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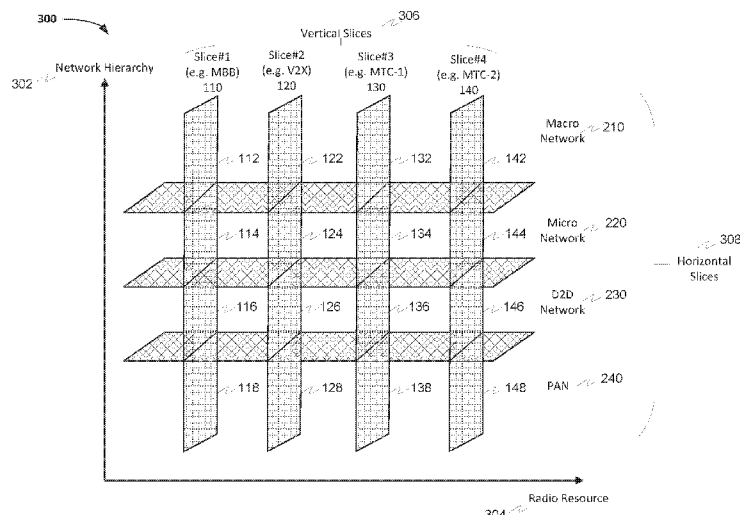
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(54) **Title:** SLICEABLE RADIO ACCESS NETWORK ARCHITECTURE FOR WIRELESS COMMUNICATIONS

**Fig. 3**

(57) **Abstract:** Embodiments provide an electronic device to implement a radio access network (RAN) control entity, the electronic device comprising circuitry to identify one or more vertical slices of a RAN, the vertical slices relating to vertical market segments of the RAN, identify one or more horizontal slices of the RAN, the horizontal slices relating to network hierarchy segments of the RAN, and slice the RAN into the one or more vertical and/or horizontal slices, and radio frequency (RF) circuitry coupled with the circuitry, the RF circuitry to send and/or receive one or more signals in accordance with the vertical and/or horizontal slices. Embodiments also provide a radio access network (RAN) control entity and a computer readable medium to implement a radio access network (RAN) control entity.

SLICEABLE RADIO ACCESS NETWORK ARCHITECTURE FOR WIRELESS COMMUNICATIONS

RELATED APPLICATIONS

5 The present application claims priority to U.S. Provisional Patent Application No. 62/217,536, filed September 11, 2015, the entire specification of which is hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

10 Embodiments described herein generally relate to the field of wireless communications systems, and in particular to the management of the Radio Access Network of a wireless communications system.

BACKGROUND

15 In fourth generation Long Term Evolution (4G-LTE) wireless communications systems, there has been a trend for heterogeneity in the network architecture and applications. Examples of these trends are the development of small cells and relay networks, device-to-device (D2D) communication networks, and machine type communications (MTC). Moving into fifth generation (5G) wireless communications systems, there is a desire for improved management of the wireless resources.

BRIEF DESCRIPTION OF THE DRAWINGS

20 Aspects, features and advantages of embodiments of the present disclosure will become apparent from the following description of embodiments in reference to the appended drawings in which like numerals denote like elements and in which:

 Figure 1 shows a first view of the broad concept of vertical and horizontal network slicing;

25 Figure 2 shows a second view of a portion of the wireless network of Figure 1;

 Figure 3 shows how a Radio Access Network (RAN) can be sliced into horizontal and vertical slices according to an embodiment that is alternative (or additional) to that shown in Figure 1;

30 Figure 4 shows a more detailed example of horizontal slicing in a sliceable wireless network architecture according to examples;

 Figure 5 illustrates how a RAN control entity according to an embodiment can control the horizontal and vertical slices of Figure 3;

Figure 6 illustrates a first, distributed, example of a RAN control entity according to an embodiment;

Figure 7 illustrates a second, centralized, example of a RAN control entity according to an embodiment;

5 Figure 8 illustrates a first, flat, example of how a RAN control entity according to an embodiment controls slices of the network;

Figure 9 illustrates a second, hierarchical, example of how a RAN control entity according to an embodiment controls slices of the network;

10 Figure 10 shows a first example method of managing a Radio Access Network according to an embodiment;

Figure 11 shows a second example method of managing a Radio Access Network according to an embodiment;

Figure 12 shows an example of a RAN control entity according to an embodiment;

15 Figure 13 shows a diagrammatic representation of hardware resources according to an embodiment.

DETAILED DESCRIPTION

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 present disclosure. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the claims 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 disclosure with unnecessary detail.

25 In fourth generation Long Term Evolution (4G-LTE) and LTE-Advanced/Pro wireless communications networks, there has been a trend for heterogeneity in the network architecture and applications. Examples of these trends are the development of small cells and relay networks, device-to-device (D2D) communication networks (also known as proximity services), and machine type communications (MTC). Small cells may be considered any form of cell that is smaller than the traditional macro eNB/base station, e.g. micro/pico/femto cells. Moving into fifth generation (5G) wireless communications networks, the trend of heterogeneity may be more prominent, and suitably improved methods and apparatus for control of the wireless resources is desirable. For example, because the 5G wireless communication networks may be

expected to serve diverse range of applications (with various traffic types and requirements), network and user equipment (with various communication and computation capabilities), and commercial markets (i.e. use-cases) other than the more traditional voice services (e.g. Voice over LTE, VoLTE) and mobile broadband (MBB), there is a desire to provide control over each
5 of these use-cases, so that an optimized, or at least improved, use of the wireless resources is possible.

Embodiments of the present disclosure generally relate to the slicing of a radio access network (RAN) architecture of a wireless communications network. The RAN may be the portion of the wireless communications network that implements one or more radio access
10 technologies (RATs), and may be considered to reside at a position located between a user device (UE) such as a mobile phone, smartphone, connected laptop, or any remotely controlled (or simply accessible) machine and provides connection with the core network (CN) servicing the wireless communications network. The RAN may be implemented using silicon chip(s) residing in the UEs and/or base stations, such as enhanced Node B (eNBs), base stations, or the
15 like that form the cellular based wireless communications network/system. Examples of RANs include, but are not limited to: GRAN (a GSM radio access network); GERAN (essentially an EDGE enabled GRAN); UTRAN (a UMTS radio access network); and E-UTRAN (an LTE, or LTE-Advance/Pro, high speed and low latency radio access network).

The herein described embodiments discuss the general architecture of network slicing in
20 a radio access network of a wireless communication network, such as but not limited to a 5G wireless communication network. In particular, embodiments may include the concept of horizontal and vertical network slicing. Vertical slicing may comprise slicing the radio access network according to vertical markets, where a vertical market may comprise a single/particular type of communication (i.e. that may be defined as a single or particular use-case for the
25 communications involved), out of the many existing and new types of communication that may be carried out over future wireless communication networks, particularly including the radio access network. A commercial market that may be provisioned over a wireless communications network may also be called a vertical market. The existing types include Mobile Broad Band (MBB) and Voice (VoLTE), while the new types of communication may include new types of
30 connectivity services and use-cases, such machine type communications (MTC), personal area networks, dedicated health networks, machine to machine (M2M), enhanced MBB (eMBB), time critical communications, vehicle communications (V2X) (including vehicle to vehicle (V2V) and vehicle to infrastructure (V2I)), and the like. The definition of a vertical market is not limited, and will cover any existing or future logical separation (i.e. segregation, partition or the

like) of a physical radio access network for exclusive use by wireless communications for particular use, or type of communication. In some examples, there may be multiple physical radio access networks in use, each separated into logically separated radio access networks.

The proposed network slices may be programmable and highly scalable and flexible, taking into consideration the availability, latency and power requirements and impact on battery life, reliability, capacity, security and speed of the wireless communications network required by each particular use-case.

Network slicing is considered as one of the key technologies to fulfill the diverse requirements and the diverse services and applications expected to be supported in 5G communication networks. This is because, in wireless communication technologies, further improving the spectral efficiency at the radio link level is becoming increasingly challenging, so new ways have been found to build future wireless networks and devices served by those wireless networks to meet the ever increasing capacity demand. To achieve these goals, 5G and future generations of wireless networks, and in particular the wireless devices serving those, or served by those wireless networks, are evolving, to be about the combination of computing and communications, and the provision of end-to-end solutions. This is a paradigm shift from previous generations where technology development focused primarily on single level communications alone.

To provide the increased capacity in wireless networks, they may be sliced. This may involve slicing (i.e. logically partitioning/separating) the traditional large, single, mobile broadband network into multiple virtual networks to serve vertical industries and applications in a more cost and resource efficient manner. Each network slice may have a different network architecture, and different application, control, packet and signal processing capabilities and capacity, in order to achieve optimum return on investment. New vertical slices (i.e. industry or type of service) can be added to an existing sliceable wireless network at any time, instead of deploying a new dedicated wireless network for that vertical market. Thus, vertical network slicing provides a practical means to segregate the traffic from a vertical application standpoint from the rest of general mobile broadband services, thereby practically avoiding or dramatically simplifying the traditional QoS engineering problem. Wireless network slicing may include slicing in both the core network and the radio access networks (i.e. is an end-to-end solution).

In 5G wireless networks and beyond, the capacity scaling of a network may no longer be as uniform as it has been in previous generations. For example, the scaling factor may be higher when the wireless network is closer to a user, and lower as we move deeper into the infrastructure of the wireless network. This non-uniform scaling may be a result of an

augmented user experience enabled by the significantly increased sensing capabilities (and/or processing resources) available at the wireless devices making use of wireless networks. Unlike previous generations of wireless networks where a network serves primarily as a data pipe, scaling uniformly (but singularly) from end-to-end as the air interface improves, 5G and future generations of wireless networks may at least partly rely on information networks comprising diverse (heterogeneous and/or homogeneous) computing, networking and storage capabilities of the wireless networks and the wireless devices they serve/are served by.

For example, the overall wireless network may continue to scale up rapidly, but the computing and networking at the network edge may grow even faster, therefore enabling user data traffic to be processed at the edge of the wireless network (so-called edge cloud applications). User devices may no longer be simply “terminals” that terminate a communication link. Instead, they may become a new generation of moving or fixed networking nodes for a new generation of consumer devices, machines, and things. For example, a laptop, a tablet, a smart phone, a home gateway or any other wireless network device (or component device forming the , or part of the, wireless network device as sold to the consumer), can become a computing and networking center of a network cluster with many devices or things deployed around it. For example, it may form a Personal Area Network (PAN). Many such mobile or fixed wireless network clusters may form what may be called an underlay network, a new type of network in 5G and beyond, with devices capable of communicating with each other or directly with the fixed networks, and with computing able to be offloaded to larger form-factor platforms or edge cloud base stations (i.e. entities in the wireless network with greater processing resources, either outright, or simply available at the that time). This may be done to achieve optimum mobile computing and communication over a virtualized platform across many devices, including the edge cloud.

This new kind of wireless network scaling may be driven by a number of factors. For example, as device sensing is typically local, the processing of sensed data may be local, and the decisions and actions upon sensed data become local. This trend may be further amplified by the proliferation of wearable devices and the internet of things. For example, as machines start playing a greater role in communication than human users, the whole communication link speed may be increased.

The definition of end-to-end is to be revisited, as an increasing number of communication links are in the proximity of users and user devices. It is therefore proposed to provide a cloud architecture framework that may incorporate data centers as well as edge clouds providing local intelligence and services closer to the end users or devices. This may be because,

for example, as wireless networks and systems get deployed in enterprise, home, office, factory and automobile, edge cloud servers become more important for both performance and information privacy and security. These latter factors may be driven by user's (and governments) growing concern on privacy and security. Moreover, data centers deep into the fixed networks may continue to grow rapidly since many existing services may be better served with centralized architecture, with the new generation of portable and wearable devices, drones, industrial machines, self-driving cars, and the like fueling even more rapid growth in communication and computing capabilities at the edge of the network and locally around users.

The newly introduced concept of network slicing, particularly of the sort that provides a wireless network system architecture that has End-to-End (E2E) vertical and horizontal network slicing may introduce changes to the air interface, the radio access network (RAN) and the core network (CN) to enable a wireless network system with E2E network slicing.

In simple terms horizontal slicing enhances device capability by allowing computing resources to be shared across devices serving or being served (i.e. in or on) the wireless network, according to the processing needs of those devices over time and space/location.

Horizontal network slicing is designed to accommodate the new trend of traffic scaling and enable edge cloud computing and computing offloading: The computing resources in the base station and the portable device may be horizontally sliced, and these slices, together with the wearable devices may be integrated to form a virtual computing platform through a new wireless air interface design as described herein, in order to significantly augment the computing capability of future portable and wearable devices. Horizontal slicing augments device capability and enhances user experience.

Network slicing, in the most general of terms, may be thought of as a way to use virtualization technology to architect, partition and organize computing and communication resources of a physical wireless network infrastructure, into one or more logically separated radio access networks, to enable flexible support of diverse use-case realizations. For example, with network slicing in operation, one physical wireless network may be sliced into multiple logical radio access networks, each architected and optimized for a specific requirement and/or specific application/service (i.e. use-case). Thus, a network slice may be defined as a self-contained, in terms of operation and traffic flow, and may have its own network architecture, engineering mechanisms and network provision. Network slicing as proposed herein is able to simplify the creation and operation of network slices and allows function reuse and resource sharing of the physical wireless network infrastructure (i.e. provides efficiencies), whilst still

providing sufficient wireless network resources (communications and processing resources) for the wireless devices served by the wireless network.

Vertical slicing is targeted at supporting diverse services and applications (i.e. use-case/types of communication). Examples include but are not limited to: Wireless/Mobile Broadband (MBB) communications; Extreme Mobile Broadband (E-MBB) communications; Real-time use-case such as Industrial Control communications, Machine-to-Machine communications (MTC/MTC1); non-real-time use-case, such as Internet-of-Things (IoT) sensors communications, or massive-scale Machine-to-Machine communications (M-MTC/MTC2); Ultra Reliable Machine-to-Machine communications (U-MTC); Mobile Edge Cloud, e.g. caching, communications; Vehicle-to-Vehicle (V2V) communications; Vehicle-to-Infrastructure (V2I) communications; Vehicle-to-everything communications (V2X). This is to say, the present disclosure relates to providing network slicing according to any readily definable/distinguishable type of communication that can be carried out over a wireless network. Vertical network slicing enables resource sharing among services and applications, and may avoid or simplify a traditional QoS engineering problem.

Horizontal network slicing, meanwhile, is targeted at extending the capabilities of devices in the wireless network, particularly mobile devices that may have limitations on the local resources available to them, and enhancing user experiences. Horizontal network slicing goes across and beyond the hardware platforms' physical boundaries. Horizontal network slicing enables resource sharing among network nodes and devices, i.e., highly capable network nodes/devices may then share their resources (e.g., computation, communication, storage) to enhance the capabilities of less capable network nodes/devices. A simple example may be to use a network base station and/or a smartphone mobile device, to supplement the processing and communication capabilities of a wearable device. An end result of horizontal network slicing may be to provide a new generation of mobile (e.g. moving) underlay network clusters, where mobile terminals become moving networking nodes. Horizontal slicing may provide over-the-air resource sharing across wireless network nodes. The wireless network air interface in use may be an integrated part and an enabler of horizontal slicing.

Vertical network slicing and horizontal network slicing may form independent slices. The end-to-end traffic flow in a vertical slice may transit between the core network and the terminal devices. The end-to-end traffic flow in a horizontal slice may be local and transit between the client and host of a mobile edge computation service.

In vertical slicing, each of the network nodes may implement similar functions among the separate slices. A dynamic aspect of vertical slicing may lie predominantly in the resource

partitioning. In horizontal slicing, however, new functions could be created at a network node when supporting a slice. For example, a portable device may use different functions to support different types of wearable devices. The dynamic aspect of horizontal slicing may therefore lie in the network functions as well as the resource partitioning.

5 Figure 1 shows a first view of the broad concept of vertical and horizontal network slicing. There is shown a complete wireless network 100, including multiple vertical slices 110 – 140, each serving a different (or at least separate) vertical market, i.e. use-case. In the example shown vertical slice #1 110 serves mobile broadband communications, vertical slice #2 120 serves vehicle-to-vehicle communications, vertical slice #3 130 serves security communications, and vertical slice #4 140 serves industrial control communications. These are only exemplary use-cases, and the use-cases that may be served by sliceable wireless network according to the present disclosure is practically unlimited.

10 The wireless network 100 includes a core network layer portion 150 (e.g. having multiple servers/control entities/control portions of eNode-Bs, etc.), a radio access network layer portion 160 (e.g. including multiple base stations, e-Node Bs, etc.), a device layer portion 170 (including e.g. portable devices such as UEs, vehicles, surveillance devices, industrial devices, etc.), and a personal/wearable layer portion 180 (including, e.g. wearable devices such as smart watches, health monitors, Google™ glasses/Microsoft™ Hololens type devices, and the like). The wearable portion may only be involved in some use-cases, as shown by its inclusion in only vertical slices #1 and #2 in the example of Figure 1.

15 In the vertical domain, the physical computation/storage/radio processing resources in the network infrastructure (as denoted by the servers and base stations 150/160) and the physical radio resources (in terms of time, frequency, and space) are sliced, by use-case (i.e. type of communication) to form end-to-end vertical slices. In the horizontal domain, the physical resources (in terms of computation, storage, radio) in adjacent layers of the network hierarchy are sliced to form horizontal slices. In the example shown, there is a first horizontal network slice 190 operating between the RAN 160 and Device 170 layers, and a second horizontal network slice 195 operating between the Device 170 and wearable 180 layers. Any given device served or to be served by the wireless network 100 as a whole, and the RAN 160 (and below layers) in particular, could operate on multiple network slices, of either (or both) types. For instance, a smart phone can operation in a vertical slice on mobile broad band (MBB) service, a vertical slice on health care service and a horizontal slice supporting wearable devices.

20 When enabling network slicing in the RAN (including the air interfaces employed in the RAN), besides meeting the 5G requirements (e.g., data rate, latency, number of connections,

etc.), further desirable features of the RAN/air interfaces used to enable network slicing and in general 5G may include Flexibility (i.e. support flexible radio resource allocation among slices); Scalability (i.e. easily scale up with the addition of new slices; and Efficiency (e.g. efficiently use the radio and energy resources).

5 Horizontal slicing may comprise slicing the network hierarchy, e.g. the layers of network connectivity and compute (i.e. processing resource) capability. This may be done across any number of the vertical slices served by the network 100, for example anything from all the vertical markets down to within a one or more vertical slice(s). This is shown as the different widths of the two exemplary horizontal slices in Figure 1 – horizontal slice #1 190 is limited to a
10 single vertical slice, whereas horizontal slice #2 is covers two vertical slices. Examples of network hierarchy/layers may include, but is not limited to, a macro network layer, a micro/small cell network layer, a device to device communications layer, and the like. Other network layers may also be involved.

 Figure 2 shows a second view 200 of a portion of the wireless network 100 of Figure 1.
15 In particular, Figure 2 shows an example of a slice-specific RAN architecture, where slices may be across multiple levels of the traditional wireless network architecture. For example, depending on factors such as traffic type, traffic load, QoS requirement, the RAN architecture of each of the slices may be dynamically configured. In a first example, slice #1 210 may only operate on the macro cell level. Whereas slice #2 220 only operates on the small cells level.
20 Finally, slice #3 230 may operate on both macro and small cells levels. In another example, a slice (e.g. slice #1 210) may open up operation on small cells while another slice (e.g. slice #3 230) may close operation on some of the small cells.

 Opening up operation/activating a slice may be referenced as a network slice turn-on, and closing operation/deactivating a slice may be referenced as a network slice turn-off. The
25 slice-specific RAN architecture may require slice-specific control-plane/user-plane operation, slice on/off operation and slice-based treatment on access control and load balancing, as will be discussed in more detail below.

 Horizontal slicing comprising slicing the network/device computation and communication resources may achieve computation offloading. Examples include the base
30 station using a slice of its computation resource to help a user device's computation, or a user device (e.g. smartphone) using a slice of its computation resource to help computation of an associated wearable device(s).

 Embodiments of the present disclosure are not limited to any particular form of slicing in the vertical (markets) or horizontal (network hierarchy/layers) directions.

Embodiments of the present disclosure may provide a management entity operable across the Control-plane (C-plane) and/or User-plane (U-plane), that may provide a management-plane entity that may be used to coordinate the operation of the different slices, either horizontal or vertical (or multiple/combined, or partial, ones thereof). The management
5 entity may use a flat management architecture or a hierarchal management architecture.

Slicing of the radio access network may be considered as compartmentalization of the radio access network according to predetermined vertical markets, or horizontal network layers (or multiple/partial layers) of the network. This may be considered a form of logical separation between the wireless resources provided by, or in use by, the radio access network. Logical
10 separation of the wireless resources may allow that they may be separately defined, managed, and/or (generally or specifically) resourced. This separation may provide the ability for the different slices to not be able to, or allowed to, affect one another. Equally, in some embodiments, one or more slices may be specifically provided with the ability to manage another one or more slices, for operational reasons.

15 In some embodiments network functions may be fully offloaded to a network slice, and the slice may operate in a standalone mode, for example a standalone millimeter-wave (mmWave) small cell network, and an out-of-coverage D2D network. A mmWave small cell is one that uses milli-meter size radio waves (i.e. high frequency – e.g. 60GHz).

In some embodiments network function(s) may be partially offloaded to a slice, and the
20 slice may operate in a non-standalone mode, for example in an anchor-booster architecture, where an anchor-booster architecture may comprise an anchor cell, providing a control-plane and a mobility anchor for maintaining connectivity. In an embodiment, the anchor cell may be a cell with wide coverage, for example a macro cell. The anchor-booster architecture may further comprise a booster cell, providing user-plane data offloading. In an embodiment, the booster cell
25 may be a small cell, and may be deployed under the coverage of an anchor cell. From a device perspective, the control-plane and user-plane may be decoupled, i.e., the control-plane may be maintained at the anchor cell while the data-plane may be maintained at the booster cell.

In some example embodiments, the horizontal slices and vertical slices may be viewed as intertwined (i.e. where the radio access network functions/resources are shared among some of
30 the vertical and horizontal slices), as illustrated in the graph 300 of Figure 3. Thus, Figure 3 shows how a Radio Access Network (RAN) can be sliced into horizontal and vertical slices according to an embodiment that is alternative (or additional) to that shown in Figure 1, where the slices are totally independent in terms of traffic flow and operation. The graph 300 of Figure 1 has Network Hierarchy 302 (i.e. the network layers involved/in use) along the y-axis, and

Radio Resource 304 (i.e. indicative of using separate radio resources, such as frequencies, time slots, etc.) along the x-axis. In the example of Figure 1, vertical slicing is shown as comprising four vertical slices 306. However, any number of different markets/use-cases may be involved. The four vertical markets/use-cases shown chosen for the vertical slices are mobile broadband (MBB) 110, a vehicle type communication (V2X) 120, a first machine type communication (MTC-1) 130, a second machine type communication (MTC-2) 140, being slices Slice#1-Slice#4, respectively. These are only exemplary choices of the use-cases that could be served.

Also shown in Figure 3 is horizontal slicing, in this example again comprising four horizontal slices 308. The four horizontal slices shown are macro network layer 210, micro network layer 220, device to device network layer 230, and Personal Area Network (PAN) (e.g. wearable) network layer 240. According to an example, each horizontal slice contains a portion of multiple vertical slices. Equally, each vertical slice contains a portion of each horizontal slice. The separate portions, as separated in both the horizontal and vertical directions may be referred to as a slice portion. Thus, in the example of Figure 1, the MBB vertical slice 110 comprises four slice portions: Macro Network layer portion 112; Micro Network layer portion 114; D2D Network layer portion 116; and PAN Network layer portion 118. Similarly, V2X vertical slice 120 comprises four slice portions: Macro Network layer portion 122; Micro Network layer portion 124; D2D Network layer portion 126; and PAN Network layer portion 128. Meanwhile, the MTC-1 vertical slice 130 comprises four slice portions: Macro Network layer portion 132; Micro Network layer portion 134; D2D Network layer portion 136; and PAN Network layer portion 138, and MTC-2 vertical slice 140 comprises four slice portions: Macro Network layer portion 142; Micro Network layer portion 144; D2D Network layer portion 146; and PAN Network layer portion 148.

An example of such an architecture is, in a personal area network, a wearable health sensor may belong to a dedicated health network. The personal area network layer may then represent a horizontal network slice. The health sensor running under the coverage of the personal area network may belong to a vertical network slice. In the same token, each horizontal network slice could comprise multiple vertical network slices. Each vertical network slice may have multiple horizontal network slices. Another example is a macro cell (i.e. macro eNB) that serves a number of different use-case communications. Likewise, each vertical slice may contain portions of multiple horizontal slices, for example, in a V2X network, there may be V2I and V2V layers. In another example, the mobile broad band (MBB) vertical slice includes portions in each of the macro, micro and device to device layers, as shown. Thus, embodiments

provide a way to logically carve up the wireless resources provided by, and/or in use by, the radio access network, according to both use-case (vertically) and network layer (horizontally).

Communication and computation have been helping each other in pushing the boundaries of information and computing technologies. At the network side, computation has been used to help communication by moving computation and storage to the edge. With edge cloud and edge computation, the communication link between the source and the destination is getting shorter, thereby improving the communication efficiency and reducing the amount of information propagation in the network. The optimal deployment of edge cloud and computation scheme varies. As a general rule, the less capable the end device is and/or the higher the device density, the closer the cloud and computation to the network edge.

Moving forward at the device side, with the devices further shrinking in size from portable devices to wearable devices and the user expectation on computation keeping increasing, we expect future communication may help to deliver the user experience, e.g., the network nodes slice out part of their computation resources to help computation at the portable device, while the portable devices slice out part of their computation resources to help the computation at the wearable devices. In this way, the network is horizontally sliced. The sliced out computation resources and the air interface connecting the two ends form an integrated part that delivers the required service.

Figure 4 shows a more detailed example of horizontal slicing in a sliceable wireless network architecture according to embodiments. The left hand side shows the traditional 3G/4G architecture (but only from the RAN down). This comprises a base station portion 410, comprising an up-stream/core network side communication function 412, a base station compute function 414 (i.e. the processing resources available in the base station, or closely coupled entity thereof), and a down-stream/wireless/device side communication function 416 (to communicate with the devices being served by that base station, or other, peer base station, e.g. in the case of fronthaul, etc.). There is also shown a portable portion 420 (e.g. a User Equipment, or a like device) comprising a similar combination of up-stream and down-stream communication resources and local processing resources. In this case, the up-stream communication link is the typical cellular wireless communication link 422 (e.g. OFDM/CDMA/LTE type link) and a down-stream communication link 426 such as a 5G radio access technology (RAT) (e.g. OFDM/CDMA/LTE type link), a next generation communication link(s) such as a 5G PAN RAT (yet to be created), or a current or next generation other PAN wireless communication technology, e.g. Bluetooth, zigbee or the like. In between is the local compute function 424, i.e. processing resources local to the portable device. Lastly, in the example, there is the wearable

portion 430, which typically has only a single up-stream communications link 432 and limited local processing resources function 434.

The right hand side of figure 4 shows the one of the new proposed horizontal network slicing concepts, in particular, how the processing resources of higher and lower entities in the network can be “combined”, i.e. shared between themselves, using the communications and processing resource abilities of the entities taking part. The basic functions are similar, therefore are denoted as items 410’ to 434’ respectively, and act in similar ways. However, there is now the concept of horizontal slices, in this case, showing the horizontal slices #1 190 and #2 195 of Figure 1 in more detail. In this basic example, the wearable device 430’ is able to make use of the processing resources 424’ of portable device 420’, by using the communications functions to share processing data (e.g. data to process and the resultant processed data). Similarly, the portable device 420’ is able to use the base station 410’ processing resources 414’.

There will now follow more detailed description of a portion of the network slicing concept, according to the present disclosure. In some example, these functions may be provided as new network function (NFs), which may be virtualized in some cases, e.g. by using network function virtualization (NFV). These NFs and NFVs may be slice specific, or operate over multiple/all slices. The proposed wireless network, both as a whole (e.g. including the core network), but particularly the RAN will now be slice aware, by making use of a newly implemented slice identification.

Figure 5 shows a schematic diagram 500 of an example illustrating the building blocks of a sliceable radio access network architecture according to an embodiment, and in particular illustrates how a RAN control entity according to an embodiment can control the horizontal and vertical slices of Figure 3. In this Figure, control-plane (c-plane) functionality is shown as a first fill type 502, management plane (m-plane) functionality is shown as a second fill type 504, and user-plane (u-plane) functionality is shown as a third fill type 506. It is to be noted that the remaining figures uses the same Key for the different plane portions, however the numbering of specific instances of those plane types in the later Figures will be numbered in series related to the Figure number being discussed, e.g. 600 series for Figure 6 = items 602-606, 700 series for Figure 7, etc.).

In Figure 5, there is shown the sliceable (and now sliced) radio access network architecture, comprising a number of horizontal RAN slices 308, and a number of vertical RAN slices 306. The vertical/horizontal slices comprise portions 112-148, as shown. Any given slice portion in the matrix may include a portion of control-plane functionality and/or a portion of user-plane functionality. For example, slice portion A, which in this example is the top

horizontal slice portion 112 of the MBB vertical market 110, comprises both c-plane and u-plane functionality. Meanwhile, Slice Portion B, which is the second level horizontal slice portion 134 of the MTC-1 vertical market 130 has only u-plane functionality.

The RAN slices in Figure 5 are being managed by a RAN control entity 510, which may include either, or both, c-plane 502 and m-plane 504 functionality. In the example shown, both types of functionality are included in the RAN control entity that controls and coordinates the network slice operation (the m-plane). Thus, the RAN control entity may run the control-plane (c-plane) 502 and the management-plane (m-plane) 504. The c-plane 502 may be responsible for establishing and maintaining the connectivity of the network slices. The m-plane 504 may be responsible for slice configuration/reconfiguration, e.g. the setup and subsequent management of the slices or slice portions, as described in more detail below. In some embodiments, the c-plane 502 function of the RAN control entity may be the c-plane anchor for slices that do not have c-plane. In the m-plane 504, the RAN control entity 510 may operate in both Layer 1 (L1, PHY Layer) and Layer 2 (L2, MAC Layer and above, up to below the IP Layer – in LTE context, the Layer 2 control functions may be the radio resource control (RRC) functions) of the protocol stack, where L1 control coordinates the normal Layer 1 (PHY) operations of the slices, and L2 control (which is a function introduced by this disclosure) coordinates the L2 (RRC) operation of the slices, i.e. the per vertical slice operation of the slices. In some examples, the RAN control entity 510 may be a virtual entity, whose functions can be physically distributed in different locations of the radio access network.

Figure 6 illustrates a first, distributed, example of a RAN control entity according to an embodiment. In this embodiment, the RAN control entity 510 may be distributed across multiple (or all) macro BSs in a wireless communications network (however, only one is such macro BS 610 is shown in the Figure, for clarity). In this example, each of the macro BSs may run a RAN control entity function 604 to manage the portion(s) of the network slice(s) within the macro BS's coverage. In the example of Figure 6, there are three slices portions: Slice Portion #1-1; Slice Portion #2-1 and Slice Portion #3-1. Slice Portion #1-1 may be, in one example, the portion of (vertical) MBB slice 110 under the coverage of macro BS #1 610, i.e. slice portion 112 in Figure 5. Slice Portion #2-1 may be, in one example, the portion of (vertical) MTC-1 slice 120 under the coverage of macro BS #1 610, i.e. slice portion 122 in Figure 5. Slice Portion #3-1 may be, in one example, the portion of (vertical) MTC-2 slice 130 under the coverage of macro BS #1 610, i.e. slice portion 132 in Figure 5. As discussed above, with reference to Figure 5, each of the slice portions may have c-plane and/or u-plane function portions.

In Figure 6, the macro BS #1 610 has an m-plane function portion 604, c-plane function portion 602 and a u-plane function portion 606, and the multiple macro BSs making up the RAN act in unison (i.e. a distributed system) to manage the slices of the RAN as a whole.

Embodiments of the present disclosure are not limited to any specific combination of slices,
5 slice portions, or their individual make-up in terms of c-plane, u-plane or m-plane functionality.

Figure 7 illustrates a second, centralized, example of a RAN control entity according to an embodiment. In this embodiment, the RAN control entity 510 may be centrally located, for example at a centralized RAN controller 710, managing all the slices in its coverage, and may, for example, span multiple macro BS areas. In this Figure, the RAN controller 710 has both m-
10 plane 704 and c-plane 706 function portions, which control the different slices as a whole, i.e. Slice#1, Slice#2 and Slice#3. In the example of Figure 7, Slice#1 is the MBB vertical slice 110, Slice#2 is the V2X vertical slice 120 and Slice#3 is the MTC-1 vertical slice 130, however the particular slices in use are not limiting. Also in the example, Slice#1 and Slice#2 are each shown as having both a c-plane function portion and a u-plane function portion 706, whereas Slice#3 is
15 shown as having only a u-plane function portion.

Thus, according to embodiments, the management plane control function that controls and coordinates the slices/slice portions (i.e. the RAN control entity) may be either distributed or centrally provisioned.

According to embodiments the Layer 1 (L1 – e.g. PHY) and Layer 2 (L2 – e.g. MAC and
20 above Layers, providing RRC functions) control functions, which may operating together to control u-plane operation, can follow a flat architecture or a hierarchical control architecture, as illustrated in Figure 8 and Figure 9 respectively.

In the flat control architecture illustrated in Figure 8, the u-plane control of all of the vertical and horizontal slices may be managed by the RAN control entity 510. According to the
25 example of Figure 8, the RAN control entity 510 has both an L2 control function portion 830 and a L1 control function portion 835. The L2 control function portion 830 may be operable to control the L2 function portions 840, 850, 860 of each of the respective slices Slice#1-Slice#3, 110-130. In the same example, the L1 control function portion 835 may be operable to control the L1 function portions 845, 855, 865 of each of the respective slices Slice#1-Slice#3, 110-130.

30 In the hierarchical control architecture illustrated in Figure 9, the RAN control entity 510 may only control one type of slice, for example a vertical slice, which will further control the other type of slice(s), for example, a horizontal slice. As a further example, in V2X, it is likely for the vertical slice (V2X) to control the horizontal slice (V2V), however in personal area

networks (PAN), it is likely for the horizontal slice (PAN) to control the vertical slice (e.g., a health sensor MTC).

According to the specific example of Figure 9, the RAN control entity 510 has both an L2 control function portion 830 and a L1 control function portion 835. The L2 control function portion 830 may be operable to control an (overall) L2 controller function portion 930 of slice#1 110, which in turn controls the L2 function portions of each of the horizontal slice portions forming the vertical slice 110 - i.e. horizontal slice portions #1-1 112, horizontal slice portions #1-2 114, etc. (only two horizontal slice portions of Slice#1 are shown, for clarity). The different vertical slices may be controlled separately, and in different ways – as shown by the vertical slice#2 120 only having a single L2 control function portion 850 (i.e. Slice #2 is controlled in a similar way to that shown in Figure 8, discussed above).

Thus, examples may provide heterogeneous control of the different vertical slices, as may be necessary in some example implementations of the disclosed sliced RAN technology. The L1 control function may operate in the same or similar way. Figure 9 shows the exact same way being applied. Thus, in Figure 9, the L1 control function portion 835 may be operable to control an (overall) L2 controller function portion 940 of slice#1 110, which in turn controls the L1 function portions of each of the horizontal slice portions forming the vertical slice 110 - i.e. horizontal slice portions #1-1 112, horizontal slice portions #1-2 114, etc. The different vertical slices may be controlled separately, and in different ways – as shown by the vertical slice#2 120 only having a single control function portion 855 (i.e. Slice #2 is controlled in a similar way to that shown in Figure 8, discussed above).

Figure 10 shows a first example method 1000 of managing a Radio Access Network according to an embodiment. This example is shown at the highest level of detail, and comprises identifying vertical slices (i.e. markets to be served) 1010 and then identifying the horizontal slices (i.e. the network layer(s)) involved 1020, and then slicing the RAN accordingly 1030. It will be appreciated that the identification of the vertical and horizontal slicing may be done in the opposite sequence, or at the same time. The slice identification may be carried out separately and out of sync for each type (horizontal or vertical, or sub-type) and may be carried out periodically. The RAN may be (re)sliced, and the operation of the slices may be altered according to any and each slice identification process carried out.

Figure 11 shows a second example method 1100 of managing a Radio Access Network according to an embodiment. This example is shown at a lower level of detail than Figure 10. The example method starts and then proceeds to determine whether a slice is going to be controlled in a flat architecture or a hierarchical architecture 1110. If a Flat architecture is

followed 1115, the method proceeds to control 1120 all the slices (and associated slice portions) by the RAN control entity 510 (as per Figure 8). The method may return to re-test the configuration at a later stage, dependent on implementation. If an hierarchical architecture is followed 1117, the method proceeds to control 1130 a first slice (and optionally its associated slice portions) by the RAN control entity 510, and then control 1140 the further slices (and their associated slice portions) by the control function of the first slice (as per Figure 9). The method may return to re-test the configuration at a later stage, dependent on implementation.

As used herein, the term RAN control entity may be any circuit, logic or circuitry suitable for and arranged to carry out the disclosed methods and control functions. The term “logic”, “circuit” and “circuitry” may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 12 illustrates, for one embodiment, example components of an electronic device 1200, for example the RAN control entity according to an embodiment. In embodiments, the electronic device 1200 may be, implement, be incorporated into, or otherwise be a part of a user equipment (UE), base station (BS) such as an evolved NodeB (eNB), a RAN controller, or some other electronic device or network entity that is capable and arranged to perform the disclosed RAN slicing methods and functions. In some embodiments, the electronic device 1200 may include application circuitry 1210, control circuitry, such as baseband circuitry 1220, Radio Frequency (RF) circuitry 1230, front-end module (FEM) circuitry 1240 and one or more antennas 1250, coupled together at least as shown.

The application circuitry 1210 may include one or more application processors. For example, the application circuitry 1210 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include

memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

The baseband circuitry 1220 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1220 may include one or
5 more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1230 and to generate baseband signals for a transmit signal path of the RF circuitry 1230. Baseband processing circuitry 1220 may interface with the application circuitry 1210 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1230. For example, in some embodiments, the
10 baseband circuitry 1220 may include a second generation (2G) baseband processor 1221, third generation (3G) baseband processor 1222, fourth generation (4G) baseband processor 1223, and/or other baseband processor(s) 1224 for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1220 (e.g., one or more of baseband processors 1221-1224) may handle
15 various radio control functions that enable communication with one or more radio networks via the RF circuitry 1230. 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 1220 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping
20 functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1220 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

25 In some embodiments, the baseband circuitry 1220 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 1226 of the baseband circuitry 1220
30 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC Layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1227. The audio DSP(s) 1227 may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

The baseband circuitry 1220 may further include memory/storage 1225. The memory/storage 1225 may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 1220. Memory/storage for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 1225 may include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. The memory/storage 1225 may be shared among the various processors or dedicated to particular processors.

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 1220 and the application circuitry 1210 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 1220 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1220 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1220 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

RF circuitry 1220 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1230 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1230 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1240 and provide baseband signals to the baseband circuitry 1220. RF circuitry 1230 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1220 and provide RF output signals to the FEM circuitry 1240 for transmission.

In some embodiments, the RF circuitry 1230 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1230 may include mixer circuitry 1231, amplifier circuitry 1232 and filter circuitry 1233. The transmit signal path of the

RF circuitry 1230 may include filter circuitry 1233 and mixer circuitry 1231. RF circuitry 1230 may also include synthesizer circuitry 1234 for synthesizing a frequency for use by the mixer circuitry 1231 of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1231 of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1240 based on the synthesized frequency provided by synthesizer circuitry 1234. The amplifier circuitry 1232 may be configured to amplify the down-converted signals and the filter circuitry 1233 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 1220 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 1231 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 1231 of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1234 to generate RF output signals for the FEM circuitry 1240. The baseband signals may be provided by the baseband circuitry 1220 and may be filtered by filter circuitry 1233. The filter circuitry 1233 may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 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 1231 of the receive signal path and the mixer circuitry 1231 may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 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 1230 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the

baseband circuitry 1220 may include a digital baseband interface to communicate with the RF circuitry 1230.

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 1234 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 1234 may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry 1234 may be configured to synthesize an output frequency for use by the mixer circuitry 1231 of the RF circuitry 1230 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1234 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 1220 or the applications processor 1210 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 1210.

Synthesizer circuitry 1234 of the RF circuitry 1230 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 N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

In some embodiments, synthesizer circuitry 1234 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 1230 may include an IQ/polar converter.

FEM circuitry 1240 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1250, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1230 for further processing. FEM circuitry 1240 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1230 for transmission by one or more of the one or more antennas 1250.

In some embodiments, the FEM circuitry 1240 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1230). The transmit signal path of the FEM circuitry 1240 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1230), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1250).

In some embodiments, the electronic device 1200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

In some embodiments, the electronic device 1200 may be, implement, incorporate, or be otherwise part of a RAN entity. In embodiments, the baseband circuitry 1220 may be to: identify one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN; identify one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and slice the RAN into the one or more vertical and/or horizontal slices. The RF circuitry may be to send and/or receive one or more signals in accordance with the vertical and/or horizontal slices.

In some embodiments, the electronic device of Figure 12 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 10. For example, in embodiments where the electronic device is, implements, is incorporated into, or is otherwise part of a RAN control entity, or a portion thereof, the process may include identifying, by a radio access network (RAN) control entity, one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN; identifying, by the RAN control entity, one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and slicing, by the RAN control entity, the RAN into the one or more vertical and/or horizontal slices.

Figure 13 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 machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 13 shows a diagrammatic representation of hardware resources 1300 including one or more processors (or processor cores) 1310, one or more memory/storage devices 1320, and one or more communication resources 1330, each of which are communicatively coupled via a bus 1340.

The processors 1310 (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 1312 and a processor 1314. The memory/storage devices 1320 may include main memory, disk storage, or any suitable combination thereof.

The communication resources 1330 may include interconnection and/or network interface components or other suitable devices to communicate with one or more peripheral devices 1304 and/or one or more databases 1306 via a network 1308. For example, the communication resources 1330 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

Instructions 1350 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1310 to perform any one or more of the methodologies discussed herein. The instructions 1350 may reside, completely or partially, within at least one of the processors 1310 (e.g., within the processor's cache memory), the memory/storage devices 1320, or any suitable combination thereof. Furthermore, any portion of the instructions 1350 may be transferred to the hardware resources 1300 from any combination of the peripheral devices 1304 and/or the databases 1306. Accordingly, the memory of processors 1310, the memory/storage devices 1320, the peripheral devices 1304, and the databases 1306 are examples of computer-readable and machine-readable media.

Embodiments can be realized according to any of the following examples taken jointly and severally in any and all permutations:

Example 1 may relate to a method of slicing a radio access network into vertical and horizontal network slices. Example 1 may further include any of the other examples herein.

Example 2 may relate to a sliceable radio access network (RAN) architecture with a RAN control entity managing the c-plane and u-plane of the underlay RAN slices. Example 2 may further include any of the other examples herein.

5 Example 3 may include the sliceable radio access network architecture of Example 2 or some other example herein, wherein the RAN control entity is physically distributed or in a central location. Example 3 may further include any of the other examples herein.

Example 4 may include the sliceable radio access network architecture of Example 3 or some other example herein, wherein, in the distributed case, the RAN control entity is co-located with a macro BS, and is to only manage vertical and/or horizontal slices, or portions thereof, that
10 are under the coverage of the macro BS. Example 4 may further include any of the other examples herein.

Example 5 may include the sliceable radio access network architecture of Example 3 or some other example herein, wherein, in the centralized case, the RAN control entity is to manage the slice portion across multiple BSs which are under a coverage of the RAN control
15 entity. Example 5 may further include any of the other examples herein.

Example 6 may include the sliceable radio access network architecture of Examples 2- 5 or some other example herein, further comprising a Layer 1 (L1) control function and a Layer 2 (L2) control function, wherein the L1 control function and a L2 control function it to apply a flat control architecture or a hierarchical control architecture. Example 6 may further include any of
20 the other examples herein.

Example 7 may include the sliceable radio access network architecture of Example 6 or some other example herein, wherein, in the case of a flat control architecture, all the horizontal and vertical slices are managed by the L1 and L2 control functions in the RAN control entity, or wherein, in the case of the hierarchical control architecture, the RAN control entity is to only
25 control one kind of slice, vertical or horizontal, and wherein the one kind of slice is to control the other kind of slice, horizontal or vertical. Example 7 may further include any of the other examples herein.

Example 8 may include a method comprising: identifying, by a radio access network (RAN) control entity, one or more vertical slices of a RAN, the vertical slices related to vertical
30 market segments of the RAN; identifying, by the RAN control entity, one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and slicing, by the RAN control entity, the RAN into the one or more vertical and/or horizontal slices. Example 8 may further include any of the other examples herein.

Example 9 may include the method of Example 8 or some other example herein, further comprising managing, by the RAN control entity, c-plane and u-plane components of one or more vertical and/or horizontal slices. Example 9 may further include any of the other examples herein.

5 Example 10 may include the method of Examples 8 or 9 or some other example herein, further comprising only managing, by the RAN control entity when the RAN control entity is co-located with a macro base station (BS), vertical and/or horizontal slices, or portions thereof that are under coverage of the macro BS. Example 10 may further include any of the other examples herein.

10 Example 11 may include the method of Examples 8 or 9 or some other example herein, further comprising managing, by the RAN control entity, vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs). Example 11 may further include any of the other examples herein

 Example 12 may include the method of any of Examples 8-11 or some other example
15 herein, further comprising providing a Layer 1 (L1) and/or Layer 2 (L2) control function in the RAN control entity. Example 12 may further include any of the other examples herein.

 Example 13 may include the method of Example 12 or some other example herein, further comprising managing vertical and/or horizontal slices, or portions thereof with the L1 and L2 control functions. Example 13 may further include any of the other examples herein.

20 Example 14 may include the method of Examples 8-13 or some other example herein, further comprising physically distributing the RAN control entity across the RAN or portion thereof, or centralizing the RAN control entity in a central location. Example 14 may further include any of the other examples herein.

 Example 15 may include the method of Examples 12-14 or some other example herein,
25 wherein managing one type of the vertical or horizontal slices, using the L1 and/or L2 control function, and in turn managing the other type of the vertical or horizontal slices with the other slice. Example 15 may further include any of the other examples herein.

 Example 16 may include the method of Examples 8-15 or some other example herein, wherein the one or more horizontal slices are related to a macro network slice, a micro network
30 slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture. Example 16 may further include any of the other examples herein.

 Example 17 may include an electronic device to implement a radio access network (RAN) control entity, the electronic device comprising: baseband circuitry to: identify one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN;

identify one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and slice the RAN into the one or more vertical and/or horizontal slices; and radio frequency (RF) circuitry coupled with the baseband circuitry, the RF circuitry to send and/or receive one or more signals in accordance with the vertical and/or horizontal slices, or portions thereof. Example 17 may further include any of the other examples herein.

Example 18 may include the electronic device of Examples 17 or some other example herein, wherein the RAN control entity is to provide an m-plane control function that controls the network slices of a sliced RAN. Example 18 may further include any of the other examples herein.

Example 19 may include the electronic device of Examples 17-18 or some other example herein, wherein the baseband circuitry is further to manage c-plane and u-plane components of one or more vertical and/or horizontal slices. Example 19 may further include any of the other examples herein.

Example 20 may include the electronic device of Examples 17-19 or some other example herein, wherein the RAN control entity is co-located with a macro base station (BS), and the RAN control entity is to only manage vertical and/or horizontal slices, or portions thereof, that are under coverage of the macro BS. Example 20 may further include any of the other examples herein.

Example 21 may include the electronic device of Examples 17-20 or some other example herein, wherein the RAN control entity is to manage vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs). Example 21 may further include any of the other examples herein.

Example 22 may include the electronic device of Examples 17-21 or some other example herein, wherein the RAN control entity further comprises a Layer 1 (L1) and/or Layer 2 (L2) control function, and wherein the L1 control function is the physical (PHY) Layer and wherein the L2 control function is the medium access control (MAC) Layer and/or above Layers. These L2 Layer(s) may comprise the RRC functions. Example 22 may further include any of the other examples herein.

Example 23 may include the electronic device of Example 22 or some other example herein, wherein L1 and L2 control function is hierarchical, such that a lower Layer portion (or portions) control an operation of each slice, and a higher Layer portion(s) coordinates the MAC operation across the slices. Example 23 may further include any of the other examples herein.

Example 24 may include the electronic device of Examples 17-23 or some other example herein, wherein the L1 and L2 control functions are to manage vertical and/or horizontal slices. Example 24 may further include any of the other examples herein.

Example 25 may include the electronic device of Examples 17-24 or some other example
5 herein, wherein the L1 and/or L2 control function are to manage one type of the vertical or horizontal slices, which in turn manages the other type of the vertical or horizontal slices.

Example 26 may include the electronic device of Examples 17-25 or some other example herein, wherein the one or more vertical slices are related to a mobile broadband (MBB) slice, a machine type communication (MTC) slice, a vehicle to anywhere (V2X) communication slice.

10 Example 26 may further include any of the other examples herein.

Example 27 may include the electronic device of Examples 17-26 or some other example herein, wherein the one or more horizontal slices are related to a macro network slice, a micro network slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture. Example 27 may further include any of the other examples
15 herein.

Example 28 may include an electronic device to implement a radio access network (RAN) control entity, the electronic device comprising: baseband circuitry to: identify one or more vertical slices of a RAN, the vertical slices relating to use-case of communications of the RAN; identify one or more horizontal slices of the RAN, wherein a horizontal slice comprises
20 definable network hierarchy portion capable of function offloading between entities forming the horizontal slice; and slice the RAN into the one or more vertical and/or horizontal slices; and radio frequency (RF) circuitry coupled with the baseband circuitry, the RF circuitry to send and/or receive one or more signals in accordance with the vertical and/or horizontal slices. Example 28 may further include any of the other examples herein.

25 Example 29 may include the electronic device of Example 28 or some other example herein, wherein the baseband circuitry is further to manage c-plane and u-plane components of one or more vertical and/or horizontal slices, or portions thereof. Example 29 may further include any of the other examples herein.

Example 30 may include the electronic device of Examples 28-29 or some other example
30 herein, wherein the one or more vertical slices are related to separable use-cases of communications to be transmitted or received over the RAN, including one or more of: a mobile broadband (MBB) use-case, a machine type communication (MTC) use-case, a vehicle to anywhere (V2X) communication use-case, a health network use-case, an industrial control use-case. Example 30 may further include any of the other examples herein.

Example 31 may include a radio access network (RAN) control entity to logically slice a RAN into one or more horizontal or vertical slices; wherein a vertical slice comprises a predetermined type of communication; and wherein a horizontal slice comprises a predetermined layer of the RAN or a system definable network hierarchy portion capable of function offloading between entities forming the horizontal slice; wherein the RAN control entity comprises at least a portion controlling allocation of RAN resources according to a need of the one or more horizontal or vertical slices. Example 31 may further include any of the other examples herein.

Example 32 may include the radio access network (RAN) control entity of Example 31 or some other example herein, wherein the RAN comprises at least two vertical slices and at least two horizontal slices. Example 32 may further include any of the other examples herein.

Example 33 may include the radio access network (RAN) control entity of Examples 31-32 or some other example herein, wherein the predetermined type of communication relates to a market segment using the RAN for communications or specific type of communication.

Example 33 may further include any of the other examples herein.

Example 34 may include the radio access network (RAN) control entity of Examples 31-33 or some other example herein, wherein the radio access network (RAN) control entity is distributed across portions of the RAN. Example 34 may further include any of the other examples herein.

Example 35 may include the radio access network (RAN) control entity of Examples 31-34 or some other example herein, wherein the portions of RAN are the eNBs of the RAN. Example 35 may further include any of the other examples herein.

Example 36 may include the radio access network (RAN) control entity of Examples 31-35 or some other example herein, wherein a predetermined layer of the RAN comprises a macro BS layer, a smaller BS layer, a device-to-device layer, a wearable layer or PAN layer. Example 36 may further include any of the other examples herein.

Example 37 may include the radio access network (RAN) control entity of Example 36 or some other example herein, wherein a smaller base station comprises any of a micro BS, pico BS, femto BS or smaller BS. Example 37 may further include any of the other examples herein.

Example 38 may include a device comprising: means for identifying, by a radio access network (RAN) control entity, one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN; means for identifying, by the RAN control entity, one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and means for slicing, by the RAN control entity, the RAN into the one or more

vertical and/or horizontal slices. Example 38 may further include any of the other examples herein.

Example 39 may include the device of Example 38 or some other example herein, further comprising means for managing, by the RAN control entity, c-plane and u-plane components of
5 one or more vertical and/or horizontal slices. Example 39 may further include any of the other examples herein.

Example 40 may include the device of Examples 38 or 39 or some other example herein, further comprising means for only managing, by the RAN control entity when the RAN control entity is co-located with a macro base station (BS), vertical and/or horizontal slices, or portions
10 thereof that are under coverage of the macro BS. Example 40 may further include any of the other examples herein.

Example 41 may include the device of any of Examples 38 -39 or some other example herein, further comprising means for managing, by the RAN control entity, vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs). Example 41 may
15 further include any of the other examples herein.

Example 42 may include the device of any of Examples 38-41 or some other example herein, further comprising means for providing a Layer 1 (L1) and/or Layer 2 (L2) control function in the RAN control entity. The L1 control function may be the physical (PHY) Layer and the L2 control function may be the medium access control (MAC) Layer and/or above
20 Layers. These L2 Layer(s) may comprise the RRC functions. Example 42 may further include any of the other examples herein.

Example 43 may include the device of Example 42 or some other example herein, further comprising means for managing vertical and/or horizontal slices, or portions thereof with the L1 and L2 control functions. Example 43 may further include any of the other examples herein.

Example 44 may include the device of Examples 38-43 or some other example herein, further comprising means for physically distributing the RAN control entity across the RAN or portion thereof, or centralizing the RAN control entity in a central location. Example 44 may further include any of the other examples herein.

Example 45 may include the device of Examples 42-44 or some other example herein, wherein means for managing one type of the vertical or horizontal slices, using the L1 and/or L2 control function, and in turn managing the other type of the vertical or horizontal slices with the other slice. Example 45 may further include any of the other examples herein.

Example 46 may include the device of Examples 38-45 or some other example herein, wherein the one or more horizontal slices are related to a macro network slice, a micro network

slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture. Example 46 may further include any of the other examples herein.

Example 47 may include a computer readable medium comprising executable instructions, which, when executed by one or more processors causes the one or more processors to: identify, by a radio access network (RAN) control entity, one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN; identifying, by the RAN control entity, one or more horizontal slices of the RAN, the horizontal slices related to network layers of the RAN or a system definable network hierarchy portion capable of function offloading between entities forming the horizontal slice; and slicing, by the RAN control entity, the RAN into the one or more vertical and/or horizontal slices. Example 47 may further include any of the other examples herein.

Example 48 may include the computer readable medium of Example 47 or some other example herein, further comprising managing, by the RAN control entity, an m-plane functionality of the RAN. Example 48 may further include any of the other examples herein.

Example 49 may include the computer readable medium of Examples 47-48 or some other example herein, further comprising managing, by the RAN control entity, c-plane and u-plane components of one or more vertical and/or horizontal slices, or portions thereof. Example 49 may further include any of the other examples herein.

Example 50 may include the computer readable medium of any of Examples 47-49 or some other example herein, wherein the RAN control entity is collocated with a macro base station (BS), and the RAN control entity only manages vertical and/or horizontal slices, or portions thereof, that are under coverage of the macro BS. Example 50 may further include any of the other examples herein.

Example 51 may include the computer readable medium of any of Examples 47-50 or some other example herein, wherein the RAN control entity manages vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs). Example 51 may further include any of the other examples herein.

Example 52 may include the computer readable medium of any of Examples 47-51 or some other example herein, wherein the RAN control entity includes an L1 and/or L2 control function. Example 52 may further include any of the other examples herein.

Examples 53 may include the computer readable medium of any of Examples 47-52 or some other example herein, wherein the L1 and L2 control functions are to manage vertical and/or horizontal slices. Example 53 may further include any of the other examples herein.

Example 54 may include the computer readable medium of any of Examples 47-52 or some other example herein, wherein the L1 and/or L2 control function are to manage one type of the vertical or horizontal slices, which in turn manages the other type of the vertical or horizontal slices. Example 54 may further include any of the other examples herein.

5 Example 55 may include the computer readable medium of any of Examples 47-52 or some other example herein, wherein the one or more vertical slices are related to a mobile broadband (MBB) slice, a machine type communication (MTC) slice, a vehicle to anywhere (V2X) communication slice, an industrial control slice. Example 55 may further include any of the other examples herein.

10 Example 56 may include the computer readable medium of any of Examples 47-52 or some other example herein, wherein the one or more horizontal slices are related to a macro network slice, a micro network slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture. Example 56 may further include any of the other examples herein.

15 Example 57 may include a method comprising: identifying one or more vertical slices of a RAN, the vertical slices relating to use-case of communications of the RAN; identifying one or more horizontal slices of the RAN, wherein a horizontal slice comprises definable network hierarchy portion capable of function offloading between entities forming the horizontal slice; and slicing the RAN into the one or more vertical and/or horizontal slices; and the method
20 further comprising: sending and/or receiving one or more signals in accordance with the vertical and/or horizontal slices using radio frequency (RF) circuitry coupled with the baseband circuitry. Example 57 may further include any of the other examples herein.

 Example 58 may include the method of Example 57 or some other example herein, further comprising managing c-plane and u-plane components of one or more vertical and/or
25 horizontal slices, or portions thereof. Example 58 may further include any of the other examples herein.

 Example 59 may include the method of Examples 57-58 or some other example herein, wherein the one or more vertical slices are related to separable use-cases of communications to be transmitted or received over the RAN, including one or more of: a mobile broadband (MBB)
30 use-case, a machine type communication (MTC) use-case, a vehicle to anywhere (V2X) communication use-case, a health network use-case, an industrial control use-case. Example 59 may further include any of the other examples herein.

 Example 60 may include a method of logically slicing a RAN into one or more horizontal or vertical slices, comprising: providing a vertical slice comprising a predetermined

type of communication; and providing a horizontal slice comprising a predetermined layer of the RAN or a system definable network hierarchy portion capable of function offloading between entities forming the horizontal slice; and controlling allocation of at least a portion of RAN resources according to a need of the one or more horizontal or vertical slices using a RAN

5 control entity. Example 60 may further include any of the other examples herein.

Example 61 may include the method of Example 60 or some other example herein, wherein the RAN comprises at least two vertical slices and at least two horizontal slices.

Example 61 may further include any of the other examples herein.

Example 62 may include the method of Examples 60-61 or some other example herein, wherein the predetermined type of communication relates to a market segment using the RAN for communications or specific type of communication. Example 62 may further include any of the other examples herein.

Example 63 may include the method of Examples 60-62 or some other example herein, further comprising distributing the radio access network (RAN) control entity across portions of the RAN. Example 63 may further include any of the other examples herein.

Examples 64 may include the method of Examples 60-63 or some other example herein, wherein the portions of the RAN are base stations of the RAN. Example 64 may further include any of the other examples herein.

Example 65 may include the method of Examples 60-64 or some other example herein, wherein a predetermined layer of the RAN comprises a macro BS layer, a smaller BS layer, a device-to-device layer, a wearable layer or PAN layer. Example 65 may further include any of the other examples herein.

Example 66 may include the method of Example 65 or some other example herein, wherein a smaller base station comprises any of a micro BS, pico BS, femto BS or smaller BS. Example 66 may further include any of the other examples herein.

Example 67 may include a base station (BS) apparatus operable in a wireless communication network, the apparatus comprising: radio frequency (RF) circuitry to receive at least one communication originating from a wireless network device or transmit at least one communication to a wireless network device; and a radio access network control entity according to any of Examples 31-37 or some other example herein; or a device comprising means for, or modules to carry out, any of method Examples 1, 8-16, or 57-66 or some other example herein; or the device of any of Examples 2-7, 17-30, or 38-56 or some other example herein. Example 67 may further include any of the other examples herein.

Example 68 may include a user equipment (UE) apparatus operable in a wireless communication network, the apparatus comprising: radio frequency (RF) circuitry to receive or transmit at least one communication to another device in the wireless communication network; and a radio access network control entity according to any of Examples 31-37 or some other example herein; or a device comprising means for, or modules to carry out, any of method Examples 1, 8-16, or 57-66 or some other example herein; or the device of any of Examples 2-7, 17-30, or 38-56 or some other example herein. Example 68 may further include any of the other examples herein.

Example 69 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of Examples 1, 8-16, or 57-66 or any other method or process described herein. Example 69 may further include any of the other examples herein.

Example 70 may include one or more 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, 8-16, or 57-66 or some other example herein, or to provide the functionality of the apparatus or device according to any of Examples 2-7, 17-30, or 38-56 or some other example herein. Example 70 may further include any of the other examples herein.

Example 71 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, 8-16, or 57-66 or some other example herein. Example 71 may further include any of the other examples herein.

Example 72 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 of any of Examples 1, 8-16, or 57-66 or some other example herein. Example 72 may further include any of the other examples herein.

Example 73 may include a method of communicating in a wireless network as shown and described herein. Example 73 may further include any of the other examples herein.

Example 74 may include a system for providing wireless communication as shown and described herein. Example 74 may further include any of the other examples herein.

Example 75 may include a device for providing wireless communication as shown and described herein. Example 75 may further include any of the other examples herein.

Example 76 may include a device to enable network slicing in a radio access network comprising any combination of the devices, entities or methods described herein, or portions of the devices, entities or methods described herein. Example 76 may further include any of the other examples herein.

5 Example 77 may include a radio access network comprising any combination of the devices, entities or methods described herein, or portions of the devices, entities or methods described herein. Example 77 may further include any of the other examples herein.

10 Example 78 may include a device for use in a radio access network comprising any combination of the devices, entities or methods described herein, or portions of the devices, entities or methods described herein. Example 78 may further include any of the other examples herein.

Example 79 may include a method, technique, or process as described in or related to any of examples 2-7, 17-27, 28-30, 31-37, 38-46, or portions or parts thereof. Example 79 may further include any of the other examples herein.

15 In some examples, if the RAN control entity is physically distributed, the RAN control entity can be collocated with the macro BS, and only manage the slice portions that under the coverage of the macro BS. In some examples, if the RAN control entity is in a central location, the RAN control entity can manage a slice portion across multiple BSs which are under the coverage of the RAN control entity.

20 In some examples, the L1 and L2 control functions can apply a flat control architecture or a hierarchical control architecture, wherein, in a case of a flat control architecture, all the horizontal and vertical slices are managed by the L1 and L2 control functions in the RAN control entity. Alternatively, in the case of a hierarchical control architecture, the RAN control entity can only control one kind of slice, horizontal or vertical, and wherein the controlled slice
25 further controls another kind of slice, horizontal or vertical.

In some examples, the RAN comprises at least two vertical slices and at least two horizontal slices.

In some examples, the predetermined type of communication relates to a market segment using the RAN for communications.

30 In some examples, the radio access network (RAN) control entity is distributed across portions of the RAN. In some examples, the portions of RAN are the base stations (e.g. eNBs) of the RAN.

In some examples, the RAN control entity provides an m-plane control function that may control the network slices of a sliced RAN. The m-plane control function may control any one or

more of: the identification of vertical markets (or at least one vertical market) applicable to, or desired to be served by, the RAN, wherein each identified vertical market has a vertical slice logically assigned thereto; the identification of horizontal slices (e.g. the network layers, or applicable portions thereof) for serving the identified vertical slice(s) that are applicable to, or
5 desired to be served by, the RAN; slicing of the RAN into the identified one or more slices (horizontal and/or vertical); the coordination of the operation of the slices, including setup and teardown of the slices. The m-plane functionality may control the c-plane and/or u-plane of respective ones of, or the totality of the identified network slices of the RAN.

In the foregoing, reference to ‘layer’ may be a reference to a predefined (or definable)
10 portion of the infrastructure, whereas reference to ‘Layer’ may be a reference to a network protocol Layer in operation on/in the network infrastructure, or portion thereof.

Examples use-cases/types of communications may include: Wireless/Mobile Broadband (MBB) communications; Extreme Mobile Broadband (E-MBB) communications; Real-time use-case such as Industrial Control communications, Machine-to-Machine communications
15 (MTC/MTC1); non-real-time use-case, such as Internet-of-Things (IoT) sensors communications, or massive-scale Machine-to-Machine communications (M-MTC/MTC2); Ultra Reliable Machine-to-Machine communications (U-MTC); Mobile Edge Cloud, e.g. caching, communications; Vehicle-to-Vehicle (V2V) communications; Vehicle-to-Infrastructure (V2I) communications; Vehicle-to-anything communications (V2X). This is to say, the present
20 disclosure relates to providing network slicing according to any readily definable/distinguishable type of communication that can be carried out over a wireless network.

In some examples, the radio access network (RAN) control entity is distributed across portions of the RAN. In some examples, the portions of RAN are the base stations (e.g. eNBs) of the RAN, in others, the portion(s) of the RAN may be a UE, or any other device being or to be
25 served by the wireless network/RAN, or forming part of (or serving) the same, e.g. mobility management engine (MME), baseband unit (BBU), remote radio head (RRH) or, etc. In some examples, if the RAN control entity is physically distributed, the RAN control entity can be collocated with the macro BS, and only manage the slice portions that under the coverage of the macro BS. In some examples, if the RAN control entity is in a central location, the RAN control
30 entity can manage a slice portion across multiple BSs which are under the coverage of the RAN control entity. The RAN control entity may comprise at least a portion controlling allocation of RAN, or device, resources according to a need of the one or more horizontal or vertical slices, for example computational resources at/in, or available to, a device in the wireless network.

As herein described, where an example or claim recites RF circuitry, for example, to form a greater entity within the wireless network, e.g. a base station, this is also intended to cover the or an alternative embodiment which does not include the RF circuitry, for example for use in (or to provide) a distributed form of entity according to the disclosure. This may be applicable, for example, when the entity forms part of a Cloud RAN, where the radio portions (e.g. RRH) are not co-located/within the same entity as at least a significant portion of the control function (entity, module, etc.) , e.g. BBU. Thus, no embodiments are intended to be restricted to only those having an RF portion that sends or receives messages to or form the wireless network. For example, some implementations may be part of front-haul capabilities, which may be the connections to radio front ends (e.g. RRHs) from a centralized, or more centralized baseband function (e.g. BBU).

As used herein, any reference to computer program product or computer readable medium, may include reference to both transitory (e.g. physical media) and non-transitory forms (e.g. signals or data structures thereof).

Various examples disclosed herein may provide many advantages, for example, but not limited to: providing full(er) coverage for the devices being served, for any given amount of core network and/or RAN resources (e.g. computing, radio, etc); less control signaling delay and signaling exchange overhead among transmission points; providing improved coverage and at the same time reducing control signaling exchange among network nodes (inc. transmission points); a more efficient (overall, or substantial portion of a) wireless network, for example because, it allows a given amount of (e.g. a single) physical radio access network infrastructure to be used by multiple use-cases, thereby resulting in less hardware/infrastructure than would otherwise be used (e.g. double, or more, hardware, for example to provide separate physical radio access network infrastructure for each use case); generally improved radio access network performance, efficiency, reliability, maintaining/maintenance of service and quality of service, for all devices operating across the RAN, and within each slice of the RAN.

As herein described, turn-on, activation or logical separation, or the like, of the, or a, network slice may be equivalent to one another, and the terms used inter-changeably. Similarly, the turn-off, deactivation or logical desperation, or the like, of a network slice may all be equivalent to one another, and the terms used inter-changeably. A network slice may also be referenced as a logically separate (separated, partitioned, etc.) radio network access, or as a logically separate (separated, partitioned, etc.) radio network access portion. A device being, or to be served by the physical radio access network infrastructure, or a network slice may include a UE, however any and all other forms of devices that may be served are also interchangeable

with a reference to a UE herein. A device may be referenced as a wireless network device. However, a wireless network device as used herein may also reference a serving entity, such as base station, MME, BBU, RRH, etc., dependent on context of use. Operationally, in terms of the disclosed network slicing, an access point and base station may be considered similar in use or deployment.

As herein described, specific examples have been used to explain the disclosed methods and functions (and function units that carry out those functions), however, the disclosure is not so limited. For example, embodiments of the disclosure is/are not limited to any specific example, such as: where a specific vertical market is disclosed in relation to a Figure, this is only an example, and any vertical market may be used instead; where a specific portion of a slice is disclosed in relation to a Figure, any portion of a slice may be used instead; where a RAN has been disclosed as having a certain size, type or number of slices (horizontal or vertical) in relation to a Figure, any size, type or number of slices may be used instead; where a slice or slice portion has been disclosed as having a certain size, type or number (in the horizontal or the vertical) in relation to a Figure, any size, type or number of slice or slice portion may be used instead. Also, in the foregoing, whilst a numbering scheme for the slices has been applied starting from 1, other numbering schemes may also be implemented, e.g. the numbers may start from 0 instead, such that Slice#1 may be Slice#0, and the like. Thus, the specific numbers are not limiting, other than by showing an exemplary distinction between slices (by being differently numbered) or an exemplary relation between numbered slice portions (by being consecutively numbered sub-parts of the same numbered slice).

As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware or software components, including a one or more virtual machines that can provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. In some embodiment, the processing/execution may be distributed instead of centralized processing/execution.

As used herein, any reference to a (RAN) architecture may include anything that may be defined as or thought of as any form of specific process(es), technique(s), technology(ies), implementation detail, improvement in or type of operation of a wireless network (or similar

networking system entity), particularly in the RAN. Architectures may be typically introduced, maintained and updated in the standards documents for the respective wireless network technologies in use, for example the third generation partnership project (3GPP) standards, and the like.

5 It will be appreciated that any of the disclosed methods (or corresponding apparatuses, programs, data carriers, etc.) may be carried out by either a host or client, depending on the specific implementation (i.e. the disclosed methods/apparatuses are a form of communication(s), and as such, may be carried out from either ‘point of view’, i.e. in corresponding to each other fashion). Furthermore, it will be understood that the terms “receiving” and “transmitting”
10 encompass “inputting” and “outputting” and are not limited to an RF context of transmitting and receiving radio waves. Therefore, for example, a chip or other device or component for realizing embodiments could generate data for output to another chip, device or component, or have as an input data from another chip, device or component, and such an output or input could be referred to as “transmit” and “receive” including gerund forms, that is, “transmitting” and
15 “receiving”, as well as such “transmitting” and “receiving” within an RF context.

As used in this specification, any formulation used of the style “at least one of A, B or C”, and the formulation “at least one of A, B and C” use a disjunctive “or” and a disjunctive “and” such that those formulations comprise any and all joint and several permutations of A, B, C, that is, A alone, B alone, C alone, A and B in any order, A and C in any order, B and C in any
20 order and A, B, C in any order. There may be more or less than three features used in such formulations.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word ‘comprising’ does not exclude the presence of other elements or steps then those listed in a claim. Furthermore, the terms “a” or “an,” as used herein, are defined
25 as one or more than one. Also, the use of introductory phrases such as “at least one” and “one or more” in the claims should not be construed to imply that the introduction of another claim element by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim element to inventions containing only one such element, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles
30 such as “a” or “an.” The same holds true for the use of definite articles. Unless stated otherwise, terms such as “first” and “second” are used to arbitrarily distinguish between the elements such terms describe. Thus, these terms are not necessarily intended to indicate temporal or other prioritization of such elements. The mere fact that certain measures are recited in mutually

different claims does not indicate that a combination of these measures cannot be used to advantage.

Unless otherwise explicitly stated as incompatible, or the physics or otherwise of the embodiments, example or claims prevent such a combination, the features of the foregoing
5 embodiments and examples, and of the following claims may be integrated together in any suitable arrangement, especially ones where there is a beneficial effect in doing so. This is not limited to only any specified benefit, and instead may arise from an “ex post facto” benefit. This is to say that the combination of features is not limited by the described forms, particularly the form (e.g. numbering) of the example(s), embodiment(s), or dependency of the claim(s).

10 Moreover, this also applies to the phrase “in one embodiment”, “according to an embodiment” and the like, which are merely a stylistic form of wording and are not to be construed as limiting the following features to a separate embodiment to all other instances of the same or similar wording. This is to say, a reference to ‘an’, ‘one’ or ‘some’ embodiment(s) may be a reference to any one or more, and/or all embodiments, or combination(s) thereof, disclosed. Also,
15 similarly, the reference to “the” embodiment may not be limited to the immediately preceding embodiment.

In the foregoing, reference to ‘layer’ may be a reference to a predefined (or definable) portion of the infrastructure, whereas reference to ‘Layer’ may be a reference to a network
20 protocol Layer in operation on/in the network infrastructure, or portion thereof. As used herein, a vertical slice may be referenced as or related to a vertical market segment. As used herein, any machine executable instructions may carry out a disclosed method, and may therefore be used synonymously with the term method.

The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of the claims to the precise
25 form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various implementations of the disclosure.

CLAIMS

1. Machine executable instructions arranged, when executed by one or more than one processor, to implement a method comprising:
 - identifying, by a radio access network (RAN) control entity, one or more vertical slices
 - 5 of a RAN, the vertical slices related to vertical market segments of the RAN;
 - identifying, by the RAN control entity, one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and
 - slicing, by the RAN control entity, the RAN into the one or more vertical and/or horizontal slices.
- 10 2. The machine executable instructions of claim 1, further comprising managing, by the RAN control entity, c-plane and u-plane components of one or more vertical and/or horizontal slices.
3. The machine executable instructions of claim 1, further comprising only managing, by the RAN control entity when the RAN control entity is co-located with a macro base station
- 15 (BS), vertical and/or horizontal slices, or portions thereof that are under coverage of the macro BS.
4. The machine executable instructions of claim 1, further comprising managing, by the RAN control entity, vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs).
- 20 5. The machine executable instructions of claim 1, further comprising providing an Layer 1 (L1) and/or Layer 2 (L2) control function in the RAN control entity.
6. The machine executable instructions of claim 5, further comprising managing vertical and/or horizontal slices, or portions thereof with the L1 and L2 control functions.
7. The machine executable instructions of claim 1, further comprising physically
- 25 distributing the RAN control entity across the RAN or portion thereof, or centralizing the RAN control entity in a central location.
8. The machine executable instructions of claim 5, wherein managing one type of the vertical or horizontal slices, using the L1 and/or L2 control function, and in turn managing the other type of the vertical or horizontal slices with the other slice.
- 30 9. The machine executable instructions of claim 1, wherein the one or more horizontal slices are related to a macro network slice, a micro network slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture.
10. An electronic device to implement a radio access network (RAN) control entity, the electronic device comprising:

circuitry to:

identify one or more vertical slices of a RAN, the vertical slices related to vertical market segments of the RAN;

5 identify one or more horizontal slices of the RAN, the horizontal slices related to network hierarchy segments of the RAN; and

slice the RAN into the one or more vertical and/or horizontal slices; and

radio frequency (RF) circuitry coupled with the circuitry, the RF circuitry to send and/or receive one or more signals in accordance with the vertical and/or horizontal slices, or portions thereof.

10 11. The electronic device of claim 10, wherein the RAN control entity is to provide a management plane (m-plane) control function that controls the network slices of a sliced RAN.

12. The electronic device of claim 10, wherein the circuitry is further to manage control plane (c-plane) and user plane (u-plane) components of one or more vertical and/or horizontal slices.

15 13. The electronic device of claim 10, wherein the RAN control entity is co-located with a macro base station (BS), and the RAN control entity is to only manage vertical and/or horizontal slices, or portions thereof, that are under coverage of the macro BS.

14. The electronic device of claim 10, wherein the RAN control entity is to manage vertical and/or horizontal slices that are under coverage of a plurality of base stations (BSs).

20 15. The electronic device of claim 10, wherein the RAN control entity further comprises a Layer 1 (L1) and/or Layer 2 (L2) control function; and

wherein the L1 control function is the physical (PHY) Layer and wherein the L2 control function is the medium access control (MAC) Layer.

25 16. The electronic device of claim 15, wherein L1 and L2 control function is hierarchical, such that a lower Layer portion (or portions) control an operation of each slice, and a higher Layer portion(s) coordinates the MAC operation across the slices.

17. The electronic device of claim 10, wherein the L1 and L2 control functions are to manage vertical and/or horizontal slices.

30 18. The electronic device of claim 10, wherein the L1 and/or L2 control function are to manage one type of the vertical or horizontal slices, which in turn manages the other type of the vertical or horizontal slices.

19. The electronic device of claim 10, wherein the one or more vertical slices are related to a mobile broadband (MBB) slice, a machine type communication (MTC) slice, a vehicle to anywhere (V2X) communication slice.

20. The electronic device of claim 10, wherein the one or more horizontal slices are related to a macro network slice, a micro network slice, a device to device (D2D) slice, a Personal Area Network, a non-standalone mode, an anchor-booster architecture.

21. An electronic device to implement a radio access network (RAN) control entity, the
5 electronic device comprising:

circuitry to:

identify one or more vertical slices of a RAN, the vertical slices relating to use-
case of communications of the RAN;

10 identify one or more horizontal slices of the RAN, wherein a horizontal slice
comprises definable network hierarchy portion capable of function offloading between entities
forming the horizontal slice; and

slice the RAN into the one or more vertical and/or horizontal slices; and

radio frequency (RF) circuitry coupled with the circuitry, the RF circuitry to send and/or
receive one or more signals in accordance with the vertical and/or horizontal slices.

15 22. The electronic device of claim 21, wherein the circuitry is further to manage control
plane (c-plane) and user plane (u-plane) components of one or more vertical and/or horizontal
slices, or portions thereof.

23. The electronic device of claim 21, wherein the one or more vertical slices are related to
separable use-cases of communications to be transmitted or received over the RAN, including
20 one or more of: a mobile broadband (MBB) use-case, a machine type communication (MTC)
use-case, a vehicle to anywhere (V2X) communication use-case, a health network use-case, an
industrial control use-case.

24. A radio access network (RAN) control entity to logically slice a RAN into one or more
horizontal or vertical slices;

25 wherein a vertical slice comprises a predetermined type of communication; and

wherein a horizontal slice comprises a predetermined layer of the RAN or a system
definable network hierarchy portion capable of function offloading between entities forming the
horizontal slice;

30 wherein the RAN control entity comprises at least a portion controlling allocation of
RAN resources according to a need of the one or more horizontal or vertical slices.

25. The radio access network (RAN) control entity of claim 24, wherein the RAN comprises
at least two vertical slices and at least two horizontal slices.

26. The radio access network (RAN) control entity of claim 24, wherein the predetermined type of communication relates to a market segment using the RAN for communications or specific type of communication.
27. The radio access network (RAN) control entity of claim 24, wherein the radio access
5 network (RAN) control entity is distributed across portions of the RAN.
28. The radio access network (RAN) control entity of claim 24, wherein the portions of RAN are e Node Bs (eNBs) of the RAN.
29. The radio access network (RAN) control entity of claim 24, wherein a predetermined layer of the RAN comprises a macro base station (BS) layer, a smaller BS layer, a device-to-
10 device layer, a wearable layer or personal area network (PAN) layer.
30. The radio access network (RAN) control entity of claim 29, wherein a smaller base station comprises any of a micro BS, pico BS, femto BS or smaller BS.

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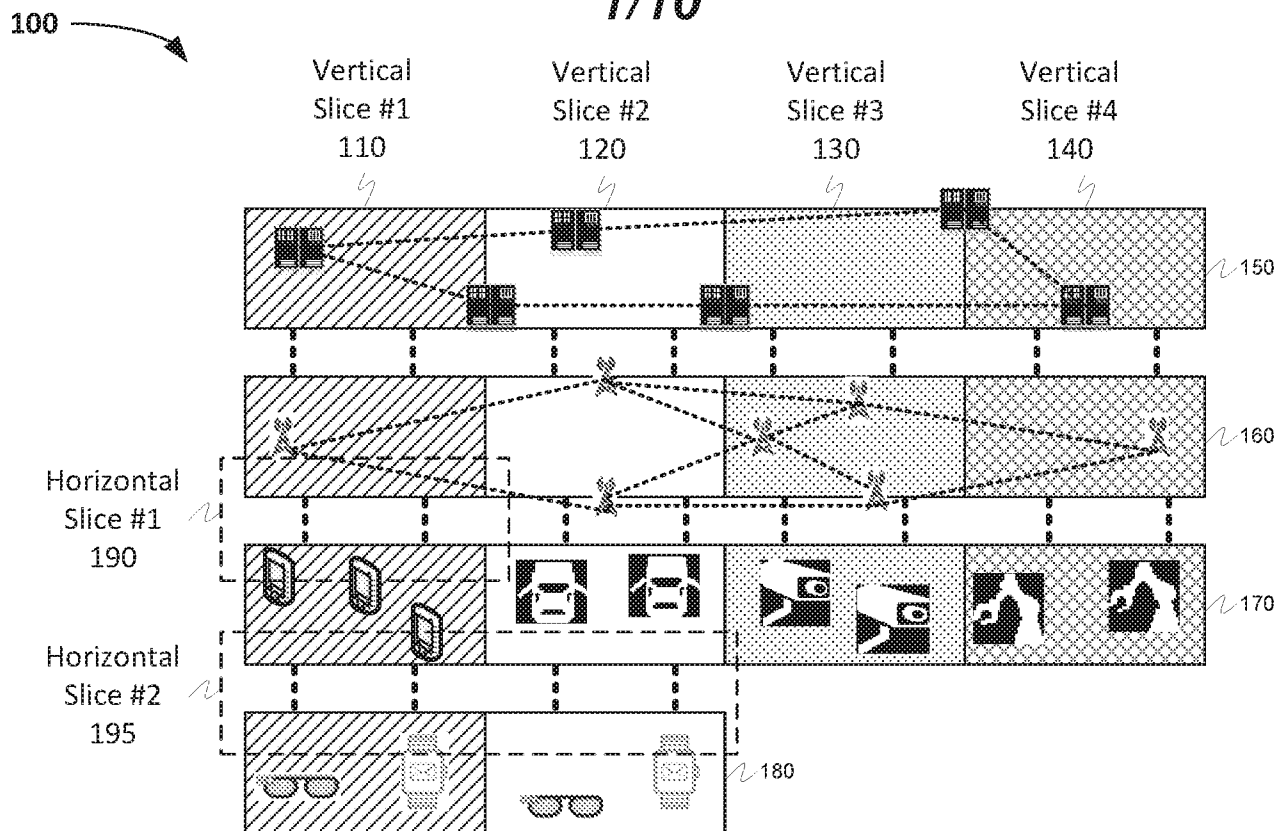


Fig. 1

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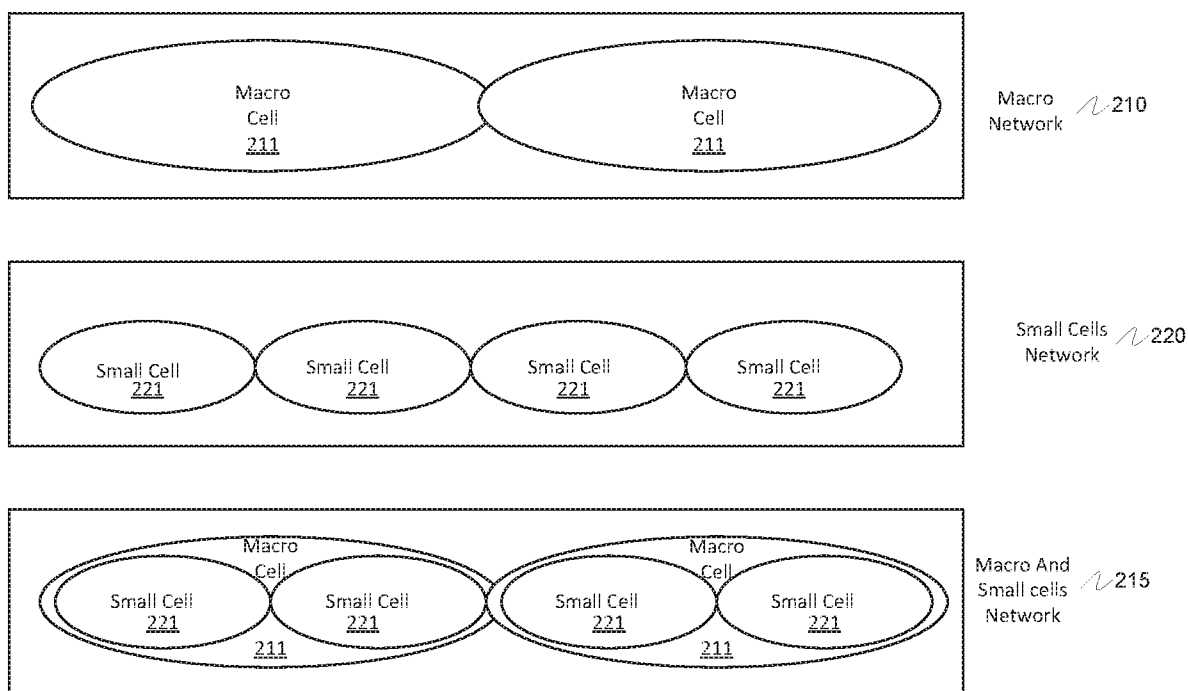


Fig. 2

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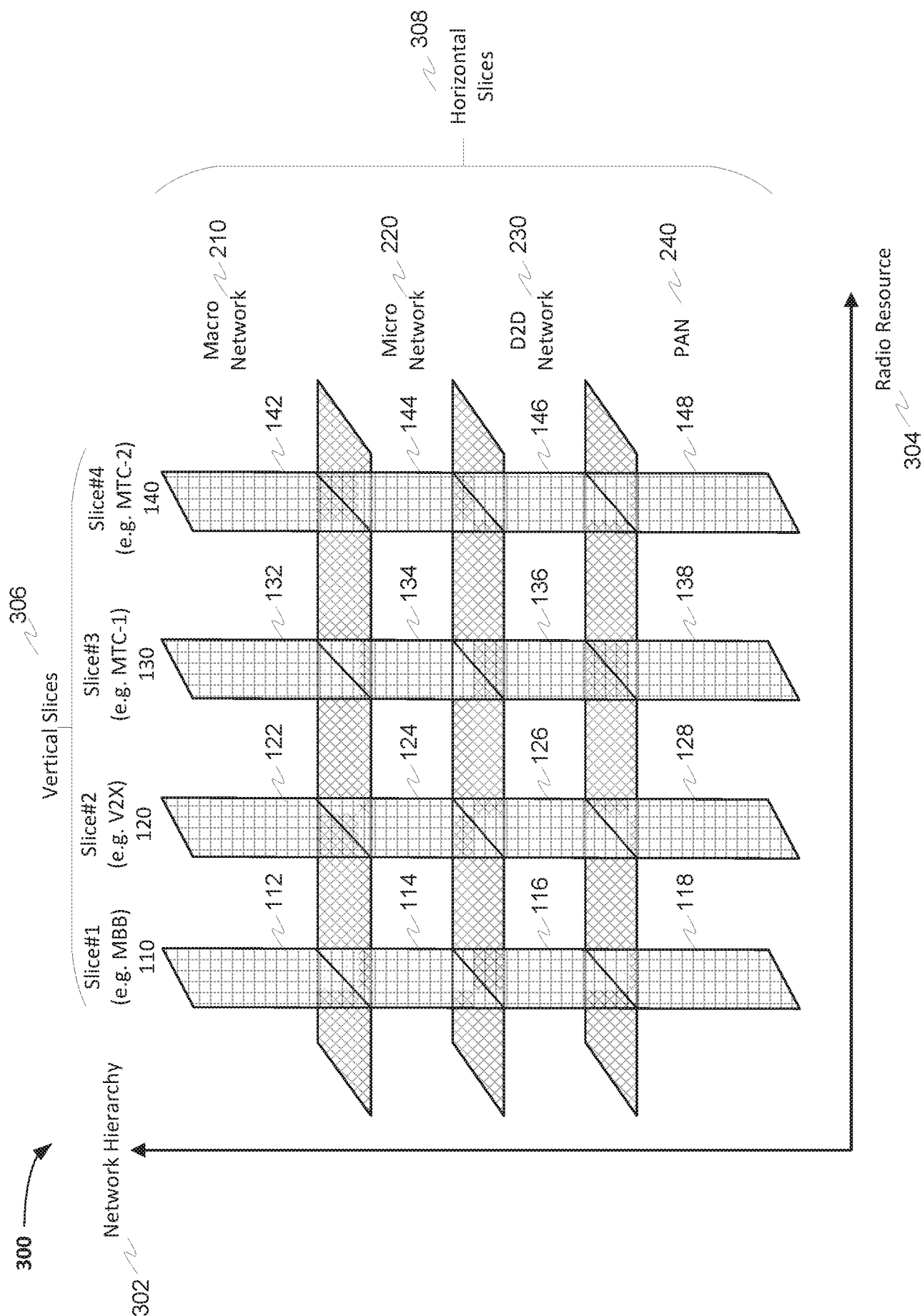


Fig. 3

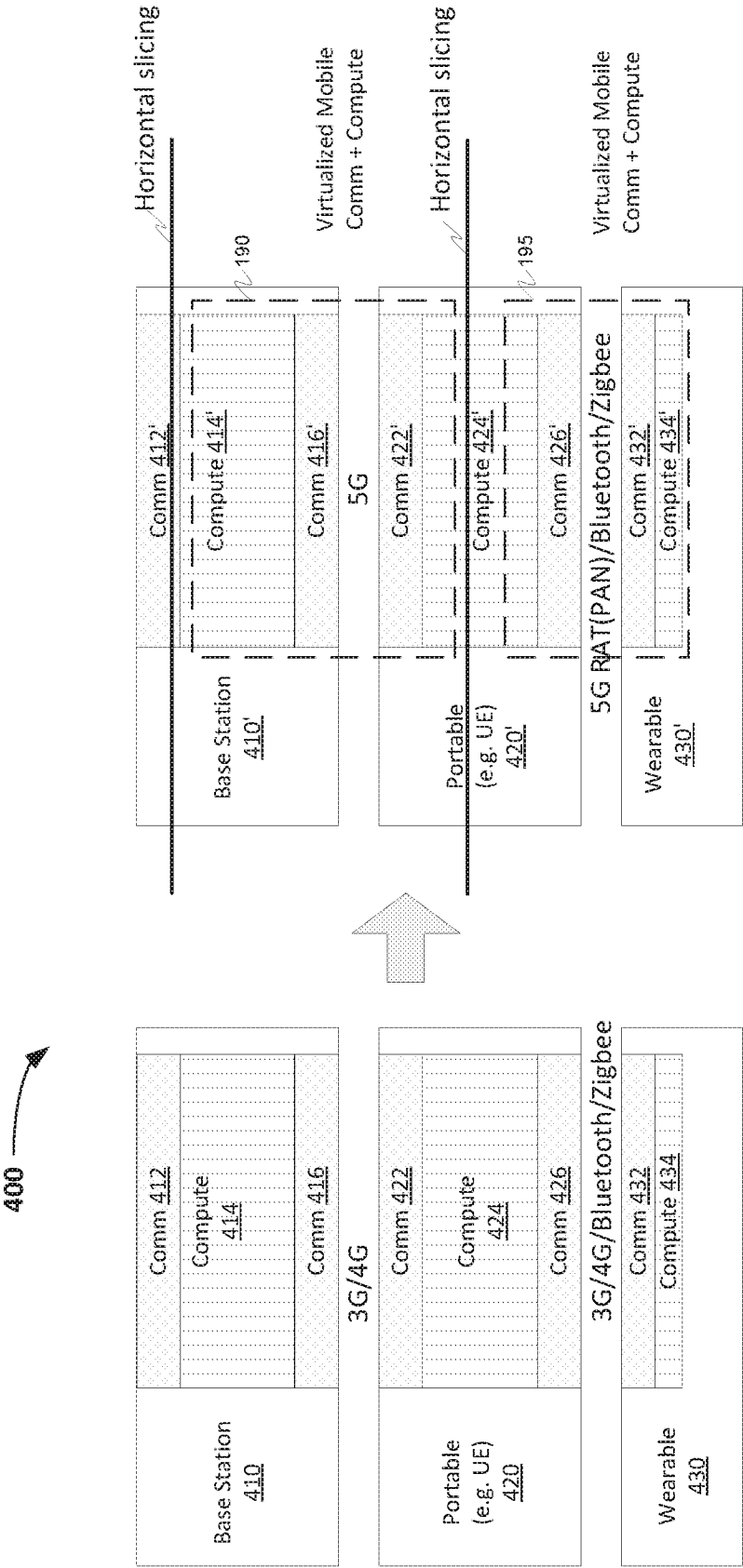
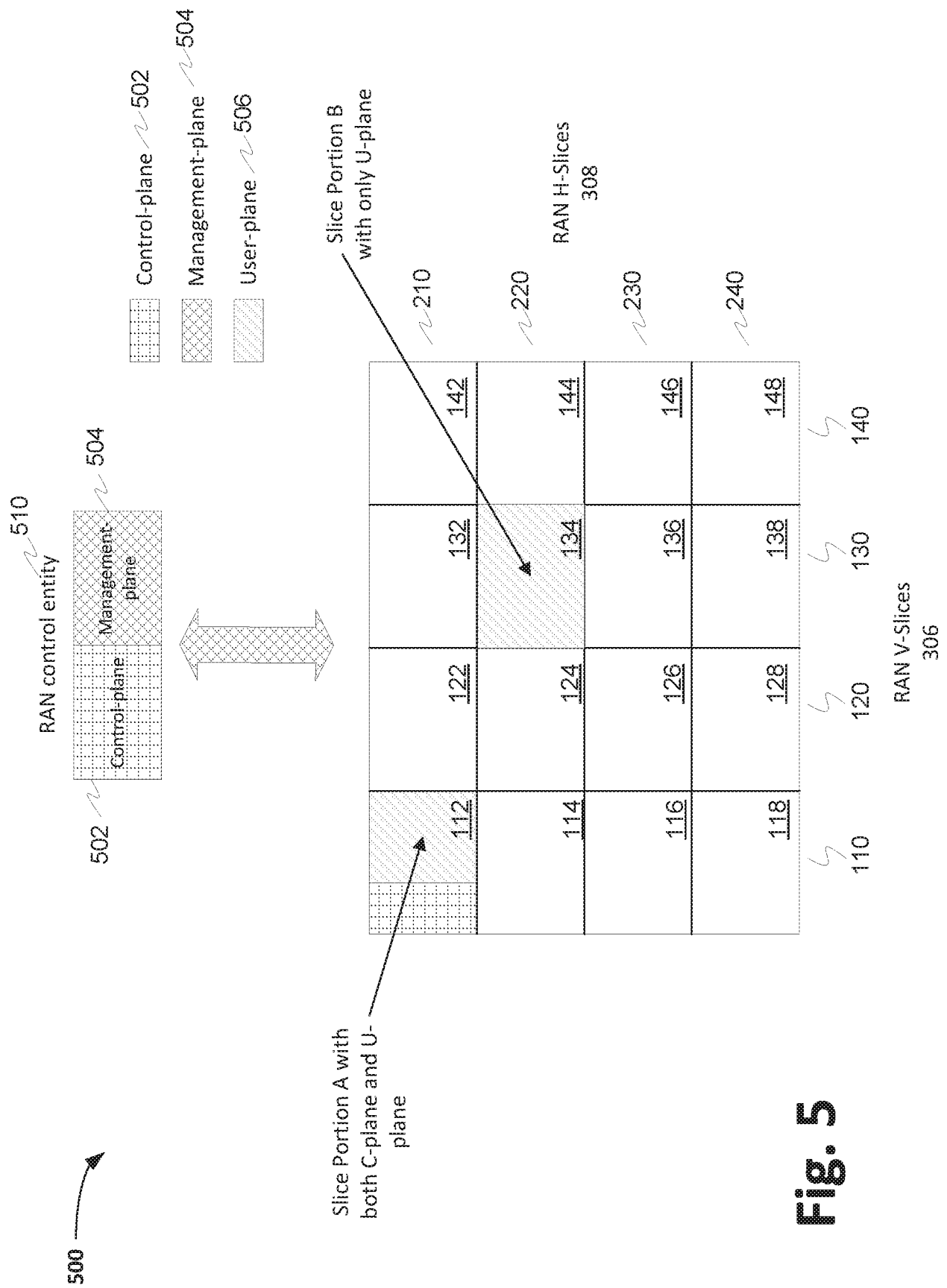


Fig. 4



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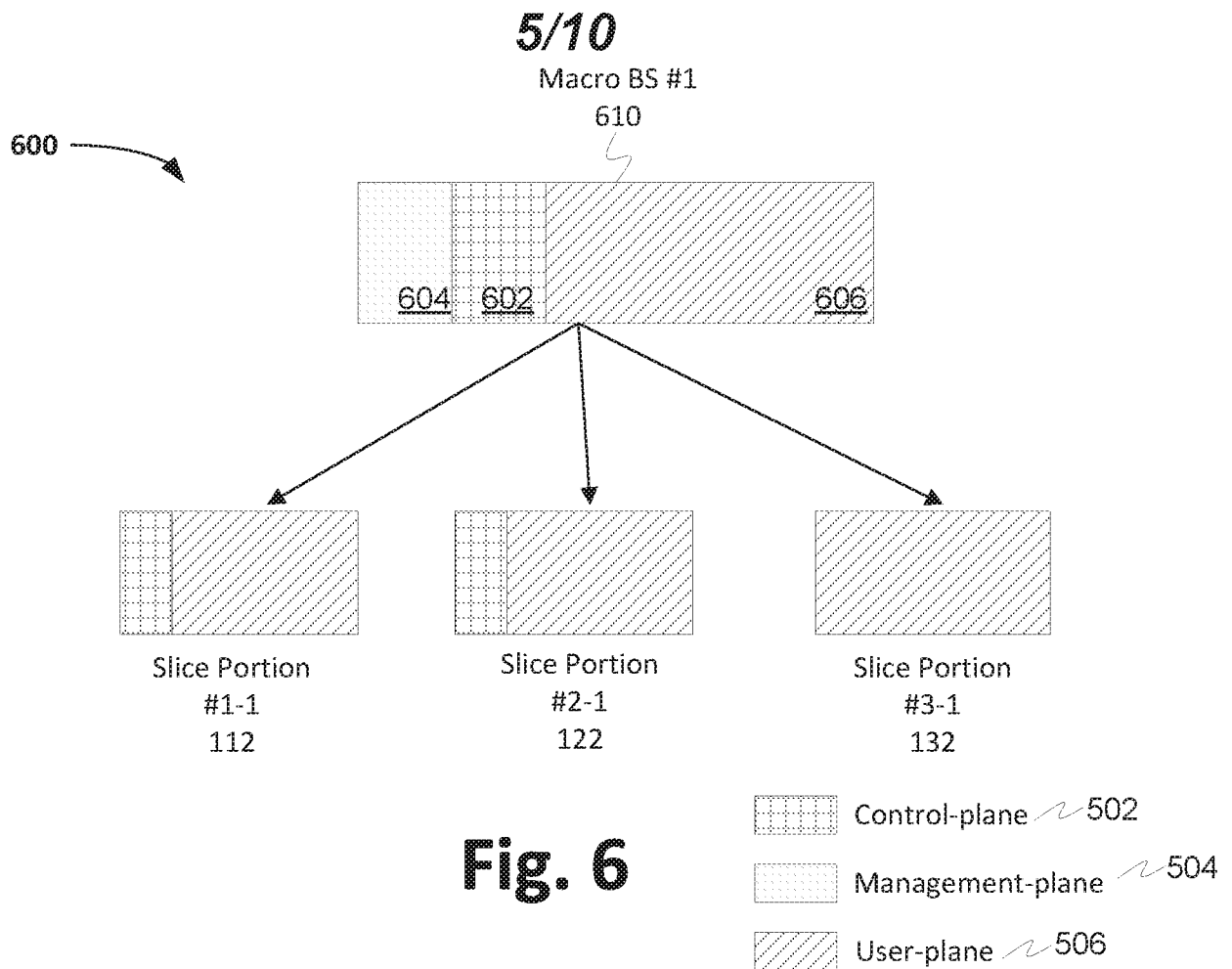


Fig. 6

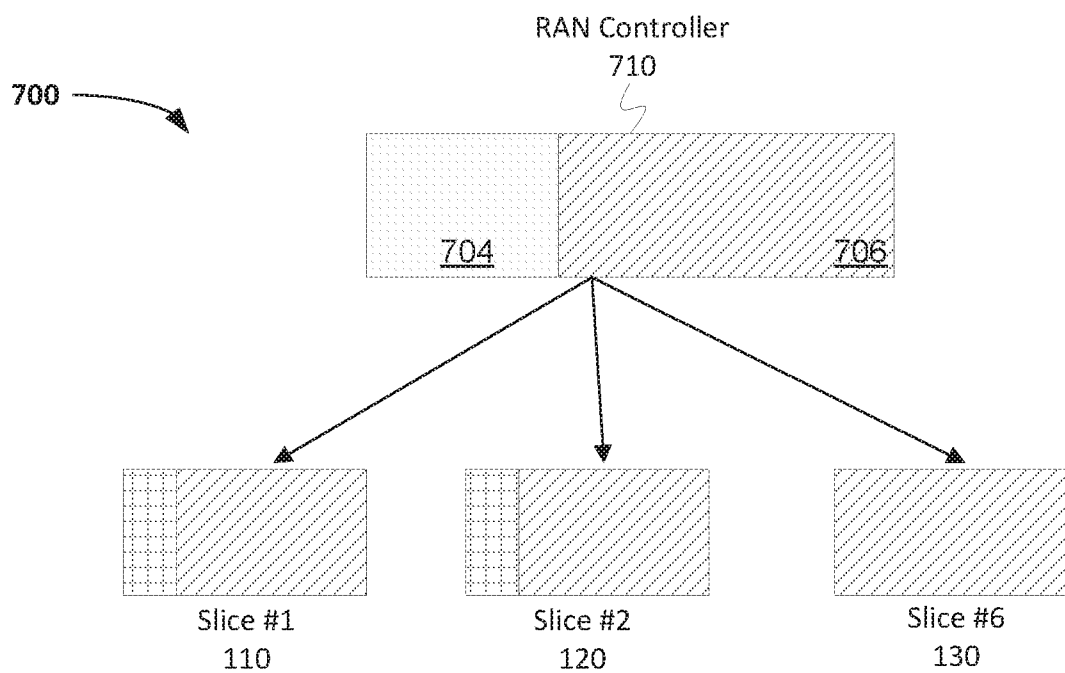


Fig. 7

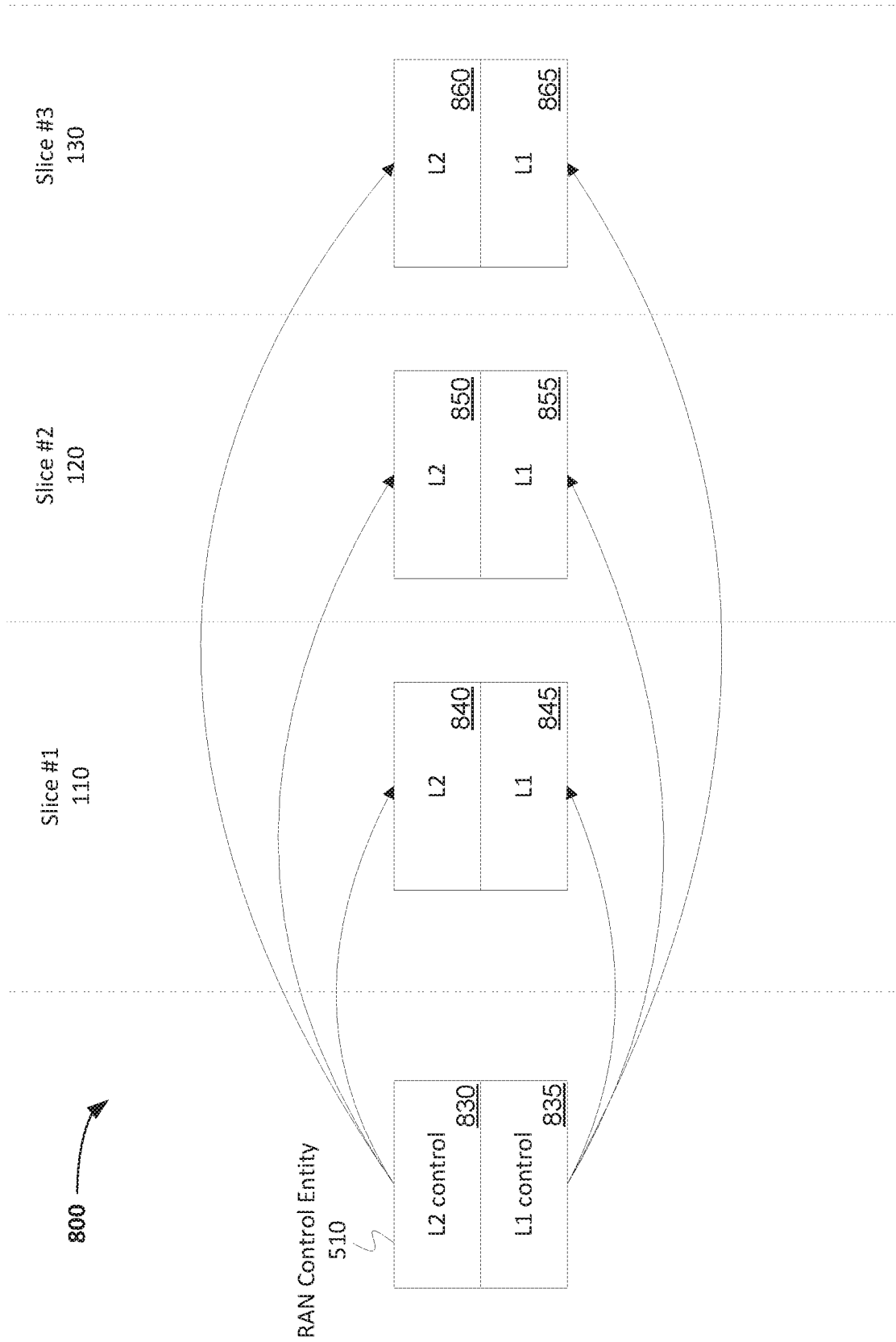


Fig. 8

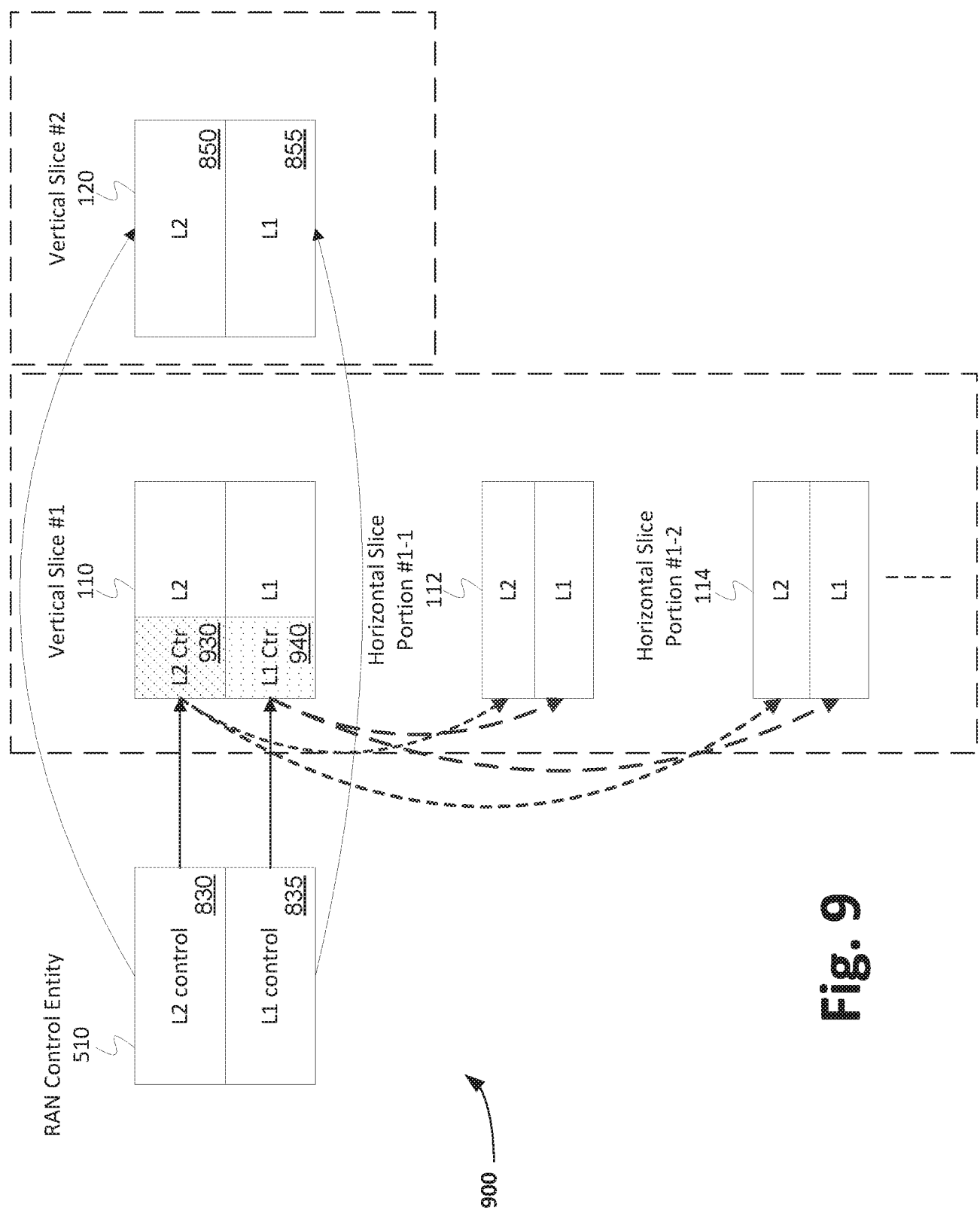
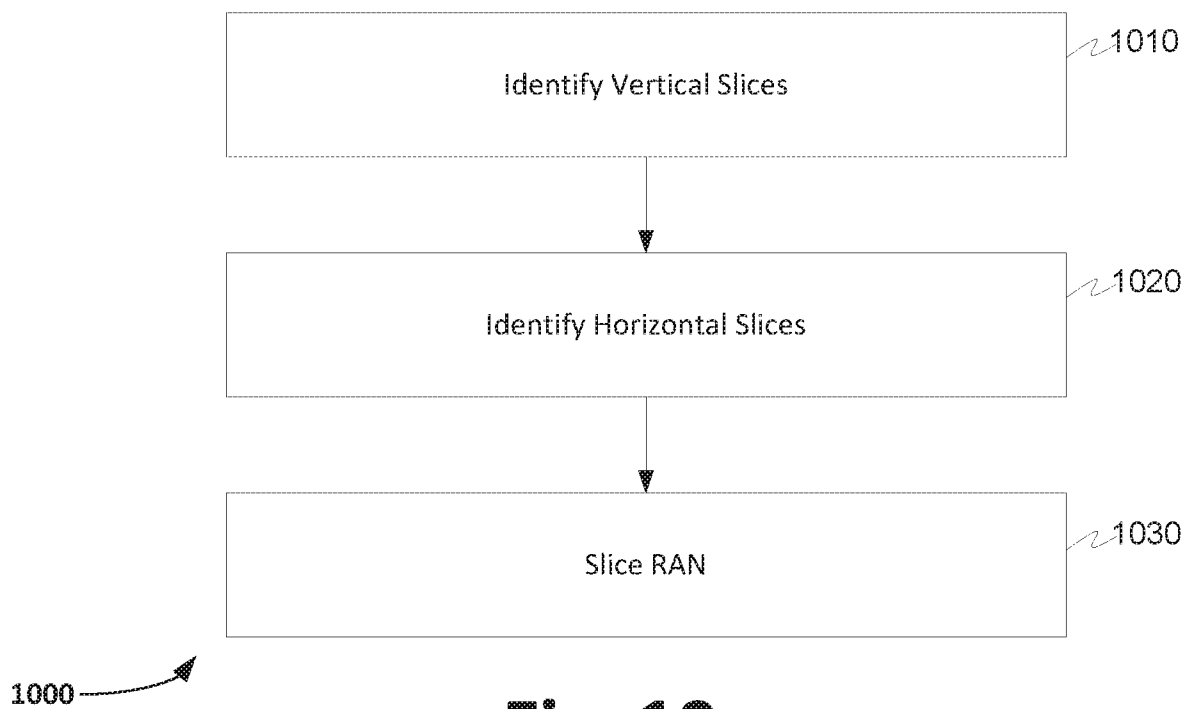
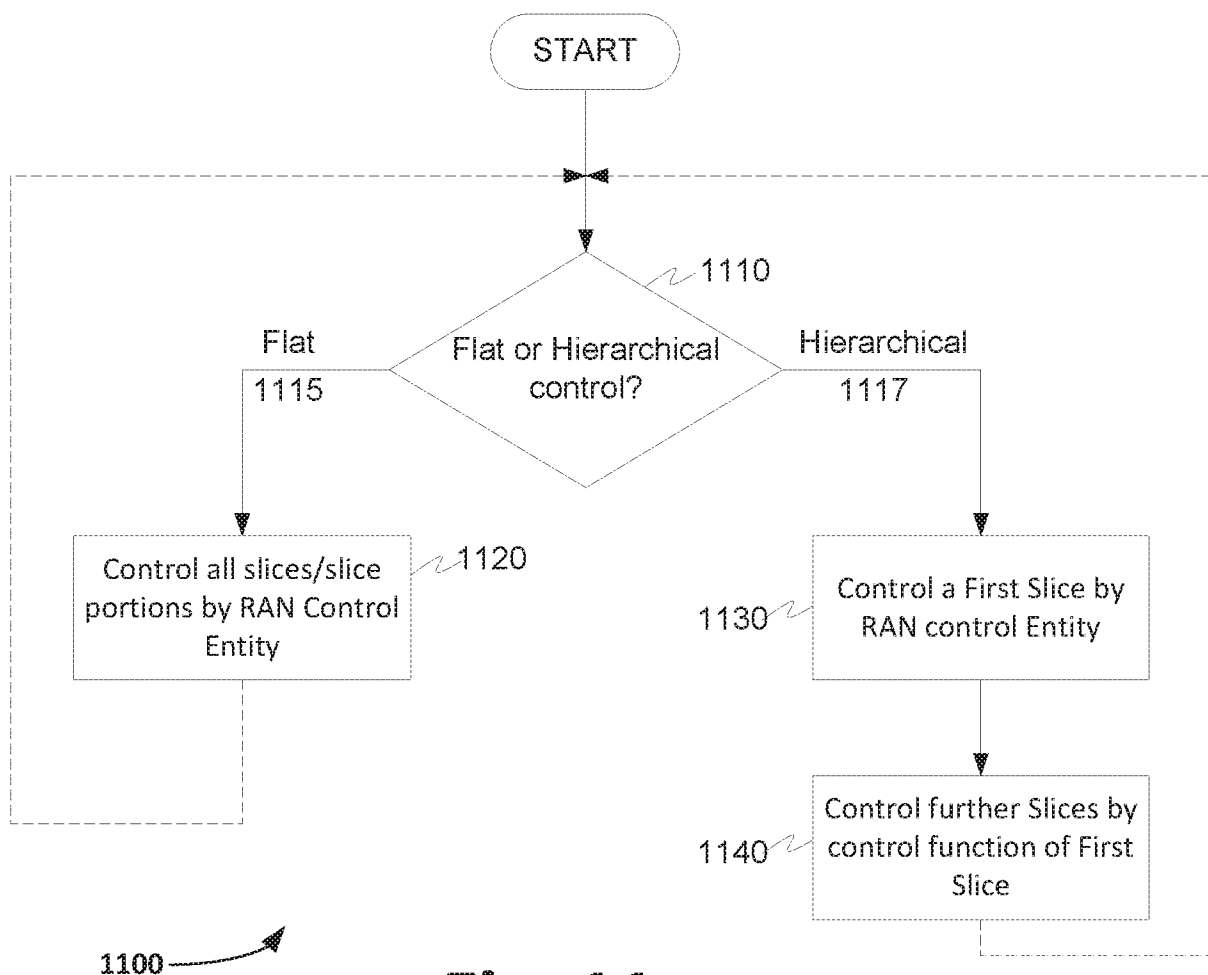


Fig. 9

8/10**Fig. 10****Fig. 11**

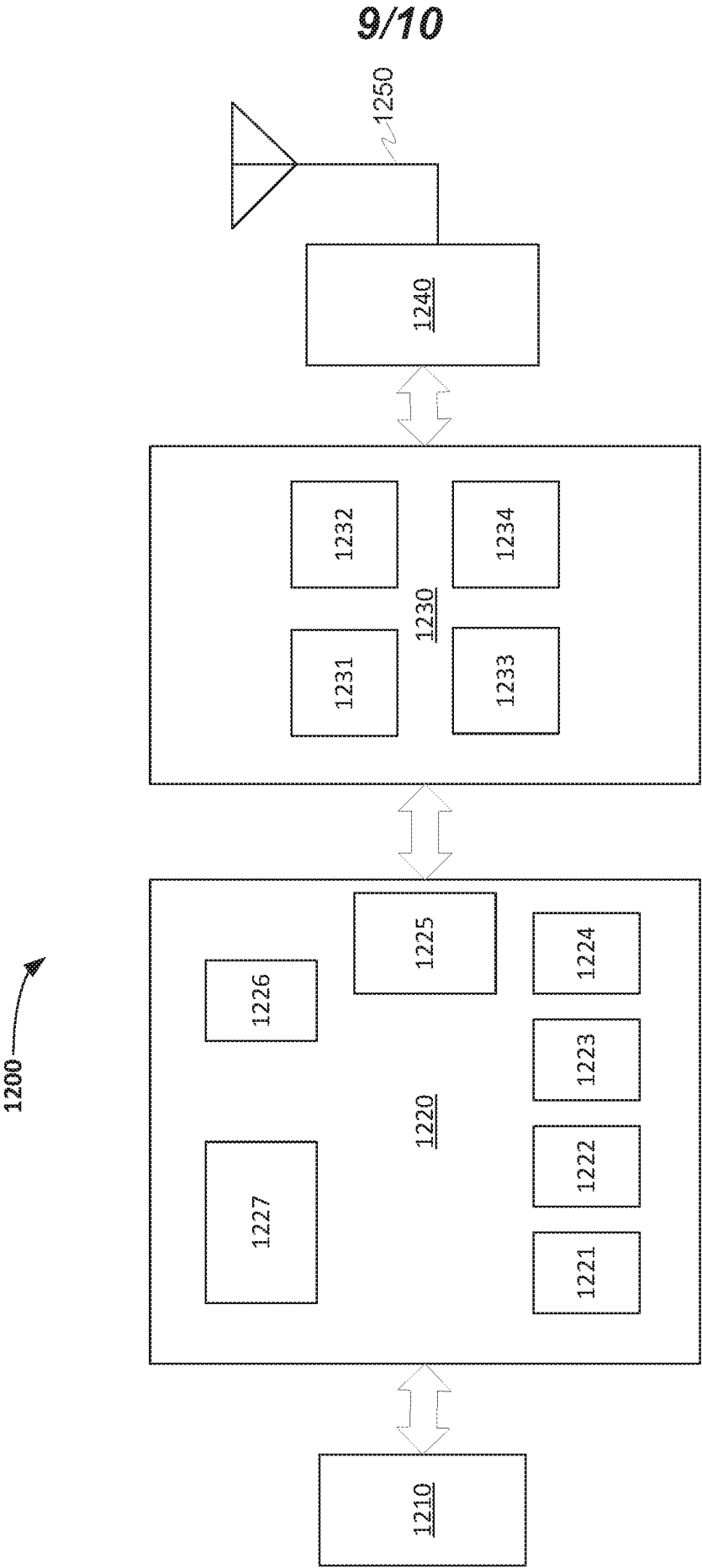
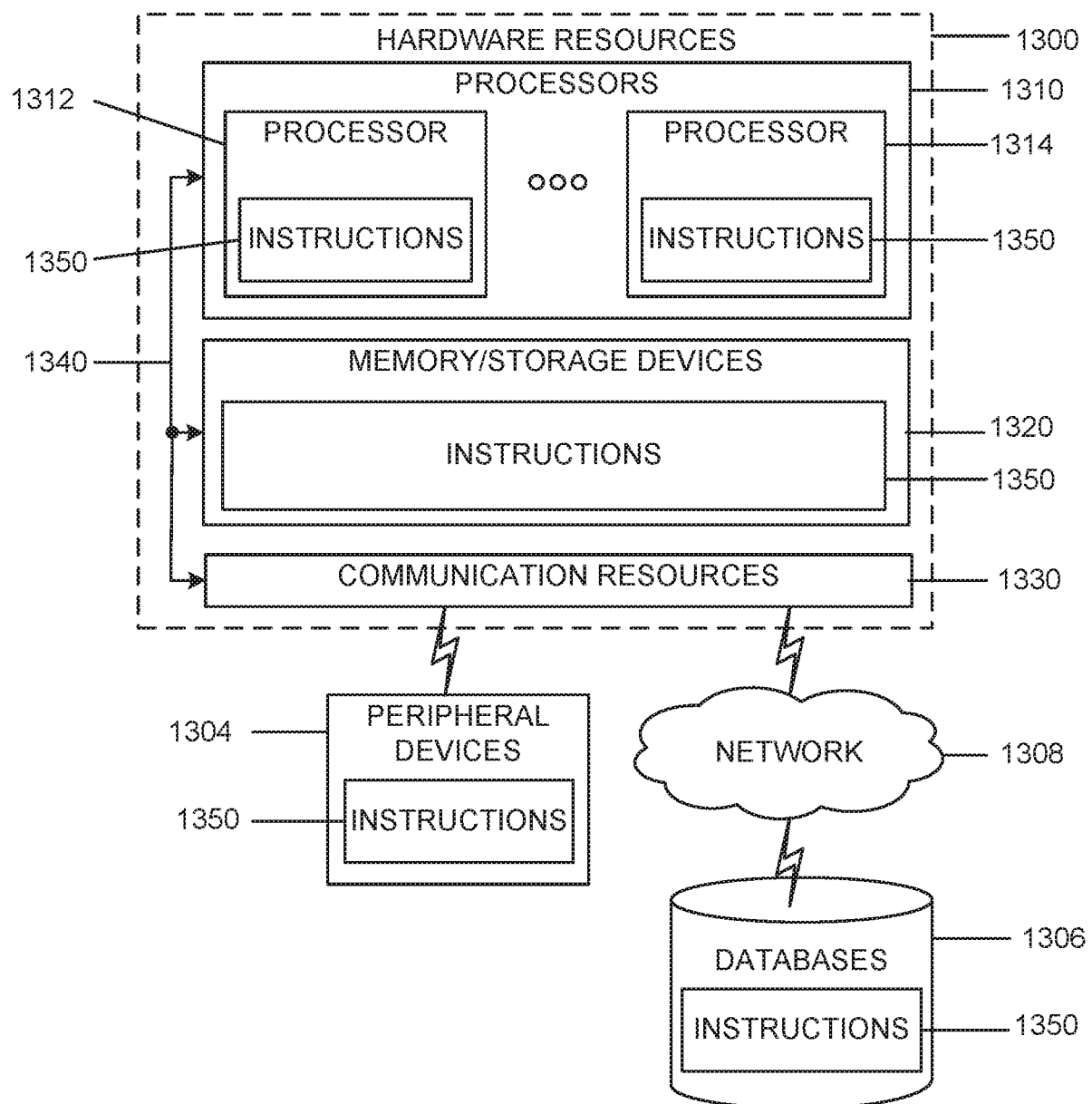


Fig. 12

10/10

**Fig. 13**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/020071

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W16/04
ADD. H04W24/02 H04L12/24 H04L12/715

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)

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)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	"NGMN 5G White Paper V1 0", ETSI DRAFT; NGMN 5G WHITE PAPER V1 0, EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE (ETSI), 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS ; FRANCE, vol. SmartM2M - Open, 25 June 2015 (2015-06-25), pages 1-125, XP014258882, [retrieved on 2015-06-25]	1-4,9, 10, 12-14, 19-27, 29,30
Y	page 46, line 2 - line 8 page 46, line 24 - line 47 page 48, line 26 - line 31 page 96 page 101 page 107 figures 8-9 paragraph 3.2.1 ----- -/-	5-8,11, 15-18,28



Further documents are listed in the continuation of Box C.



See patent family annex.

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"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

6 May 2016

Date of mailing of the international search report

13/05/2016

Name and mailing address of the ISA/

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Fax: (+31-70) 340-3016

Authorized officer

Ruscitto, Alfredo

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/020071

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	----- US 2015/257012 A1 (ZHANG HANG [CA]) 10 September 2015 (2015-09-10) paragraph [0029] paragraph [0031] - paragraph [0034] figures 1,3	5-8,11, 15-18,28
A	----- "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Feasibility Study on New Services and Markets Technology Enablers; Stage 1 (Release 14)", 3GPP DRAFT; S1-151623, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE 23 April 2015 (2015-04-23), XP050961033, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_sa/WG1_Serv/TSGS1_70_Los_Cabos/Docs/ [retrieved on 2015-04-23] paragraph 5.2 paragraph 5.9.3	1-30
A	----- INTEL CORPORATION ET AL: "SMARTER Use case for Bio-connectivity", 3GPP DRAFT; S1-152413 SMARTER EHEALTH V5, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE vol. SA WG1, no. Belgrade, Serbia; 20150817 - 20150821 24 August 2015 (2015-08-24), XP051033561, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_sa/WG1_Serv/TSGS1_71_Belgrade/Docs/ [retrieved on 2015-08-24] the whole document ----- -/--	1-30

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/020071

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	NGMN ALLIANCE: "NGMN 5G P1 Requirements & Architecture Work Stream End-to-End Architecture Description of Network Slicing Concept", 3GPP DRAFT; 160113 NETWORK SLICING V1 0, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , 18 January 2016 (2016-01-18), XP051071947, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_sa/WG2_Arch/TSGS2_113_St_Kitts/Docs/ [retrieved on 2016-01-18] paragraph 4 figure 1 -----	1-30
X,P	"3 rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Feasibility Study on New Services and Markets Technology Enablers; Stage 1 (Release 14)", 3GPP DRAFT; TR22 891-V131-CL, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , 18 February 2016 (2016-02-18), XP051071727, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_sa/WG1_Serv/TSGS1_73_Okinawa/docs/ [retrieved on 2016-02-18] paragraph 5.2 paragraph 5.24 paragraph 5.25 paragraph 5.36 -----	1-30

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/020071

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015257012 A1	10-09-2015	US 2015257012 A1	10-09-2015
		WO 2015134751 A1	11-09-2015
