US012389320B2

(12) **United States Patent**
Chou et al.

(10) **Patent No.: US 12,389,320 B2**
(45) **Date of Patent: *Aug. 12, 2025**

(54) **ENERGY SAVINGS FOR 5G NETWORKS**

(71) Applicant: **Intel Corporation**, Santa Clara, CA (US)

(72) Inventors: **Joey Chou**, Santa Clara, CA (US); **Yizhi Yao**, Chandler, AZ (US)

(73) Assignee: **Intel Corporation**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/408,370**

(22) Filed: **Jan. 9, 2024**

(65) **Prior Publication Data**

US 2024/0147359 A1 May 2, 2024

Related U.S. Application Data

(60) Continuation of application No. 18/089,964, filed on Dec. 28, 2022, now Pat. No. 11,902,895, which is a division of application No. 16/912,474, filed on Jun. 25, 2020, now Pat. No. 11,589,301.

(60) Provisional application No. 62/881,249, filed on Jul. 31, 2019.

(51) **Int. Cl.**

H04W 36/04	(2009.01)
H04W 36/22	(2009.01)
H04W 36/38	(2009.01)
H04W 52/02	(2009.01)
H04W 36/00	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 52/0206*** (2013.01); ***H04W 36/04*** (2013.01); ***H04W 36/22*** (2013.01); ***H04W 36/38*** (2013.01); *H04W 36/00698* (2023.05)

(58) **Field of Classification Search**

CPC H04W 52/02; H04W 36/04

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,515,410	B1	8/2013	Bach
2012/0329449	A1	12/2012	Das et al.
2013/0250908	A1	9/2013	Bach et al.
2014/0187234	A1	7/2014	Chou
2015/0282070	A1	10/2015	Salem et al.
2019/0245748	A1*	8/2019	Gandhewar H04L 47/41

OTHER PUBLICATIONS

3GPP, "Technical Specification Group Radio Access Network; NR; NR and NG-RAN Overall Description; Stage 2 (Release 15)," 3GPP TS 38.300 V15.6.0 (Jun. 2019), 5G, 99 pages.

(Continued)

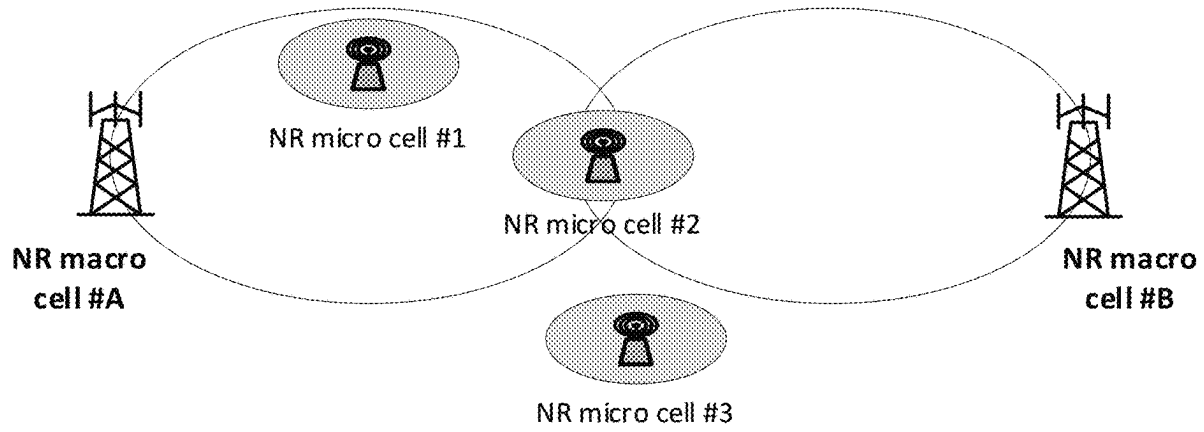
Primary Examiner — Michael T Vu

(74) *Attorney, Agent, or Firm* — Eversheds Sutherland (US) LLP

(57) **ABSTRACT**

Methods, systems, and storage media are described for Load Balancing Optimization (LBO) and Mobility Robustness Optimization (MRO) for fifth generation (5G) systems. In particular, some embodiments may be directed intra-radio access technology (RAT) energy saving scenarios while other embodiments may be directed to and inter-RAT energy saving scenarios. Other embodiments may be described and/or claimed.

20 Claims, 5 Drawing Sheets



(56) **References Cited**

OTHER PUBLICATIONS

3GPP, "Technical Specification Group Radio Access Network; Study on RAN-centric data collection and utilization for LTE and NR (Release 16)," 3GPP TR 37.816 V16.0.0 (Jul. 2019), 5G, 35 pages.

3GPP, "Technical Specification Group Services and System Aspects; Telecommunication management; Energy Saving Management (ESM); Concepts and requirements (Release 15)," 3GPP TS 32.551 V15.0.0 (Jun. 2018), 5G, 26 pages.

3GPP, "Technical Specification Group Services and System Aspects; Management and orchestration; Generic management services; (Release 16)," 3GPP TS 28.532 V16.0.0 (Jun. 2019), 5G, 180 pages.

* cited by examiner

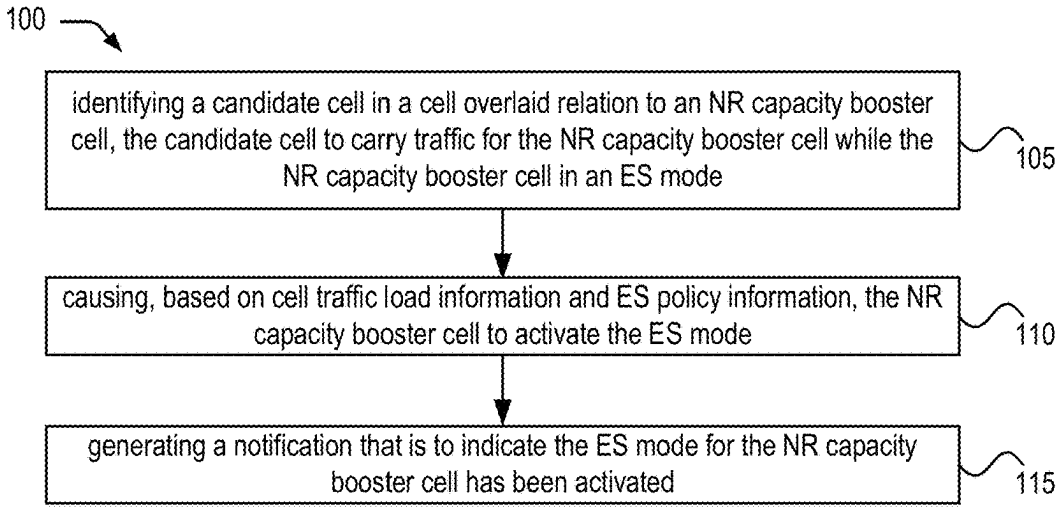


FIG. 1

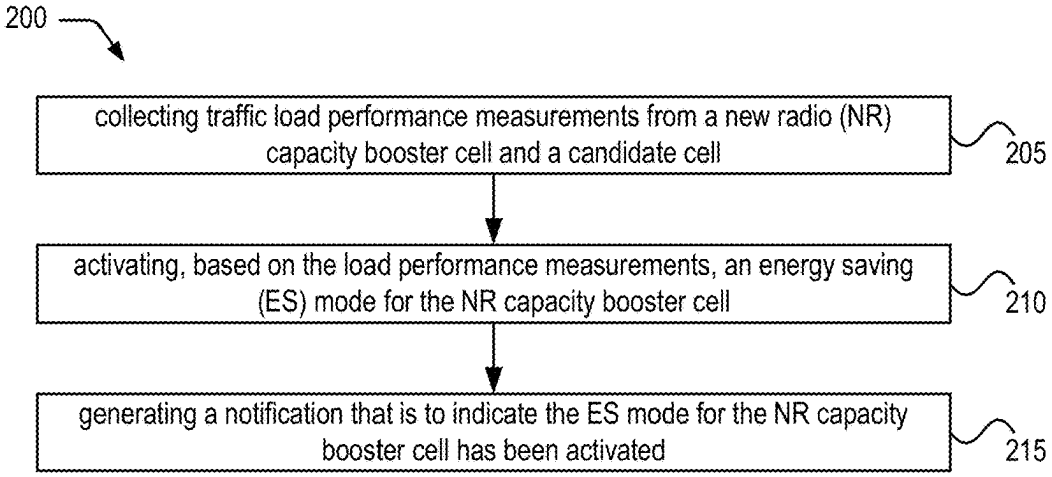


FIG. 2

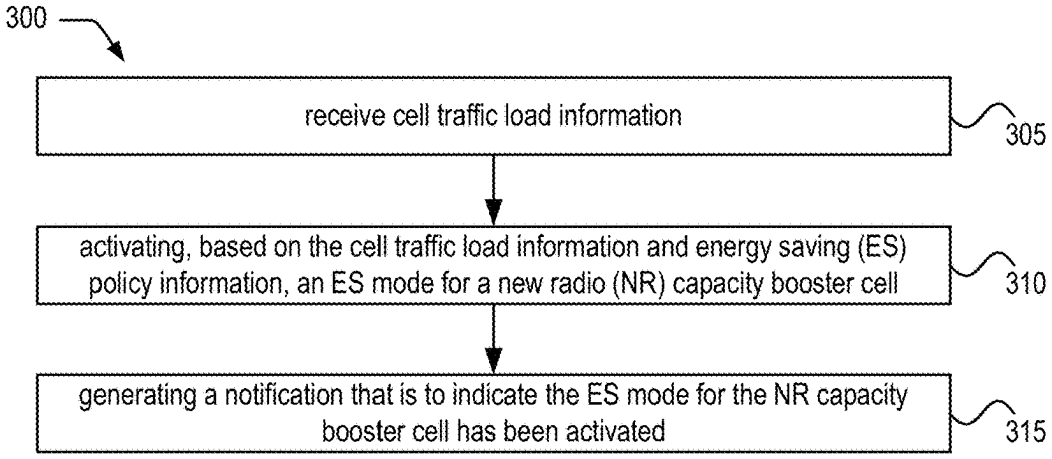


FIG. 3

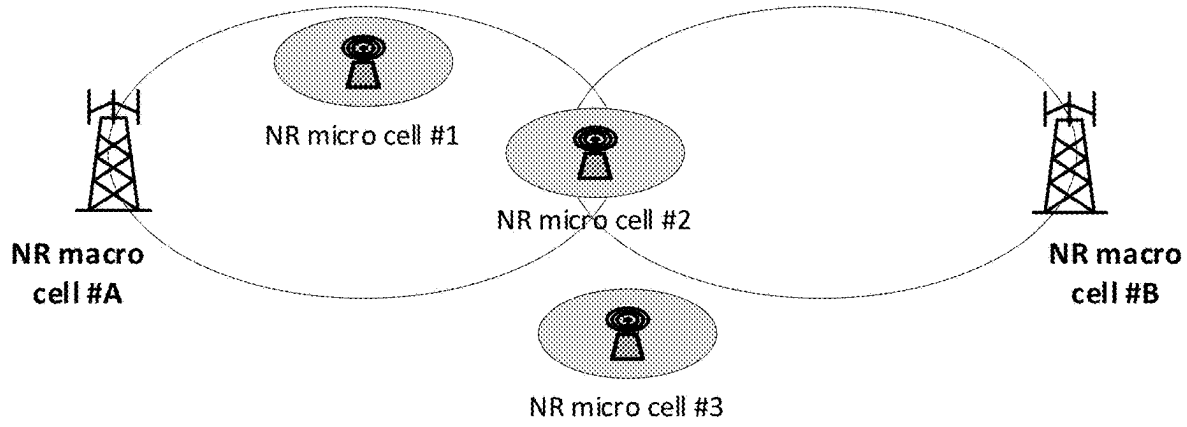

NR micro cell #1
NR micro cell #2
NR macro cell #A
NR macro cell #B
NR micro cell #3

FIG. 4A

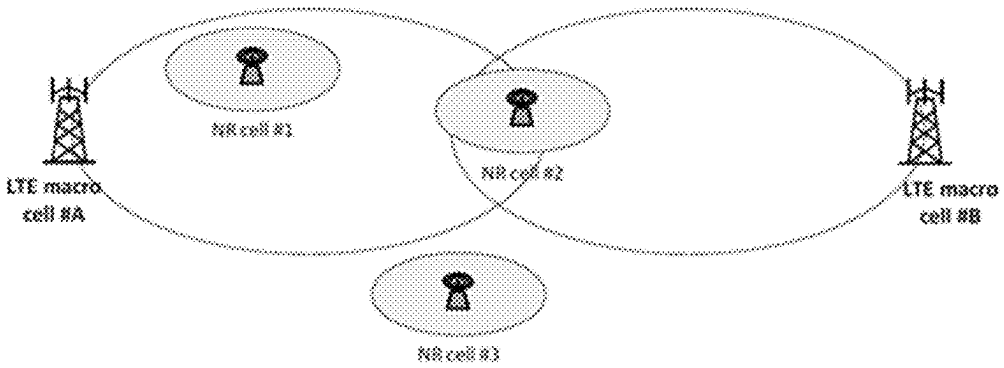

LTE macro cell #A
LTE macro cell #B

FIG. 4B

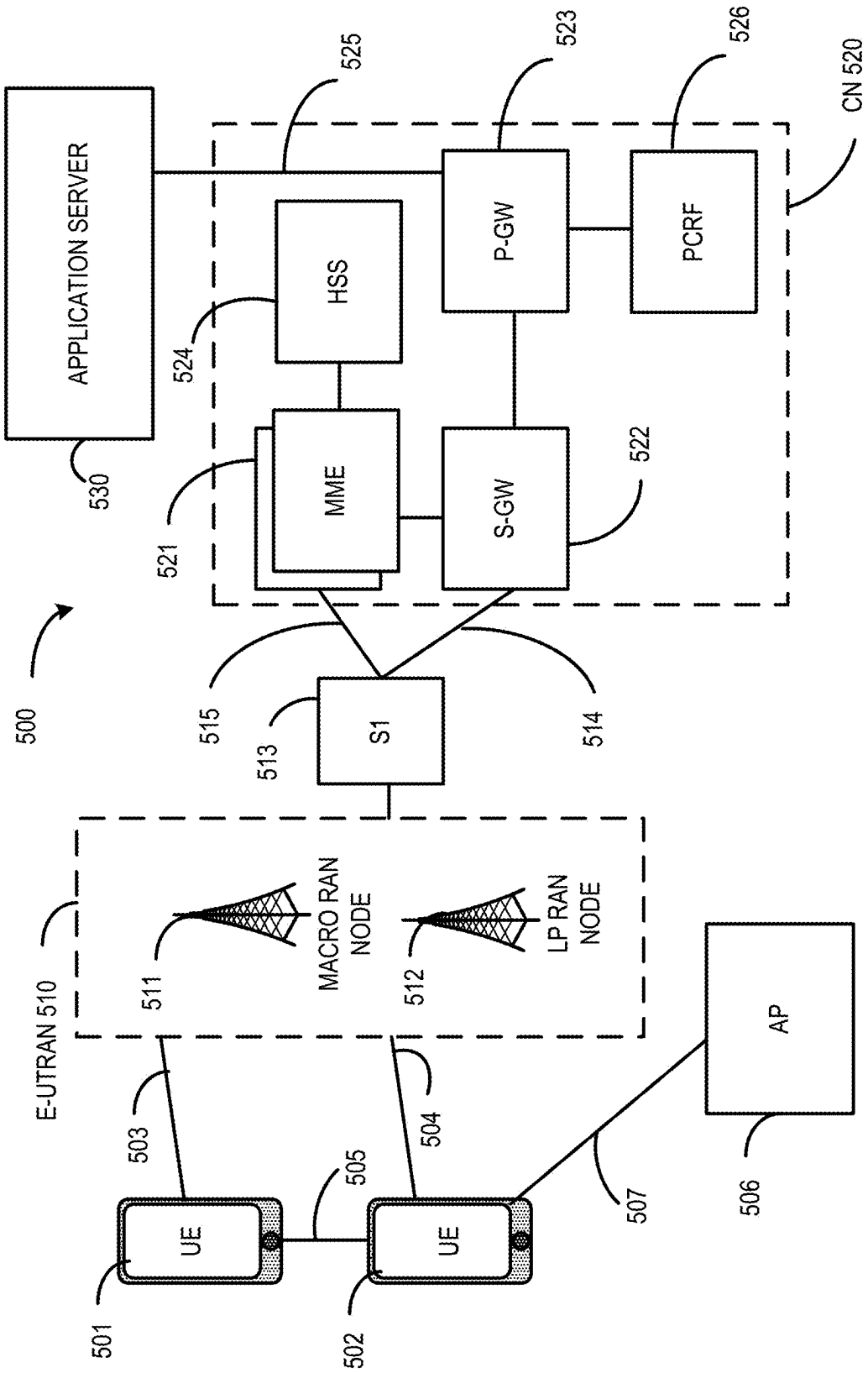

APPLICATION SERVER
530
525
523
526
CN 520
HSS
524
P-GW
PCRF
MME
521
S-GW
522
500
515
513
S1
514
E-UTRAN 510
511
MACRO RAN NODE
512
LP RAN NODE
AP
503
504
505
507
506
UE
UE
501
502

FIG. 5

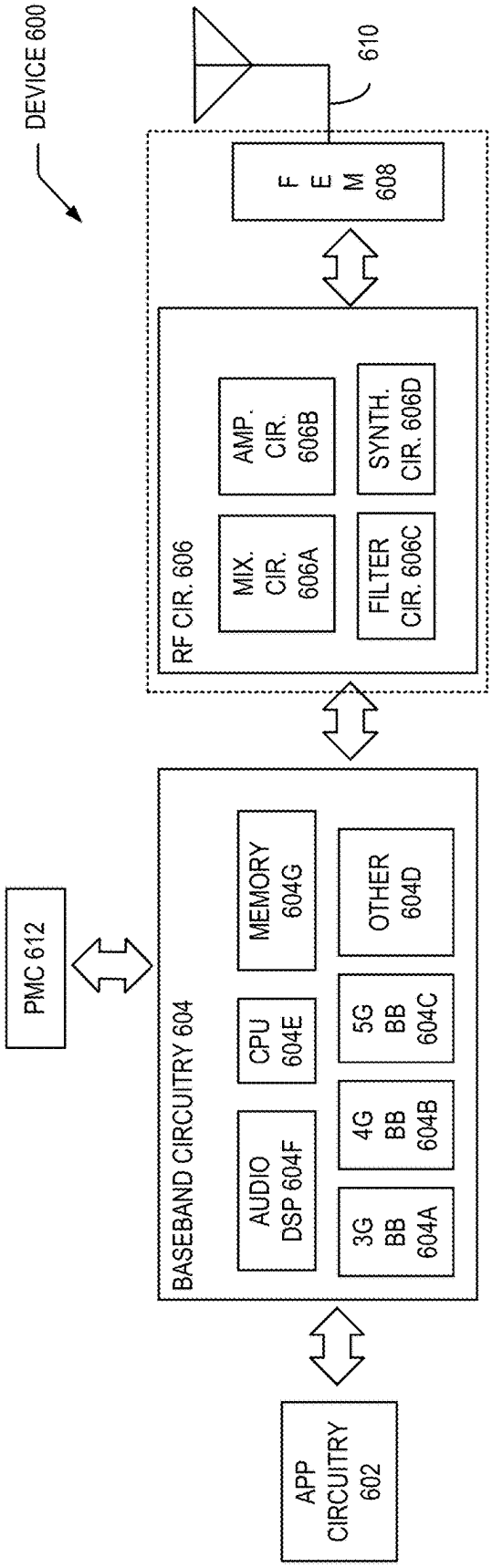

DEVICE 600
610
FEM 608
RF CIR. 606
MIX. CIR. 606A
AMP. CIR. 606B
FILTER CIR. 606C
SYNTH. CIR. 606D
BASEBAND CIRCUITRY 604
3G BB 604A
4G BB 604B
5G BB 604C
CPU 604E
AUDIO DSP 604F
MEMORY 604G
OTHER 604D
PMC 612
APP CIRCUITRY 602

FIG. 6

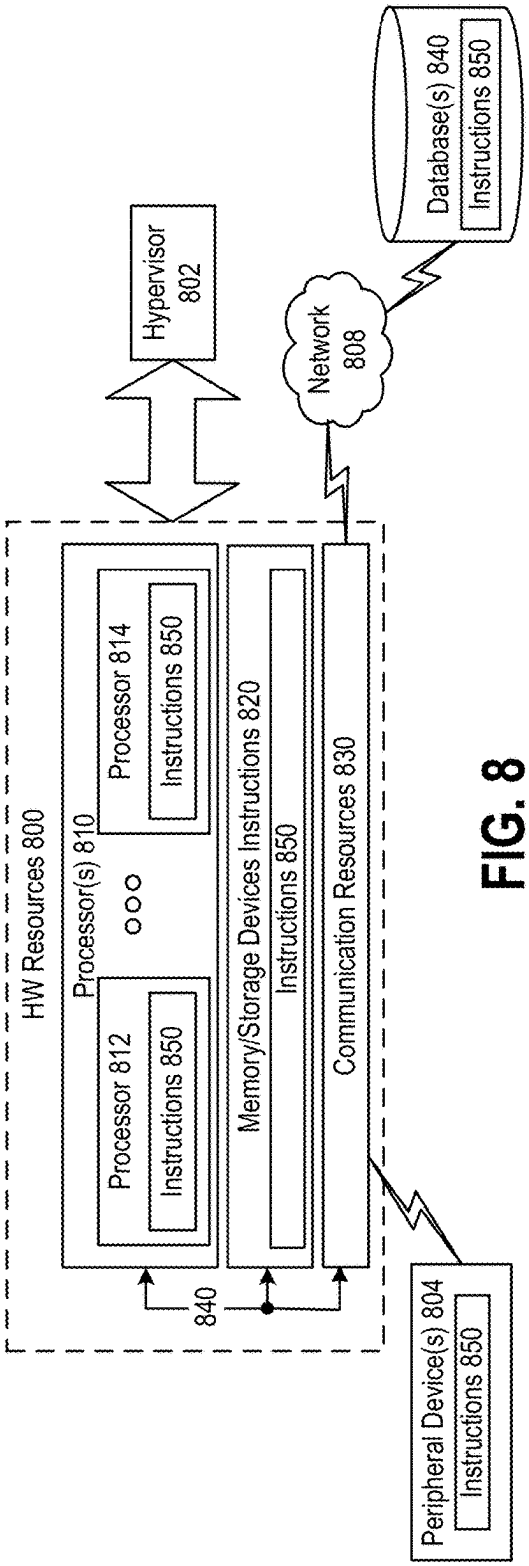

HW Resources 800
Processor(s) 810
Processor 812
Instructions 850
Processor 814
Instructions 850
840
Memory/Storage Devices Instructions 820
Instructions 850
Communication Resources 830
Hypervisor 802
Network 808
Database(s) 840
Instructions 850
Peripheral Device(s) 804
Instructions 850

FIG. 8

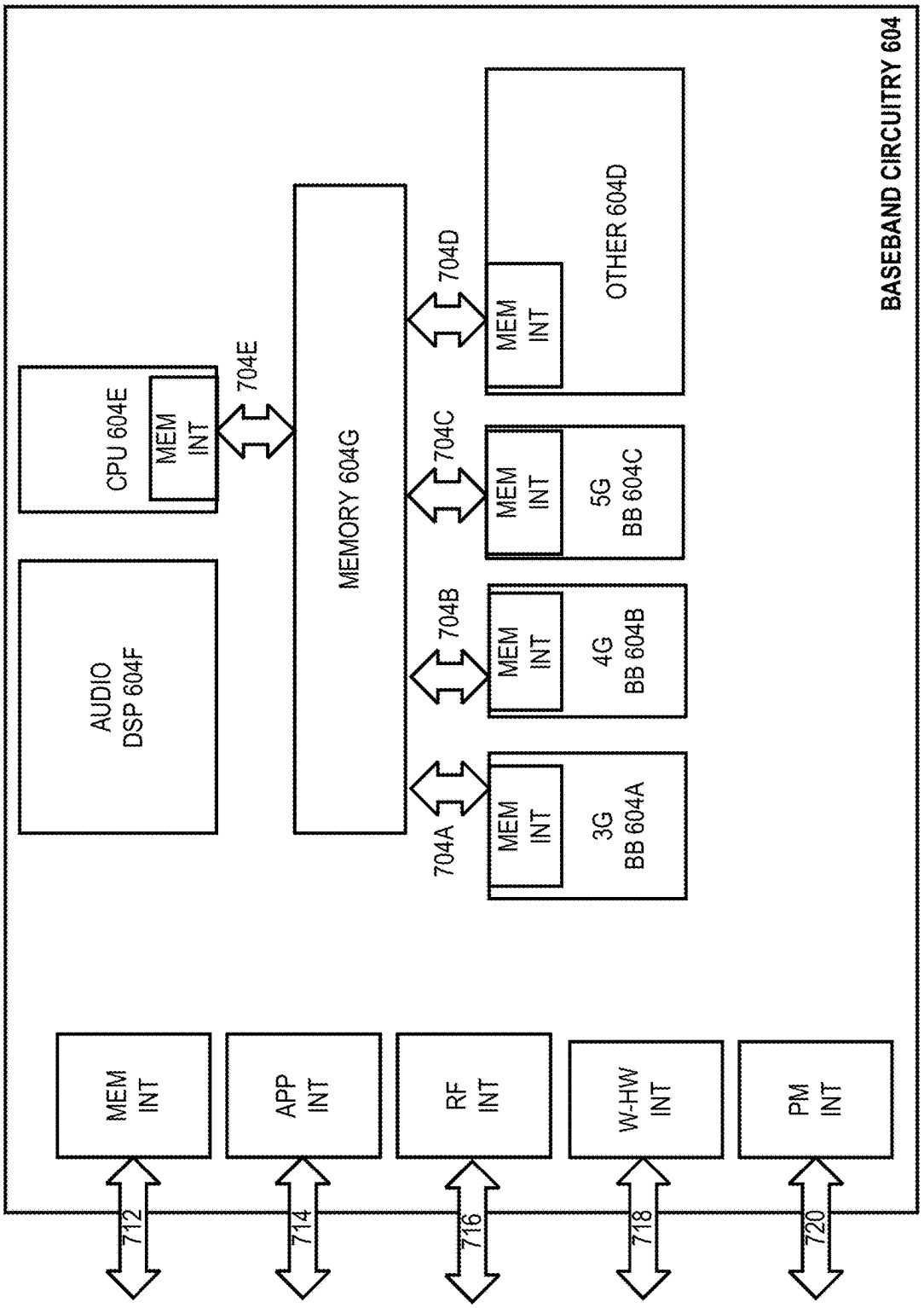

BASEBAND CIRCUITRY 604
MEM INT
APP INT
RF INT
W-HW INT
PM INT
712
714
716
718
720
AUDIO DSP 604F
CPU 604E
MEM INT
704E
MEMORY 604G
704A
704B
704C
704D
3G BB 604A
4G BB 604B
5G BB 604C
OTHER 604D

FIG. 7

ENERGY SAVINGS FOR 5G NETWORKS

RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 18/089,964 filed Dec. 28, 2022, which is a divisional of U.S. application Ser. No. 16/912,474 filed Jun. 25, 2020, which claims priority to U.S. Provisional App. No. 62/881,249 filed Jul. 31, 2019, the contents of each of which are hereby incorporated by reference in their entireties.

FIELD

Embodiments of the present disclosure relate generally to the technical field of wireless communications.

BACKGROUND

3rd Generation Partnership Project (3GPP) System Aspects Management and orchestration of networks includes self-organizing networks (SON). SON refers to a set of technologies and mechanisms designed to enable automatic configuration, optimization, and management of cellular networks. A goal of SON is to enhance the performance, efficiency, and reliability of mobile networks while minimizing the need for manual (e.g., human) intervention by network operators.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

FIGS. **1** and **2**, and **3** illustrate examples of operation flow/algorithmic structures in accordance with some embodiments.

FIG. **4**A illustrates an example of intra-RAT cells overlaid in accordance with some embodiments.

FIG. **4**B illustrates an example of inter-RAT cells overlaid in accordance with some embodiments.

FIG. **5** depicts an architecture of a system of a network in accordance with some embodiments.

FIG. **6** depicts an example of components of a device in accordance with some embodiments.

FIG. **7** depicts an example of interfaces of baseband circuitry in accordance with some embodiments.

FIG. **8** depicts a block diagram illustrating components, according to some embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

DETAILED DESCRIPTION

Embodiments discussed herein may relate to Load Balancing Optimization (LBO) and Mobility Robustness Optimization (MRO) for fifth generation (5G) systems. In particular, some embodiments may be directed intra-radio access technology (RAT) energy saving (ES) scenarios while other embodiments may be directed to and inter-RAT ES scenarios. Among other things, embodiments of the present disclosure may help provide Load Balancing Optimization (LBO) and Mobility Robustness Optimization (MRO) for fifth generation (5G) systems. In particular, some embodiments may be directed intra-radio access technology (RAT) ES scenarios while other embodiments may be directed to and inter-RAT ES scenarios. Other embodiments may be described and/or claimed.

The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc., in order to provide a thorough understanding of the various aspects of the claimed invention. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the invention claimed may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

Various aspects of the illustrative embodiments will be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. However, it will be apparent to those skilled in the art that alternate embodiments may be practiced with only some of the described aspects. For purposes of explanation, specific numbers, materials, and configurations are set forth in order to provide a thorough understanding of the illustrative embodiments. However, it will be apparent to one skilled in the art that alternate embodiments may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the illustrative embodiments.

Further, various operations will be described as multiple discrete operations, in turn, in a manner that is most helpful in understanding the illustrative embodiments; however, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

The phrase "in various embodiments," "in some embodiments," and the like may refer to the same, or different, embodiments. The terms "comprising," "having," and "including" are synonymous, unless the context dictates otherwise. The phrase "A and/or B" means (A), (B), or (A and B). The phrases "A/B" and "A or B" mean (A), (B), or (A and B), similar to the phrase "A and/or B." For the purposes of the present disclosure, the phrase "at least one of A and B" means (A), (B), or (A and B). The description may use the phrases "in an embodiment," "in embodiments," "in some embodiments," and/or "in various embodiments," which may each refer to one or more of the same or different embodiments. Furthermore, the terms "comprising," "including," "having," and the like, as used with respect to embodiments of the present disclosure, are synonymous.

Examples of embodiments may be described as a process depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations may be performed in parallel, concurrently, or simultaneously. In addition, the order of the operations may be re-arranged. A process may be terminated when its operations are completed, but may also have additional steps not included in the figure(s). A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, and the like. When a process corre-

sponds to a function, its termination may correspond to a return of the function to the calling function and/or the main function.

Examples of embodiments may be described in the general context of computer-executable instructions, such as program code, software modules, and/or functional processes, being executed by one or more of the aforementioned circuitry. The program code, software modules, and/or functional processes may include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular data types. The program code, software modules, and/or functional processes discussed herein may be implemented using existing hardware in existing communication networks. For example, program code, software modules, and/or functional processes discussed herein may be implemented using existing hardware at existing network elements or control nodes.

One objective of ES is to lower operating expenses (OPEX) for mobile operators. Additionally, the reduction of power consumption in the mobile networks is becoming more challenging, as there are many more network elements in new radio (NR) (e.g., small cells with massive MIMO in higher frequency bands) than those used in long-term evolution (LTE) systems. One typical scenario of ES is to switch off capacity boosters when the traffic demand is low, and re-activate them on a need basis (see e.g., clause 5.6 in 3GPP TR 37.816 v 16.0.0 (2019-07-23) ("TR 37.816")). ES may include two scenarios—intra-RAT ES and inter-RAT ES (see e.g., 3GPP TS 32.551 v 15.0.0 (2018-06-27)).

FIG. **4**A illustrates an example of an intra-RAT cell overlaid scenario, where: NR micro cell #1 is fully overlaid by NR macro cell #A; NR micro cell #2 is partially overlaid by multiple NR macro cells #A and #B; and NR micro cell #3 is not overlaid at all.

FIG. **4**B illustrates an example of an inter-RAT cell overlaid scenario, where: NR cell #1 is fully overlaid by LTE macro cell #A; NR cell #2 is partially overlaid by multiple LTE macro cells #A and #B; and NR cell #3 is not overlaid at all. Embodiments of the present disclosure may configure such cell overlaid relations (e.g., as illustrated in FIGS. **4**A and **4**B) as well as addressing centralized energy savings and distributed energy savings scenarios.

Among other things, embodiments of the present disclosure may help provide Load Balancing Optimization (LBO) and Mobility Robustness Optimization (MRO). The objective of ES is to lower OPEX for mobile operators, through the reduction of power consumption in the mobile networks that is becoming more urgent and challenging, as there are more network elements in NR (e.g., small cells with massive MIMO in higher frequency bands) than those used in LTE. One typical scenario of ES is to switch off capacity boosters when the traffic demand is low, and re-activate them on a need basis (see e.g., clause 5.6 in TR 37.816).

ES may include two scenarios—intra-RAT ES and inter-RAT ES. Each scenario can be further composed of centralized ES and distributed ES.

1. Intra-Rat Es

Intra-RAT ES includes distributed ES (intra-RAT D-ES) where the ES decision is made in the NR cells with operations administration and maintenance (OAM) assist to provide relevant information, such as policies, or centralized ES-intra-RAT C-ES where the ES decision is made in OAM. A NR capacity booster cell can only enter ES mode if its traffic load can be taken over by the candidate cells.

FIG. **4**A shows an intra-RAT cell overlaid scenario, where NR micro cell #1 is fully overlaid by NR macro cell #A; NR micro cell #2 is partially overlaid by multiple NR macro cells #A and #B; and NR micro cell #3 is not overlaid at all.

1.1. Distributed Intra-RAT ES

1.1.1. Intra-RAT D-ES Activation

1. The intra-RAT D-ES management function configures the cell overlaid relations for NR capacity booster cells, and macro cells.
2. The intra-RAT D-ES management function configures the ES policy that includes the thresholds for the ES activation and deactivation for NR capacity booster cells and candidate cells.
3. The intra-RAT D-ES management function enables the intra-RAT D-ES function for a NR capacity booster cell.
4. The intra-RAT D-ES function makes decision for a NR capacity booster cell to enter the ES mode based on the cell traffic load information (see e.g., clause 15.4.2 in 3GPP TS 38.300 v 15.6.0 (2019 Jun. 28) ("TS 38.300")).
5. The intra-RAT D-ES function finds one or more candidate cells in the cell overlaid relation that can carry the traffic for the NR capacity booster cell in the ES mode.
6. The intra-RAT D-ES function: Asks the NR capacity booster cell to enter the ES mode. NOTE: The NR capacity booster cell may initiate handover actions to off-load its traffic to the candidate cells, before activating the ES mode (see e.g., clause 15.4.2 in TS 38.300); and/or sends a notification to the intra-RAT D-ES management function indicating the ES mode of the NR capacity booster cell has been activated.

1.1.2. Intra-RAT D-ES Deactivation

1. The intra-RAT D-ES function monitors the traffic load on the candidate cells and decides to re-activate the NR capacity booster cell when it detects additional capacity is needed (see e.g., clause 15.4.2 in TS 38.300).
2. The intra-RAT D-ES function sends a notification to the intra-RAT D-ES management function indicating the ES mode of the NR capacity booster cell has been deactivated.
3. After the NR capacity booster cell has been re-activated, the intra-RAT D-ES function sends a notification to the intra-RAT D-ES management function indicating the re-activation of the NR capacity booster cell.

1.2. Centralized Intra-RAT ES

It is assumed that intra-RAT C-ES function has been enabled, and has received the cell overlaid relations and ES policies for NR capacity booster cell and macro cells.

1.2.1. Intra-RAT C-ES Activation

1. The intra-RAT C-ES function collects the traffic load performance measurements from the NR capacity booster cell and candidate cells.
2. The intra-RAT C-ES function analyzes the traffic load performance measurements decides that a NR capacity booster cell should enter the ES mode.
3. The intra-RAT C-ES function requests the NR capacity booster cell to enter the ES mode.
4. The NR capacity booster cell may initiate handover actions to off-load the traffic to the neighboring cells (see e.g., clause 15.4.2 in TS 38.300) prior to entering into the ES mode, and then sends a response to the intra-RAT C-ES function indicating it is in the ES mode.

5. The intra-RAT C-ES function sends a notification to the consumer indicating the NR capacity booster is in the ES mode.

1.2.2. Intra-RAT C-ES Deactivation

1. The intra-RAT C-ES function collects the traffic load performance measurements from the candidate cell(s) that are backing up the NR capacity booster cell.
2. The intra-RAT C-ES function monitors the traffic load on the candidate cells, and decides to re-activate the NR capacity booster cell if it detects that the capacity is needed (see e.g., clause 15.4.2 in TS 38.300).
3. The intra-RAT C-ES function sends a notification to the consumer indicating the NR capacity booster is not in the ES mode.

2. Inter-Rat Es

Inter-RAT ES focuses on a scenario where the LTE evolved NodeB (eNB) provides basic coverage, with the next-generation NodeB (gNB) providing the capacity booster that can be switched off, based on its own cell load information or by OAM. The LTE eNB is allowed to activate the dormant capacity booster NR cell (see e.g., clause 5.6 in TR 37.816).

Inter-RAT ES includes distributed ES-inter-RAT D-ES where the ES decision is made in the NR cells with OAM assist to provide relevant information, or centralized ES where the ES decision is made in inter-RAT C-ES function. A NR capacity booster cell can only enter the ES mode if its traffic load can be taken over by the candidate cells.

FIG. **4**B illustrates an example of an inter-RAT cell overlaid scenario, where: NR cell #1 is fully overlaid by LTE macro cell #A; NR cell #2 is partially overlaid by multiple LTE macro cells #A and #B; and NR cell #3 is not overlaid at all. This cell overlaid relation needs to be configured in NR cells.

2.1. Distributed Inter-RAT ES

2.1.1. ES Activation

1. The inter-RAT D-ES management function configures the cell overlaid relations for NR capacity booster cells, and LTE macro cells.
2. The inter-RAT D-ES management function configures the ES policy that includes the thresholds for the ES activation and deactivation for NR capacity booster cells and candidate cells.
3. The inter-RAT D-ES management function enables the intra-RAT D-ES function for a NR capacity booster cell.
4. The inter-RAT D-ES function makes decision for a NR capacity booster cell to enter the ES mode if it detects that the capacity is no longer needed (see e.g., clause 5.6.1 in 3GPP TR 37.861).
5. The inter-RAT D-ES function finds one or more candidate cells in the cell overlaid relation that can carry the traffic for the NR capacity booster cell in the ES mode.
6. The inter-RAT D-ES function: asks the NR capacity booster cell to enter the ES mode. NOTE: The NR capacity booster cell may initiate handover actions to off-load its traffic to the candidate cells, before activating the ES mode (see e.g., clause 15.4.2 in TS 38.300); and/or sends a notification to the inter-RAT D-ES management function indicating the ES mode of the NR capacity booster cell has been activated.

2.1.2. ES Deactivation

1. The inter-RAT D-ES function monitors the traffic load on the candidate cells, and decides to re-activate the NR capacity booster cell if it detects that the capacity is needed (see e.g., clause 5.6.1 in 3GPP TR 37.861).
2. The inter-RAT D-ES function sends a notification to the intra-RAT D-ES management function indicating the ES mode of the NR capacity booster cell has been deactivated.
3. After the NR capacity booster cell has been re-activated, the inter-RAT D-ES function sends a notification to the inter-RAT D-ES management function indicating the re-activation of the NR capacity booster cell.

2.2. Centralized Inter-RAT ES

It is assumed that inter-RAT C-ES function has been enabled, and has received the cell overlaid relations and ES policies for NR capacity booster cell and macro cells.

2.2.1. ES Activation

1. The inter-RAT C-ES function collects the traffic load performance measurements from the NR capacity booster cell and candidate cells.
2. The inter-RAT C-ES function analyzes the traffic load performance measurements decides that a NR capacity booster cell should enter the ES mode.
3. The inter-RAT C-ES function requests the NR capacity booster cell to enter the ES mode.
4. The NR capacity booster cell may initiate handover actions to off-load the traffic to the neighboring cells (see e.g., clause 15.4.2 in TS 38.300) prior to entering into the ES mode, and then sends a response to the inter-RAT C-ES function indicating it is in the ES mode.
5. The inter-RAT C-ES function sends a notification to the consumer indicating the NR capacity booster is in the ES mode.

2.2.2. ES Deactivation

1. The inter-RAT C-ES function collects the traffic load performance measurements from the candidate cell(s) that are backing up the NR capacity booster cell.
2. The inter-RAT C-ES function monitors the traffic load on the candidate cells, and decides to re-activate the NR capacity booster cell if it detects that the capacity is needed (see e.g., clause 15.4.2 in TS 38.300).
3. The inter-RAT C-ES function sends a notification to the consumer indicating the NR capacity booster is not in the ES mode.

3. Potential Requirements

3.1. ES Management

REQ-ESM-1 The intra-RAT D-ES and inter-RAT D-ES management functions should have the capability to configure the cell overlaid relations, and ES policies, and to enable or disable the function for a NR capacity booster cell to enter ES mode.

REQ-ESM-2 The intra-RAT D-ES function should have the capability to send notifications to the intra-RAT D-ES management function to indicate the ES mode has been activated or deactivated in the NR capacity booster cell.

REQ-ESM-3 The intra-RAT C-ES should have the capability to collect the traffic load performance measurements of NR capacity booster and macro cells.

REQ-ESM-4 The intra-RAT C-ES should have the capability to request the NR capacity booster cell to enter the ES mode.

REQ-ESM-5 The intra-RAT C-ES should have the capability to activate the ES mode of the NR capacity booster cell after receiving a confirmation to do so.

REQ-ESM-6 The intra-RAT C-ES should have the capability to deactivate the ES mode of a NR capacity booster cell.

REQ-ESM-7 The inter-RAT D-ES function should have the capability to send notifications to the inter-RAT D-ES management function to indicate the ES mode has been activated or deactivated in the NR capacity booster cell.

REQ-ESM-8 The inter-RAT C-ES should have the capability to collect the traffic load performance measurements of NR capacity booster and LTE macro cells.

REQ-ESM-9 The inter-RAT C-ES should have the capability to request the NR capacity booster cell to enter the ES mode.

REQ-ESM-10 The inter-RAT C-ES should have the capability to activate the ES mode of the NR capacity booster cell after receiving a confirmation to do so.

REQ-ESM-11 The inter-RAT C-ES should have the capability to deactivate the ES mode of a NR capacity booster cell.

4. Example Es Solutions

The basic concept of 5G ES is to divert the UE traffic of the NR capacity booster cell to the candidate cell(s) when its traffic load is low, and switch off the cell to operate in the low energy consumption mode. The difference between intra-RAT ES and inter-RAT ES is in that the candidate cell(s) for intra-RAT ES are NR macro cells, while the candidate cell(s) for the inter-RAT ES are LTE macro cells.

4.1. Distributed ES Function Management Services (MnS)

This solution is applicable to intra-RAT D-ES and inter-RAT D-ES by using NR macro cells as the candidate cells of intra-RAT D-ES, and LTE macro cells as the candidate cells of inter-RAT D-ES. It is assumed that all relevant MOIs have been created.

4.1.1. ES Activation

The D-ES management function consumes the management service (MnS) for network function (NF) provisioning with modifyMOIAttributes operation to: configure the cell overlaid relations for NR capacity booster cells, and macro cells as candidate cells; configure the ES policy that includes the thresholds for the ES activation and deactivation for NR capacity booster cells and candidate cells; and/or enable the distribute ES function for intra-RAT or inter-RAT.

NOTE: NRM may need to be enhanced to support cell overlaid relations, ES policy, and ES control.

The D-ES function makes decision for the NR capacity booster cell to enter the ES mode based on the cell traffic load information (see e.g., clause 15.4.2 in TS 38.300).

The D-ES function indicates the change of ES mode to its MnS producer for NF provisioning that will send a notifyMOIAttributeValueChanges (see e.g., clause 5.1.9 in TS 28.532 v 15.2.0 (2019 Mar. 28) ("TS 28.532")) to notify the D-ES management function to indicate the NR capacity booster has entered the ES mode (or ES state).

4.1.2. ES Deactivation

The D-ES function monitors the traffic load of candidate cell, and decides to re-activate the NR capacity booster cell when it detects that additional capacity is needed (see e.g., clause 15.4.2 in TS 38.300).

The D-ES function indicates the change of ES mode to its MnS producer for NF provisioning that will send a notifyMOIAttributeValueChanges (see e.g., clause 5.1.9 in TS 28.532) to notify the D-ES management function to indicate the NR capacity booster has been re-activated.

4.2. Centralized ES Function

This solution is applicable to intra-RAT C-ES and inter-RAT C-ES by using NR macro cells as the candidate cells of intra-RAT C-ES, and LTE macro cells as the candidate cells of inter-RAT C-ES. It is assumed that all relevant MOIs have been created.

4.2.1. ES Activation

The C-ES function collects the traffic load performance measurements from the NR capacity booster cell and candidate cells.

The C-ES function analyzes the traffic load performance measurements and decide that the NR capacity booster cell should enter the ES mode.

The C-ES function consumes the MnS for NF provisioning with modifyMOIAttributes operation to request the NR capacity booster cell to enter the ES mode.

The NR capacity booster cell may initiate handover actions to off-load the traffic to the neighbor cells (see e.g., clause 15.4.2 in TS 38.300), prior to entering into the ES mode, and then informs the MnS producer for NF provisioning to send a notifyMOIAttributeValueChanges to notify the C-ES function that the NR capacity booster cell has entered the ES mode.

4.2.2. ES Deactivation

The C-ES function collects the traffic load performance measurements from the candidate cells.

The C-ES function decides to re-activate the NR capacity booster cell if it detects that the capacity is needed (see e.g., clause 15.4.2 in TS 38.300).

The C-ES function consumes the MnS for NF provisioning with modifyMOIAttributes operation to re-activate the NR capacity booster cell that informs the MnS producer for NF provisioning to send a notifyMOIAttributeValueChanges to notify that the NR capacity booster cell has been re-activated. NOTE: Traffic load performance measurements may be defined to support C-ES function.

5. Example Device, System, and Networks

FIG. **5** illustrates an architecture of a system **500** of a network in accordance with some embodiments. The system **500** is shown to include a user equipment (UE) **501** and a UE **502**. The UEs **501** and **502** are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface.

In some embodiments, any of the UEs **501** and **502** can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

The UEs **501** and **502** may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) **510**—the RAN **510** may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs **501** and **502** utilize connections **503** and **504**, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections **503** and **504** are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

In this embodiment, the UEs **501** and **502** may further directly exchange communication data via a ProSe interface **505**. The ProSe interface **505** may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

The UE **502** is shown to be configured to access an access point (AP) **506** via connection **507**. The connection **507** can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP **506** would comprise a wireless fidelity (WiFi®) router. In this example, the AP **506** is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

The RAN **510** can include one or more access nodes that enable the connections **503** and **504**. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). The RAN **510** may include one or more RAN nodes for providing macrocells, e.g., macro RAN node **511**, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node **512**.

Any of the RAN nodes **511** and **512** can terminate the air interface protocol and can be the first point of contact for the UEs **501** and **502**. In some embodiments, any of the RAN nodes **511** and **512** can fulfill various logical functions for the RAN **510** including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

In accordance with some embodiments, the UEs **501** and **502** can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes **511** and **512** over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes **511** and **512** to the UEs **501** and **502**, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs **501** and **502**. The physical downlink control channel (PDCCH) may carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs **501** and **502** about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE **502** within a cell) may be performed at any of the RAN nodes **511** and **512** based on channel quality information fed back from any of the UEs **501** and **502**. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs **501** and **502**.

The PDCCH may use control channel elements (CCEs) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as resource element groups (REGs). Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the downlink control information (DCI) and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more enhanced control channel elements (ECCEs). Similar to above, each ECCE may correspond to nine sets of four physical resource elements

known as enhanced resource element groups (EREGs). An ECCE may have other numbers of EREGs in some situations.

The RAN **510** is shown to be communicatively coupled to a core network (CN) **520**—via an S1 interface **513**. In embodiments, the CN **520** may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment, the S1 interface **513** is split into two parts: the S1-U interface **514**, which carries traffic data between the RAN nodes **511** and **512** and the serving gateway (S-GW) **522**, and the S1-mobility management entity (MME) interface **515**, which is a signaling interface between the RAN nodes **511** and **512** and MMEs **521**.

In this embodiment, the CN **520** comprises the MMEs **521**, the S-GW **522**, the Packet Data Network (PDN) Gateway (P-GW) **523**, and a home subscriber server (HSS) **524**. The MMEs **521** may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs **521** may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS **524** may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN **520** may comprise one or several HSSs **524**, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS **524** can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

The S-GW **522** may terminate the S1 interface **513** towards the RAN **510**, and routes data packets between the RAN **510** and the CN **520**. In addition, the S-GW **522** may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

The P-GW **523** may terminate an SGi interface toward a PDN. The P-GW **523** may route data packets between the EPC network and external networks such as a network including the application server **530** (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface **525**. Generally, the application server **530** may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW **523** is shown to be communicatively coupled to an application server **530** via an IP communications interface **525**. The application server **530** can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs **501** and **502** via the CN **520**.

The P-GW **523** may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) **526** is the policy and charging control element of the CN **520**. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF **526** may be communicatively coupled to the application server **530** via the P-GW **523**. The application server **530** may signal the PCRF **526** to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF **526** may provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server **530**.

FIG. **6** illustrates example components of a device **600** in accordance with some embodiments. In some embodiments, the device **600** may include application circuitry **602**, baseband circuitry **604**, Radio Frequency (RF) circuitry **606**, front-end module (FEM) circuitry **608**, one or more antennas **610**, and power management circuitry (PMC) **612** coupled together at least as shown. The components of the illustrated device **600** may be included in a UE or a RAN node. In some embodiments, the device **600** may include fewer elements (e.g., a RAN node may not utilize application circuitry **602**, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device **600** may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

The application circuitry **602** may include one or more application processors. For example, the application circuitry **602** may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device **600**. In some embodiments, processors of application circuitry **602** may process IP data packets received from an EPC.

The baseband circuitry **604** may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry **604** may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry **606** and to generate baseband signals for a transmit signal path of the RF circuitry **606**. Baseband processing circuitry **604** may interface with the application circuitry **602** for generation and processing of the baseband signals and for controlling operations of the RF circuitry **606**. For example, in some embodiments, the baseband circuitry **604** may include a third generation (3G) baseband processor **604**A, a fourth generation (4G) baseband processor **604**B, a fifth generation (5G) baseband processor **604**C, or other baseband processor(s) **604**D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry **604** (e.g., one or more of baseband processors **604**A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry **606**. In other embodiments, some or all of the functionality of baseband processors **604**A-D may be included in modules stored in the memory **604**G and executed via a Central Processing Unit (CPU) **604**E. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments,

modulation/demodulation circuitry of the baseband circuitry **604** may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry **604** may include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry **604** may include one or more audio digital signal processor(s) (DSP) **604**F. The audio DSP(s) **604**F may be include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry **604** and the application circuitry **602** may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry **604** may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry **604** may support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry **604** is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

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

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

In some embodiments, the mixer circuitry **606***a* of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry **606***d* to generate RF output signals for the FEM circuitry **608**. The baseband signals may be provided by the baseband circuitry **604** and may be filtered by filter circuitry **606***c*.

In some embodiments, the mixer circuitry **606***a* of the receive signal path and the mixer circuitry **606***a* of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry **606***a* of the receive signal path and the mixer circuitry **606***a* of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry **606***a* of the receive signal path and the mixer circuitry **606***a* of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry **606***a* of the receive signal path and the mixer circuitry **606***a* of the transmit signal path may be configured for super-heterodyne operation.

In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry **606** may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry **604** may include a digital baseband interface to communicate with the RF circuitry **606**.

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

In some embodiments, the synthesizer circuitry **606***d* may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry **606***d* may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry **606***d* may be configured to synthesize an output frequency for use by the mixer circuitry **606***a* of the RF circuitry **606** based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry **606***d* may be a fractional N/N+1 synthesizer.

In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry **604** or the applications processor **602** depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor **602**.

Synthesizer circuitry **606***d* of the RF circuitry **606** may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide

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

In some embodiments, synthesizer circuitry **606***d* may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry **606** may include an IQ/polar converter.

FEM circuitry **608** may include a receive signal path, which may include circuitry configured to operate on RF signals received from one or more antennas **610**, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry **606** for further processing. FEM circuitry **608** may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry **606** for transmission by one or more of the one or more antennas **610**. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry **606**, solely in the FEM **608**, or in both the RF circuitry **606** and the FEM **608**.

In some embodiments, the FEM circuitry **608** may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry **608** may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry **608** may include a low noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry **606**). The transmit signal path of the FEM circuitry **608** may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry **606**), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas **610**).

In some embodiments, the PMC **612** may manage power provided to the baseband circuitry **604**. In particular, the PMC **612** may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC **612** may often be included when the device **600** is capable of being powered by a battery, for example, when the device is included in a UE. The PMC **612** may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

FIG. **6** shows the PMC **612** coupled only with the baseband circuitry **604**. However, in other embodiments, the PMC **612** may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry **602**, RF circuitry **606**, or FEM **608**.

In some embodiments, the PMC **612** may control, or otherwise be part of, various power saving mechanisms of the device **600**. For example, if the device **600** is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device **600** may power down for brief intervals of time and thus save power.

If there is no data traffic activity for an extended period of time, then the device **600** may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device **600** goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device **600** may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

Processors of the application circuitry **602** and processors of the baseband circuitry **604** may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry **604**, alone or in combination, may be used to execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry **602** may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY) layer of a UE/RAN node, described in further detail below.

FIG. **7** illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry **604** of FIG. **6** may comprise processors **604**A-**604**E and a memory **604**G utilized by said processors. Each of the processors **604**A-**604**E may include a memory interface, **704**A-**704**E, respectively, to send/receive data to/from the memory **604**G. The baseband circuitry **604** may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface **712** (e.g., an interface to send/receive data to/from memory external to the baseband circuitry **604**), an application circuitry interface **714** (e.g., an interface to send/receive data to/from the application circuitry **602** of FIG. **6**), an RF circuitry interface **716** (e.g., an interface to send/receive data to/from RF circuitry **606** of FIG. **6**), a wireless hardware connectivity interface **718** (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface **720** (e.g., an interface to send/receive power or control signals to/from the PMC **612**.

FIG. **8** is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. **8** shows a diagrammatic

representation of hardware resources **800** including one or more processors (or processor cores) **810**, one or more memory/storage devices **820**, and one or more communication resources **830**, each of which may be communicatively coupled via a bus **840**. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor **802** may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources **800**.

The processors **810** (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor **812** and a processor **814**.

The memory/storage devices **820** may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices **820** may include, but are not limited to, any type of volatile or non-volatile memory such as dynamic random access memory (DRAM), static random-access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

The communication resources **830** may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices **804** or one or more databases **806** via a network **808**. For example, the communication resources **830** may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, NFC components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

Instructions **850** may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors **810** to perform any one or more of the methodologies discussed herein. The instructions **850** may reside, completely or partially, within at least one of the processors **810** (e.g., within the processor's cache memory), the memory/storage devices **820**, or any suitable combination thereof. Furthermore, any portion of the instructions **850** may be transferred to the hardware resources **800** from any combination of the peripheral devices **804** or the databases **806**. Accordingly, the memory of processors **810**, the memory/storage devices **820**, the peripheral devices **804**, and the databases **806** are examples of computer-readable and machine-readable media.

In various embodiments, the devices/components of FIGS. **5-8**, and particularly the baseband circuitry of FIG. **7**, may be used to practice, in whole or in part, any of the operation flow/algorithmic structures depicted in FIGS. **1-3**.

One example of an operation flow/algorithmic structure is depicted in FIG. **1**, which may be performed by a new radio (NR) capacity booster cell or portion thereof. In this example, operation flow/algorithmic structure **100** may include, at **105**, identifying a candidate cell in a cell overlaid relation to an NR capacity booster cell, the candidate cell to carry traffic for the NR capacity booster cell while the NR capacity booster cell in an ES mode. Operation flow/algorithmic structure **100** may further include, at **110**, causing, based on cell traffic load information and ES policy information, the NR capacity booster cell to activate the ES mode. Operation flow/algorithmic structure **100** may further include, at **115**, generating a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

Another example of an operation flow/algorithmic structure is depicted in FIG. **2**, which may be performed by a new radio (NR) capacity booster cell or portion thereof. In this example, operation flow/algorithmic structure **200** may include, at **205**, collecting traffic load performance measurements from a new radio (NR) capacity booster cell and a candidate cell. Operation flow/algorithmic structure **200** may further include, at **210**, activating, based on the load performance measurements, an energy saving (ES) mode for the NR capacity booster cell. Operation flow/algorithmic structure **200** may further include, at **215**, generating a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

Another example of an operation flow/algorithmic structure is depicted in FIG. **3**, which may be performed by a new radio (NR) capacity booster cell or portion thereof. In this example, operation flow/algorithmic structure **300** may include, at **305**, receiving cell traffic load information. Operation flow/algorithmic structure **300** may further include, at **310**, activating, based on the cell traffic load information and energy saving (ES) policy information, an ES mode for a new radio (NR) capacity booster cell. Operation flow/algorithmic structure **300** may further include, at **315**, generating a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

6. Example Implementations

Some non-limiting examples are provided below.

Example 1 includes an apparatus comprising: memory to store energy saving (ES) policy information that includes an ES activation threshold and an ES deactivation threshold for a new radio (NR) capacity booster cell; and processor circuitry, coupled with the memory, to: identify a candidate cell in a cell overlaid relation to the NR capacity booster cell, the candidate cell to carry traffic for the NR capacity booster cell while the NR capacity booster cell in an ES mode; cause, based on cell traffic load information and the ES policy information, the NR capacity booster cell to activate the ES mode; and generate a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

Example 2 includes the apparatus of example 1 or some other example herein, wherein the identified candidate cell is one of a plurality NR macro cells at least partially overlaid with the NR capacity booster cell.

Example 3 includes the apparatus of example 1 or some other example herein, wherein the processor circuitry is further to cause the NR capacity booster cell to deactivate the ES mode.

Example 4 includes the apparatus of example 3 or some other example herein, wherein the processor circuitry is to cause the NR capacity booster cell to deactivate the ES mode based on a monitored traffic load on the candidate cell.

Example 5 includes the apparatus of example 3 or some other example herein, wherein the processor circuitry is further to generate a notification that the ES mode for the NR capacity booster cell has been deactivated.

Example 6 includes the apparatus of example 1 or some other example herein, wherein to cause the NR capacity booster cell to activate the ES mode is to cause the NR capacity booster cell to initiate one or more handover actions to offload traffic to the candidate cell.

Example 7 includes the apparatus of example 1 or some other example herein, wherein the processor circuitry includes an intra-radio access technology (RAT) distributed-energy saving (D-ES) function to identify the candidate cell, cause the NR capacity booster cell to activate the ES mode, and generate the notification.

Example 8 includes one or more non-transitory computer-readable media storing instructions that, when executed by one or more processors, are to cause an intra-radio access technology (RAT) centralized-energy saving (C-ES) function to: collect traffic load performance measurements from a new radio (NR) capacity booster cell and a candidate cell; activate, based on the load performance measurements, an energy saving (ES) mode for the NR capacity booster cell; and generate a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

Example 9 includes the one or more non-transitory computer-readable media of example 8 or some other example herein, wherein the intra-RAT C-ES function is to collect traffic load performance measurements from a plurality of candidate cells.

Example 10 includes the one or more non-transitory computer-readable media of example 8 or some other example herein, wherein to activate the ES mode, the intra-RAT C-ES function is to cause the NR capacity booster cell to initiate a handover action to offload traffic to the candidate cell prior to entering the ES mode.

Example 11 includes the one or more non-transitory computer-readable media of example 8 or some other example herein, wherein the instructions are further to cause the intra-RAT C-ES function to deactivate the ES mode for the NR capacity booster cell.

Example 12 includes the one or more non-transitory computer-readable media of example 11 or some other example herein, wherein the ES mode for the NR capacity booster cell is deactivated based on traffic load performance measurements from the candidate cell.

Example 13 includes the one or more non-transitory computer-readable media of example 11 or some other example herein, wherein the instructions are further to cause the intra-RAT C-ES function to generate a notification that the ES mode is deactivated.

Example 14 includes one or more non-transitory computer-readable media storing instructions that, when executed by one or more processors, cause a distributed-energy saving (D-ES) function to: receive cell traffic load information; activate, based on the cell traffic load information and energy saving (ES) policy information, an ES mode for a new radio (NR) capacity booster cell; and generate a notification that is to indicate the ES mode for the NR capacity booster cell has been activated.

Example 15 includes the one or more non-transitory computer-readable media of example 14 or some other example herein, wherein the ES policy information is to indicate thresholds for ES activation and deactivation for the NR capacity booster cell.

Example 16 includes the one or more non-transitory computer-readable media of example 14 or some other example herein, wherein the instructions are further to cause the D-ES function to deactivate the ES mode for the NR capacity booster cell, wherein the ES mode is deactivated based on a monitored traffic load on a candidate cell.

Example 17 includes the one or more non-transitory computer-readable media of example 16 or some other example herein, wherein the notification is a first notification, and the instructions are further to cause the D-ES function to generate a second notification that the ES mode for the NR capacity booster cell has been deactivated.

Example 18 includes the one or more non-transitory computer-readable media of example 17 or some other example herein, wherein the second notification is a notifyMOIAttributeValueChanges message that indicates the ES mode for the NR capacity booster has been deactivated.

Example 19 includes the one or more non-transitory computer-readable media of example 14 or some other example herein, wherein to cause the NR capacity booster cell to activate the ES mode, the D-ES function is to cause the NR capacity booster cell to initiate one or more handover actions to offload traffic to a candidate cell.

Example 20 includes the one or more non-transitory computer-readable media of example 14 or some other example herein, wherein the notification is a notifyMOIAttributeValueChanges message that indicates the ES mode for the NR capacity booster has been activated.

Example 21 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples 1-20, or any other method or process described herein.

Example 22 may include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of a method described in or related to any of examples 1-20, or any other method or process described herein.

Example 23 may include an apparatus comprising logic, modules, and/or circuitry to perform one or more elements of a method described in or related to any of examples 1-20, or any other method or process described herein.

Example 24 may include a method, technique, or process as described in or related to any of examples 1-20, or portions or parts thereof.

Example 25 may include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples 1-20, or portions thereof.

Example 26 may include a method of communicating in a wireless network as shown and described herein.

Example 27 may include a system for providing wireless communication as shown and described herein.

Example 28 may include a device for providing wireless communication as shown and described herein.

The description herein of illustrated implementations, including what is described in the Abstract, is not intended to be exhaustive or to limit the present disclosure to the precise forms disclosed. While specific implementations and examples are described herein for illustrative purposes, a variety of alternate or equivalent embodiments or implementations calculated to achieve the same purposes may be made in light of the above detailed description, without departing from the scope of the present disclosure.

The invention claimed is:

1. An apparatus, comprising:

memory circuitry to store instructions for operating a distributed energy saving (D-ES) management function; and

processor circuitry connected to the memory circuitry, wherein the processor circuitry is to execute the instructions to:

consume a management service (MnS) of a network function (NF) provisioning producer to configure

cell overlaid relations for a set of capacity booster cells and a set of macrocells as candidate cells;

consume an MnS of the NF provisioning producer to configure an energy saving(ES) policy that includes one or more thresholds for ES activation and ES deactivation for the capacity booster cells and the candidate cells; and

consume an MnS of the NF provisioning producer to enable a D-ES function for intra-radio access technology (RAT) or inter-RAT.

2. The apparatus of claim **1**, wherein consumption of the MnS of the NF provisioning producer to configure the cell overlaid relations is to cause the NF provisioning producer to configure the D-ES function with the cell overlaid relations.

3. The apparatus of claim **1**, wherein, to consume the MnS of the NF provisioning producer to configure the cell overlaid relations, the processor circuitry is to execute the instructions to:

invoke a modifyMOIAttributes operation to request modification of one or more cell overlaid relations managed object instances (MOIs) from the NF provisioning producer.

4. The apparatus of claim **1**, wherein consumption of the MnS of the NF provisioning producer to configure the ES policy is to cause the NF provisioning producer to configure the D-ES function with the ES policy.

5. The apparatus of claim **1**, wherein, to consume the MnS of the NF provisioning producer to configure the ES policy, the processor circuitry is to execute the instructions to:

invoke a modifyMOIAttributes operation to request modification of one or more ES policy MOIs from the NF provisioning producer.

6. The apparatus of claim **1**, wherein consumption of the MnS of the NF provisioning producer to enable the D-ES function is to cause the NF provisioning producer to switch on an ES functionality in the D-ES function.

7. The apparatus of claim **1**, wherein, to consume the MnS of the NF provisioning producer to enable the D-ES function, the processor circuitry is to execute the instructions to:

invoke a modifyMOIAttributes operation to request modification of one or more ES functionality MOIs from the NF provisioning producer.

8. The apparatus of claim **1**, wherein the processor circuitry is to execute the instructions to:

receive, from the NF provisioning producer, a notifyMOIAttributeValueChanges notification indicating that at least one capacity booster cell in the set of capacity booster cells has entered an ES state based on a decision at the D-ES function to enter the ES state.

9. The apparatus of claim **1**, wherein the processor circuitry is to execute the instructions to:

receive, from the NF provisioning producer, a notifyMOIAttributeValueChanges notification indicating that at least one capacity booster cell in the set of capacity booster cells has exited an ES state based on a decision at the D-ES function to exit the ES state.

10. One or more non-transitory computer-readable media (NTCRM) comprising instructions for operating a distributed-energy saving (D-ES) management function, wherein execution of the instructions by one or more processors is to cause a computing device to:

consume a management service (MnS) of a provisioning MnS producer to configure cell overlaid relations for a set of capacity booster cells and a set of macrocells as candidate cells, wherein consumption of the MnS of the provisioning MnS producer to configure the cell overlaid relations is to cause the provisioning MnS producer to configure the D-ES function with the cell overlaid relations;

consume an MnS of the provisioning MnS producer to configure an energy saving(ES) policy that includes one or more thresholds for ES activation and ES deactivation for the capacity booster cells and the candidate cells, wherein consumption of the MnS of the provisioning MnS producer to configure the ES policy is to cause the provisioning MnS producer to configure the D-ES function with the ES policy; and

consume an MnS of the provisioning MnS producer to enable a D-ES function for intra-radio access technology (RAT) or inter-RAT, wherein consumption of the MnS of the provisioning MnS producer to enable the D-ES function is to cause the provisioning MnS producer to switch on an ES functionality in the D-ES function.

11. The one or more NTCRM of claim **10**, wherein, to consume the MnS of the provisioning MnS producer to configure the cell overlaid relations, execution of the instructions is to cause the computing device to:

invoke a modifyMOIAttributes operation to request modification of one or more cell overlaid relations managed object instances (MOIs) from the provisioning MnS producer.

12. The one or more NTCRM of claim **10**, wherein, to consume the MnS of the provisioning MnS producer to configure the ES policy, execution of the instructions is to cause the computing device to:

invoke a modifyMOIAttributes operation to request modification of one or more ES policy MOIs from the provisioning MnS producer.

13. The one or more NTCRM of claim **10**, wherein, to consume the MnS of the provisioning MnS producer to enable the D-ES function, execution of the instructions is to cause the computing device to:

invoke a modifyMOIAttributes operation to request modification of one or more ES functionality MOIs from the provisioning MnS producer.

14. The one or more NTCRM of claim **10**, wherein execution of the instructions is to cause the computing device to:

receive, from the provisioning MnS producer, a notifyMOIAttributeValueChanges notification indicating that at least one capacity booster cell in the set of capacity booster cells has entered an ES state based on a decision at the D-ES function to enter the ES state; and

receive, from the provisioning MnS producer, another notifyMOIAttributeValueChanges notification indicating that at least one capacity booster cell in the set of capacity booster cells has exited an ES state based on a decision at the D-ES function to exit the ES state.

15. An apparatus, comprising:

memory circuitry to store instructions for operating a distributed energy saving (D-ES) function; and

processor circuitry connected to the memory circuitry, wherein the processor circuitry is to execute the instructions to:

receive, from a network function (NF) provisioning producer, a configuration of cell overlaid relations for a set of capacity booster cells and a set of macrocells as candidate cells;

receive, from the NF provisioning producer, a configuration of an energy saving(ES) policy that includes

one or more thresholds for ES activation and ES deactivation for the capacity booster cells and the candidate cells; and

receive, from the NF provisioning producer, an indication to enable the D-ES function for intra-radio access technology (RAT) or inter-RAT communication.

16. The apparatus of claim **15**, wherein the processor circuitry is to execute the instructions to:

detect a cell traffic load of at least one capacity booster cell of the set of capacity booster cells;

determine that the at least one capacity booster cell is to enter an ES state when the detected cell traffic load is below at least one threshold of the one or more thresholds included in the ES policy; and

inform the NF provisioning producer that the ES state of the at least one capacity booster cell has been switched to "ON".

17. The apparatus of claim **16**, wherein the processor circuitry is to execute the instructions to:

determine that the at least one capacity booster cell is to enter the ES state when a coverage area of the at least one capacity booster cell is partially or completely overlaid by at least one candidate cell of the set of candidate cells.

18. The apparatus of claim **17**, wherein the processor circuitry is to execute the instructions to:

cause the at least one capacity booster cell to be switched off after one or more handovers are performed to offload cell traffic of the at least one capacity booster cell to the at least one candidate cell.

19. The apparatus of claim **17**, wherein the processor circuitry is to execute the instructions to:

monitor a cell traffic load of the at least one candidate cell;

determine that the at least one candidate cell is to exit the ES state when the monitored cell traffic load is below at least one other threshold of the one or more thresholds included in the ES policy; and

inform the NF provisioning producer that the ES state of the at least one capacity booster cell has been switched to "OFF".

20. The apparatus of claim **15**, wherein the apparatus is a capacity booster cell among the set of capacity booster cells.

* * * * *