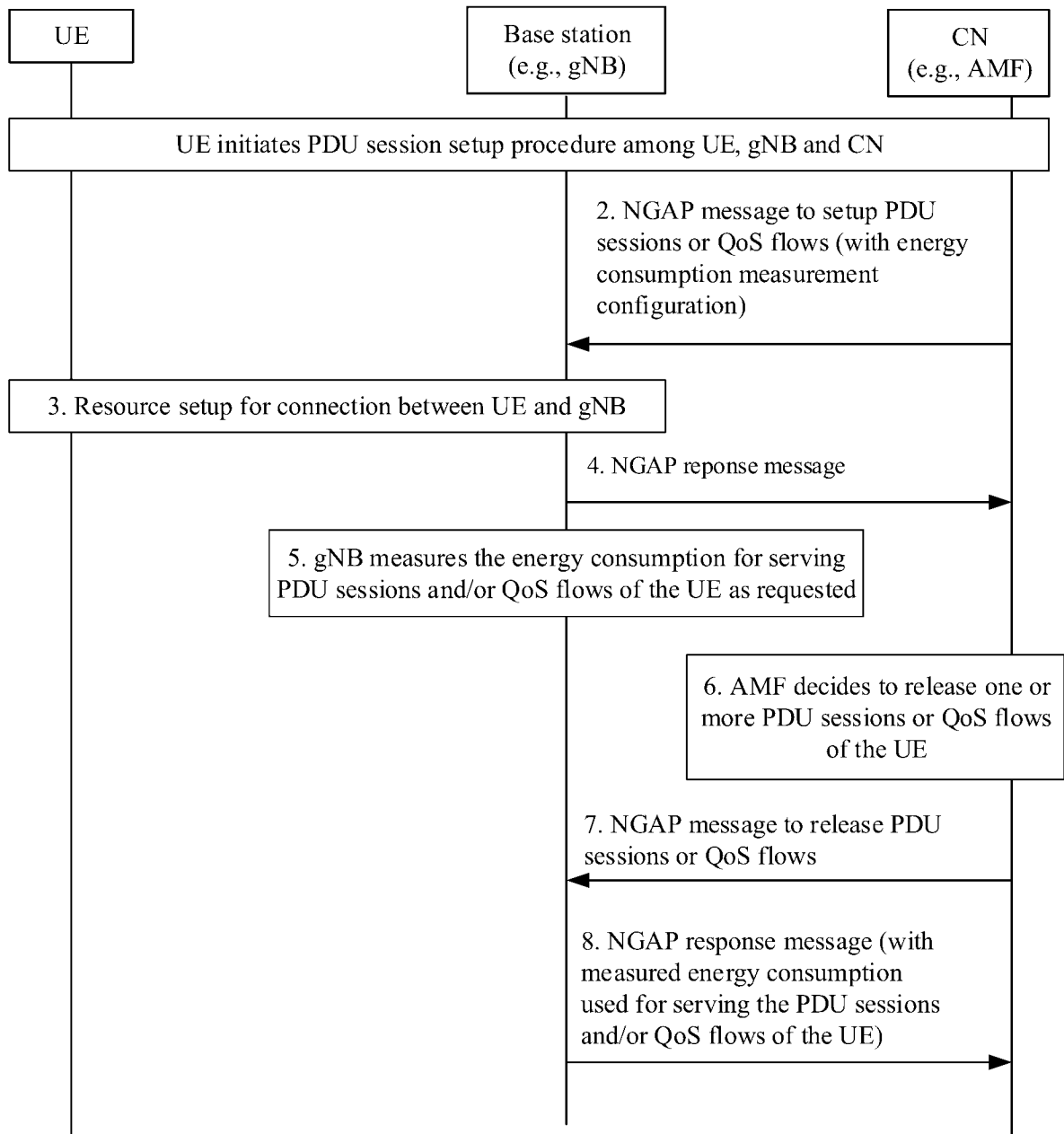


FIG. 6

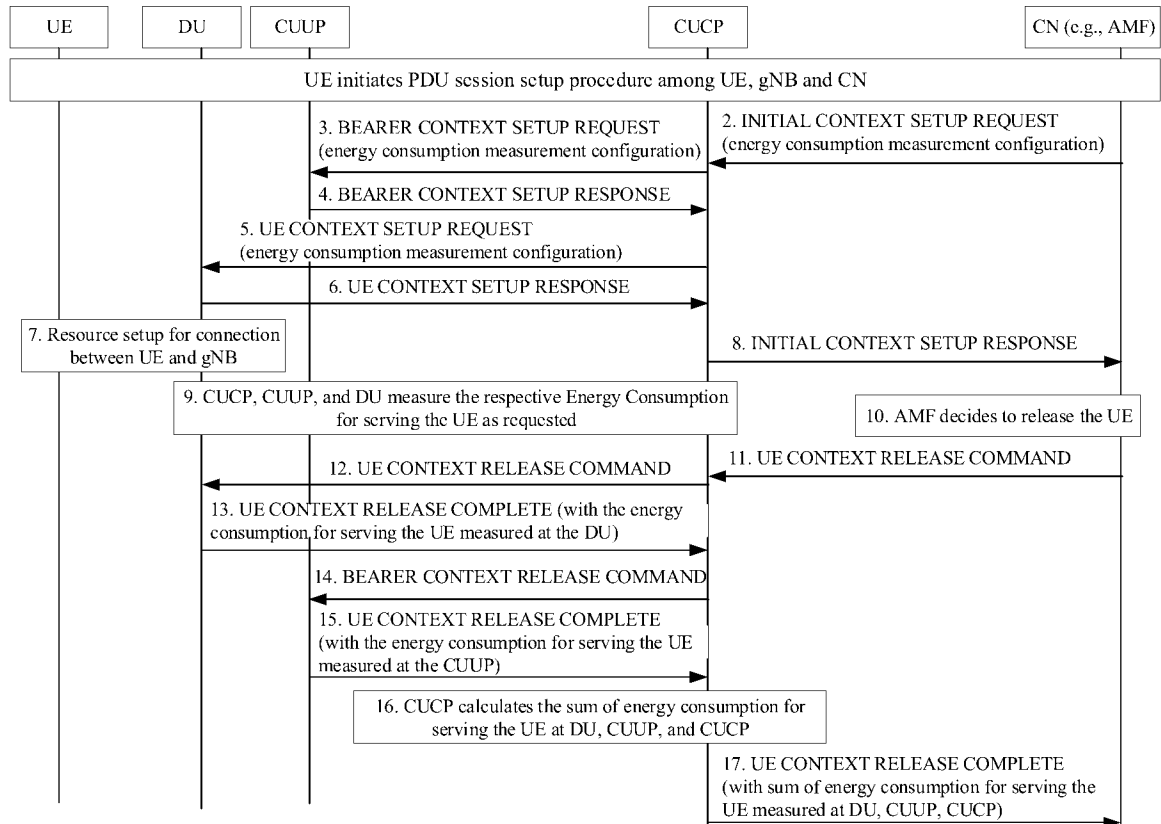


FIG. 7

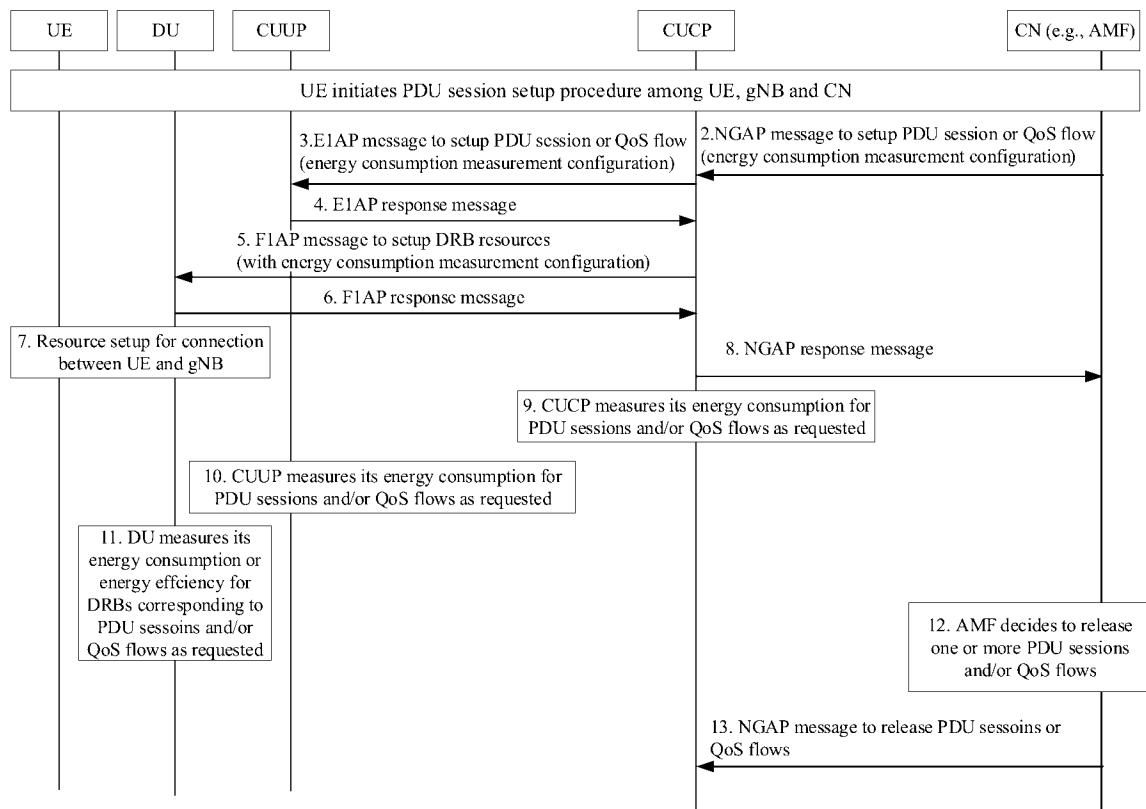


FIG. 8A

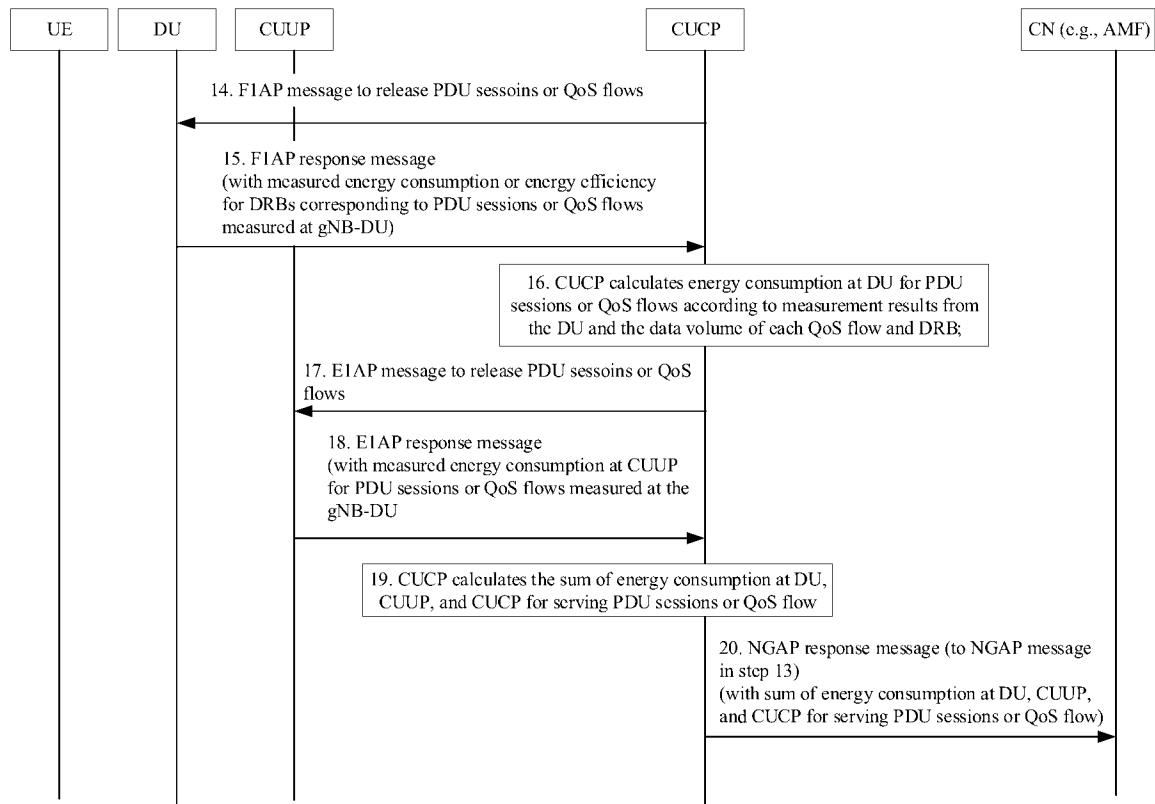


FIG. 8B

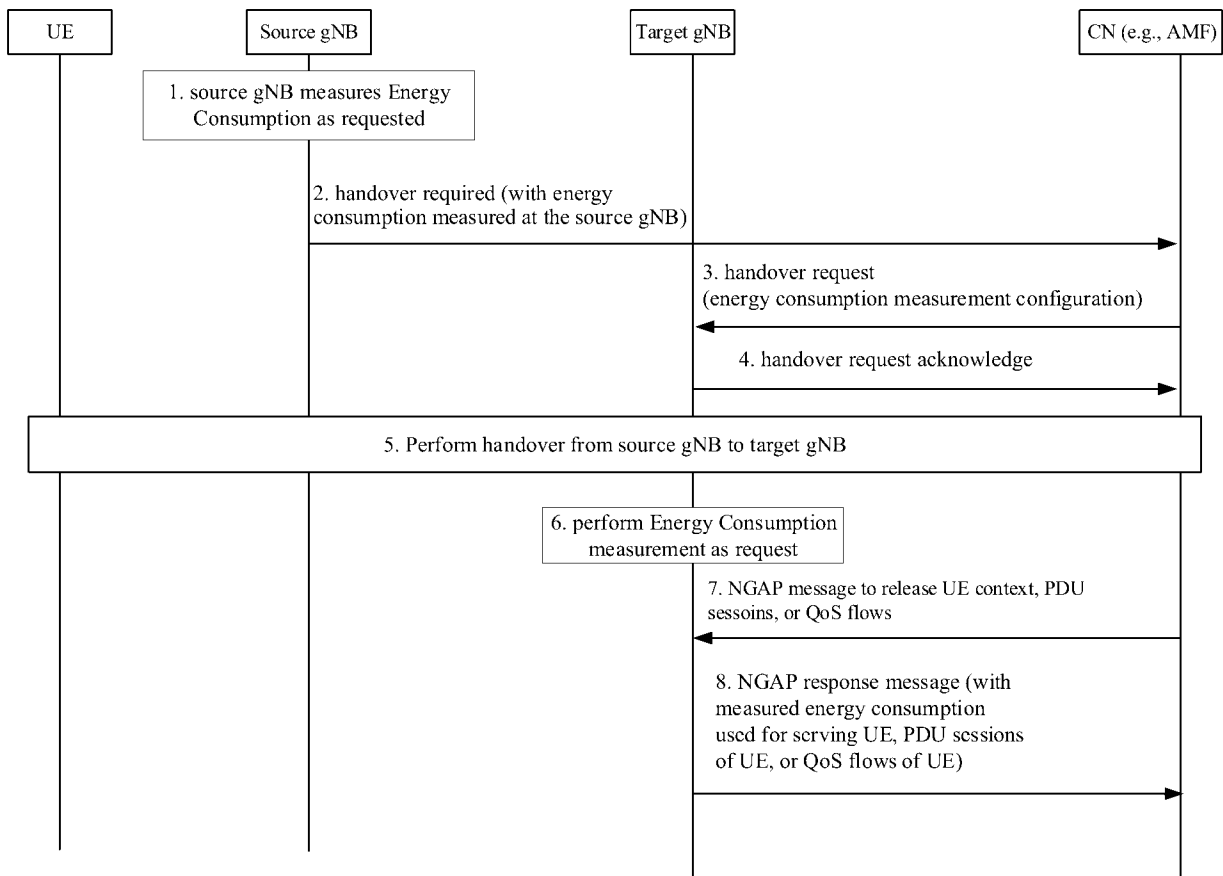


FIG. 9

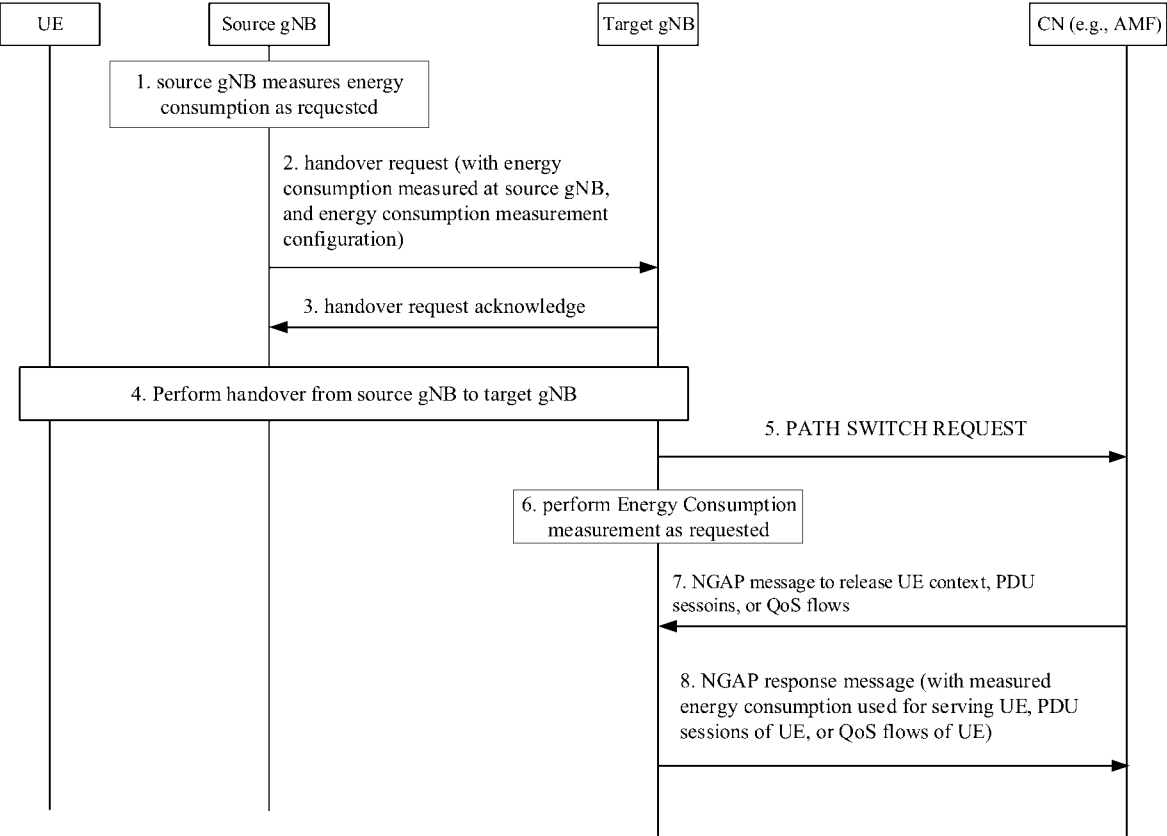


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/139256

A. CLASSIFICATION OF SUBJECT MATTER

H04W 24/02(2009.01)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)

IPC: H04W H04L

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

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

DWPI, CNTXT, ENTXTC, ENTXT, 3GPP: energy, consumption, measure, configuration, XNAP, QOS, PDU, core network

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2022229420 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 03 November 2022 (2022-11-03) description, paragraphs [042]-[0084]	1-52
A	CN 113498098 A (SHANGHAI LANGBO COMMUNICATION TECHNOLOGY COMPANY LIMITED) 12 October 2021 (2021-10-12) the whole document	1-52
A	US 2019014537 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 10 January 2019 (2019-01-10) the whole document	1-52
A	WO 2022101658 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 19 May 2022 (2022-05-19) the whole document	1-52



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“D” document cited by the applicant in the international application

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“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“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

14 August 2024

Date of mailing of the international search report

22 August 2024

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2023/139256

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				EP	4245068	A1	20 September 2023
				US	2024015553	A1	11 January 2024
				CN	116472748	A	21 July 2023