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(54) **LOGICAL CHANNEL PRIORITIZATION FOR PRE-EMPTION**

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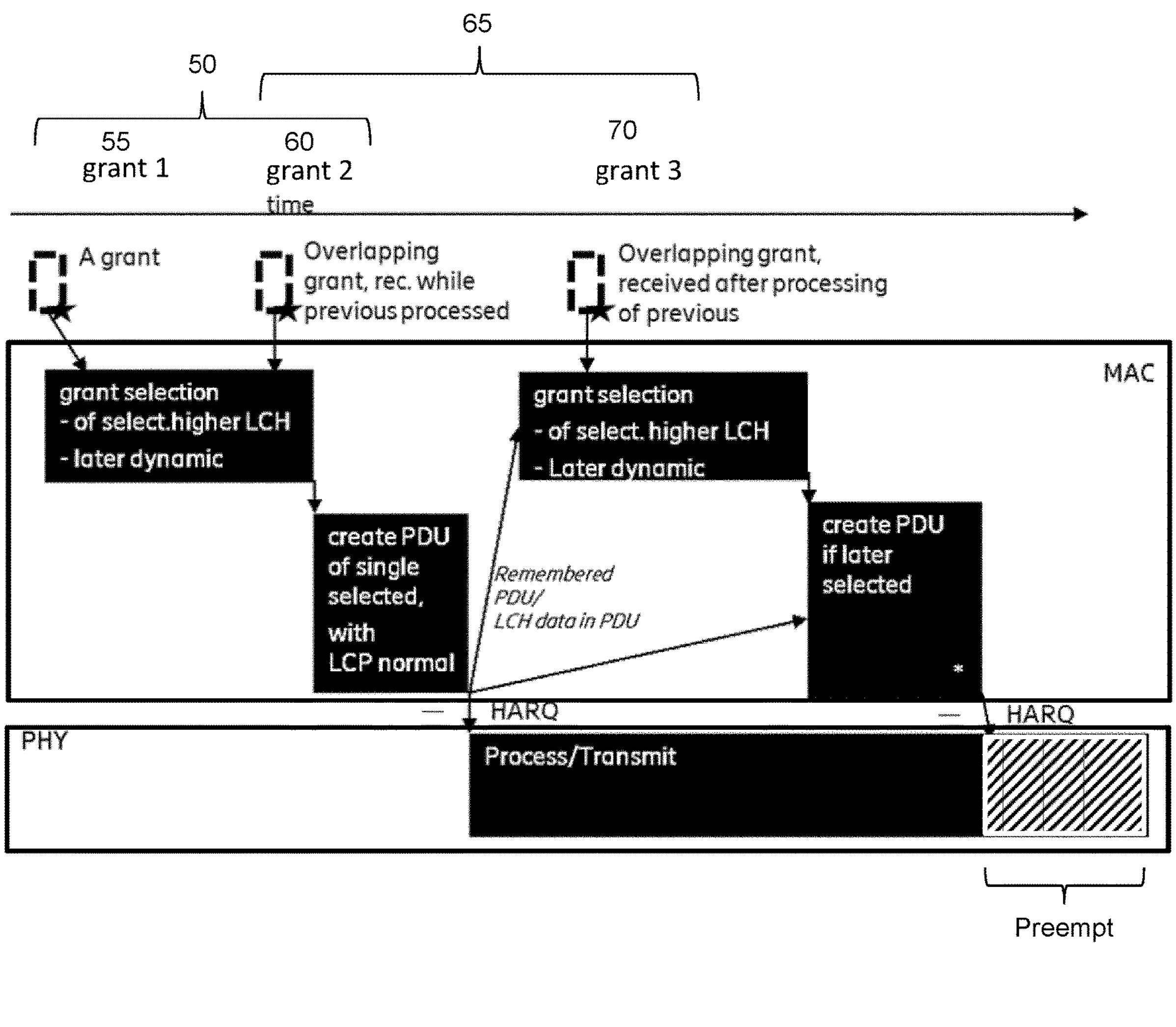
(57) **ABSTRACT**

A method performed by a wireless device includes receiving a first grant of resources from a network node. The first grant of resources is associated with first prioritization information. The wireless device constructs a Medium Access Control Protocol Data Unit, MAC PDU, based on the first grant. A second grant of resources that overlaps with the first grant of resources is received from the network node, and the second grant of resources is associated with second prioritization information. The wireless device determines whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information and pre-empts the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.



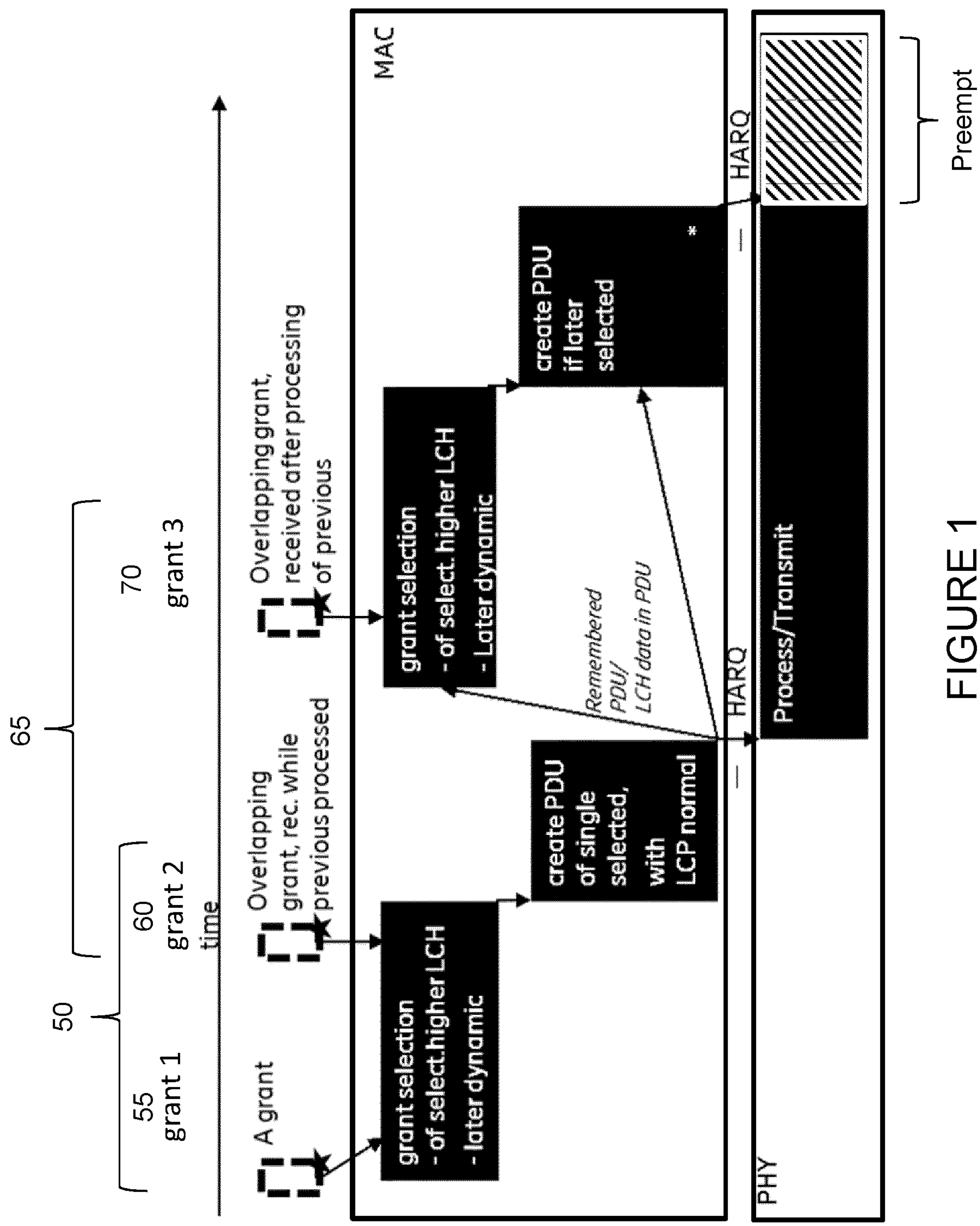

65
50
55
grant 1
60
grant 2
70
grant 3
time
A grant
Overlapping grant, rec. while previous processed
Overlapping grant, received after processing of previous
MAC
grant selection
- of select.higher LCH
- later dynamic
create PDU of single selected, with LCP normal
grant selection
- of select. higher LCH
- Later dynamic
create PDU if later selected
*
Remembered PDU/ LCH data in PDU
HARQ
HARQ
PHY
Process/Transmit
Preempt

FIGURE 1

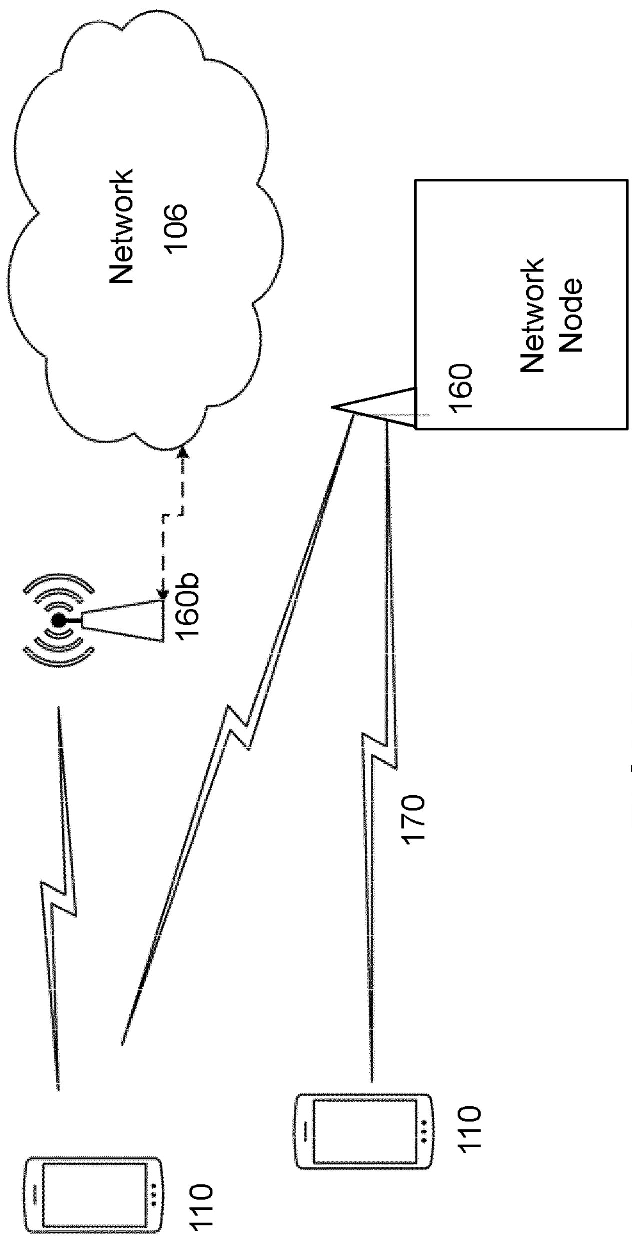


FIGURE 2

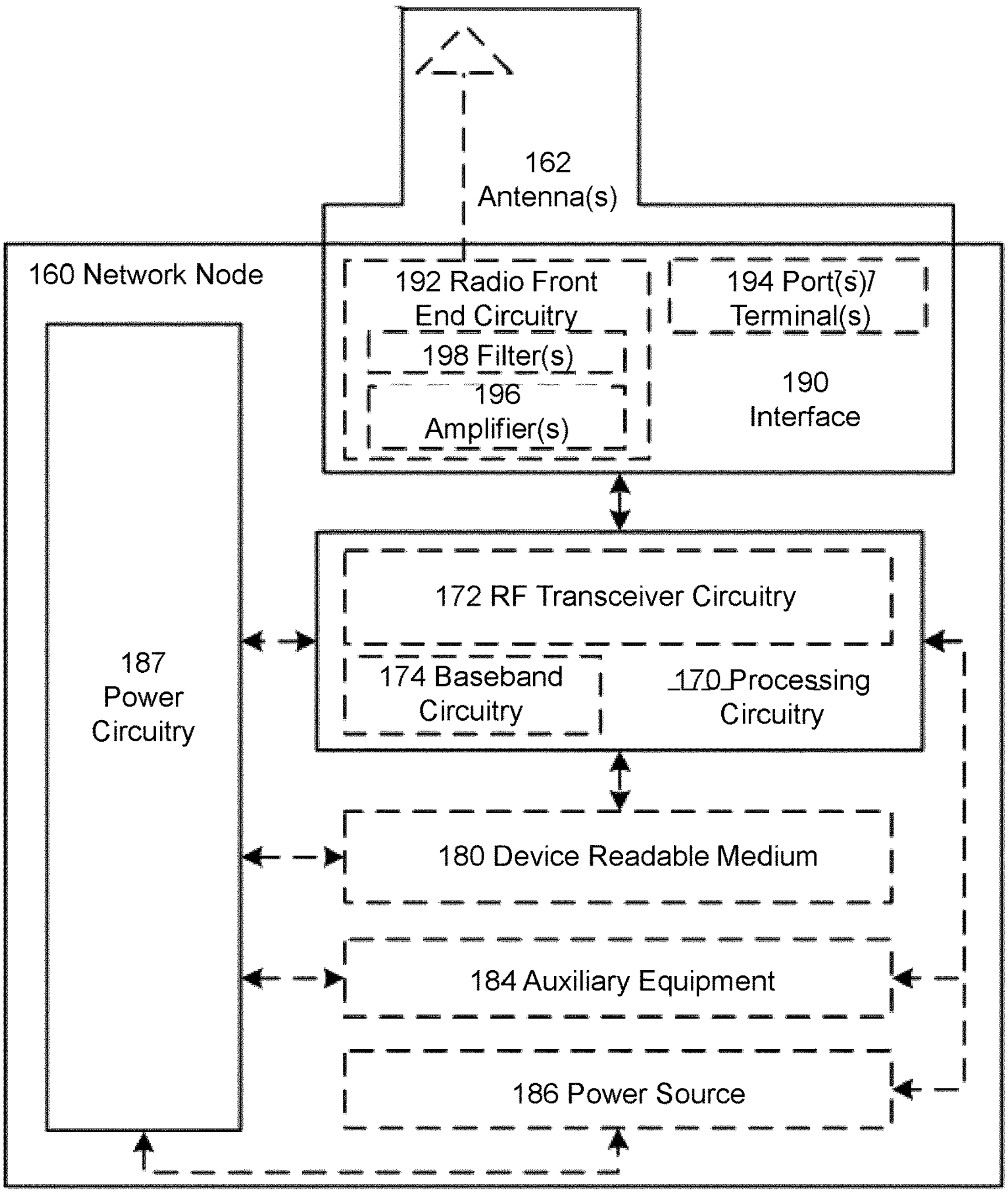

162
Antenna(s)
160 Network Node
192 Radio Front
End Circuitry
198 Filter(s)
196
Amplifier(s)
194 Port(s)/
Terminal(s)
190
Interface
172 RF Transceiver Circuitry
174 Baseband
Circuitry
170 Processing
Circuitry
187
Power
Circuitry
180 Device Readable Medium
184 Auxiliary Equipment
186 Power Source

FIGURE 3

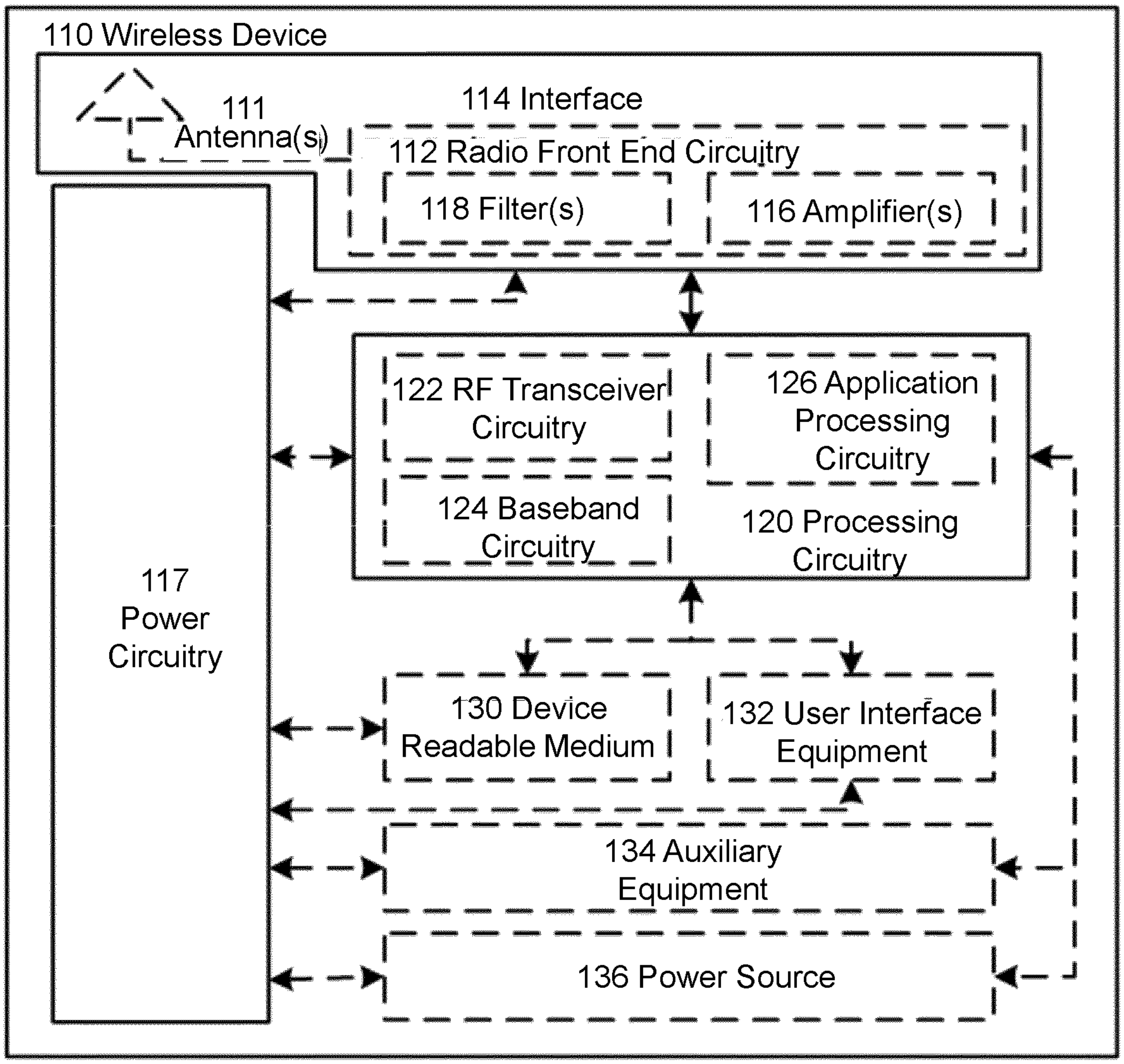

110 Wireless Device
111
Antenna(s)
114 Interface
112 Radio Front End Circuitry
118 Filter(s)
116 Amplifier(s)
122 RF Transceiver Circuitry
126 Application Processing Circuitry
124 Baseband Circuitry
120 Processing Circuitry
117
Power
Circuitry
130 Device Readable Medium
132 User Interface Equipment
134 Auxiliary Equipment
136 Power Source

FIGURE 4

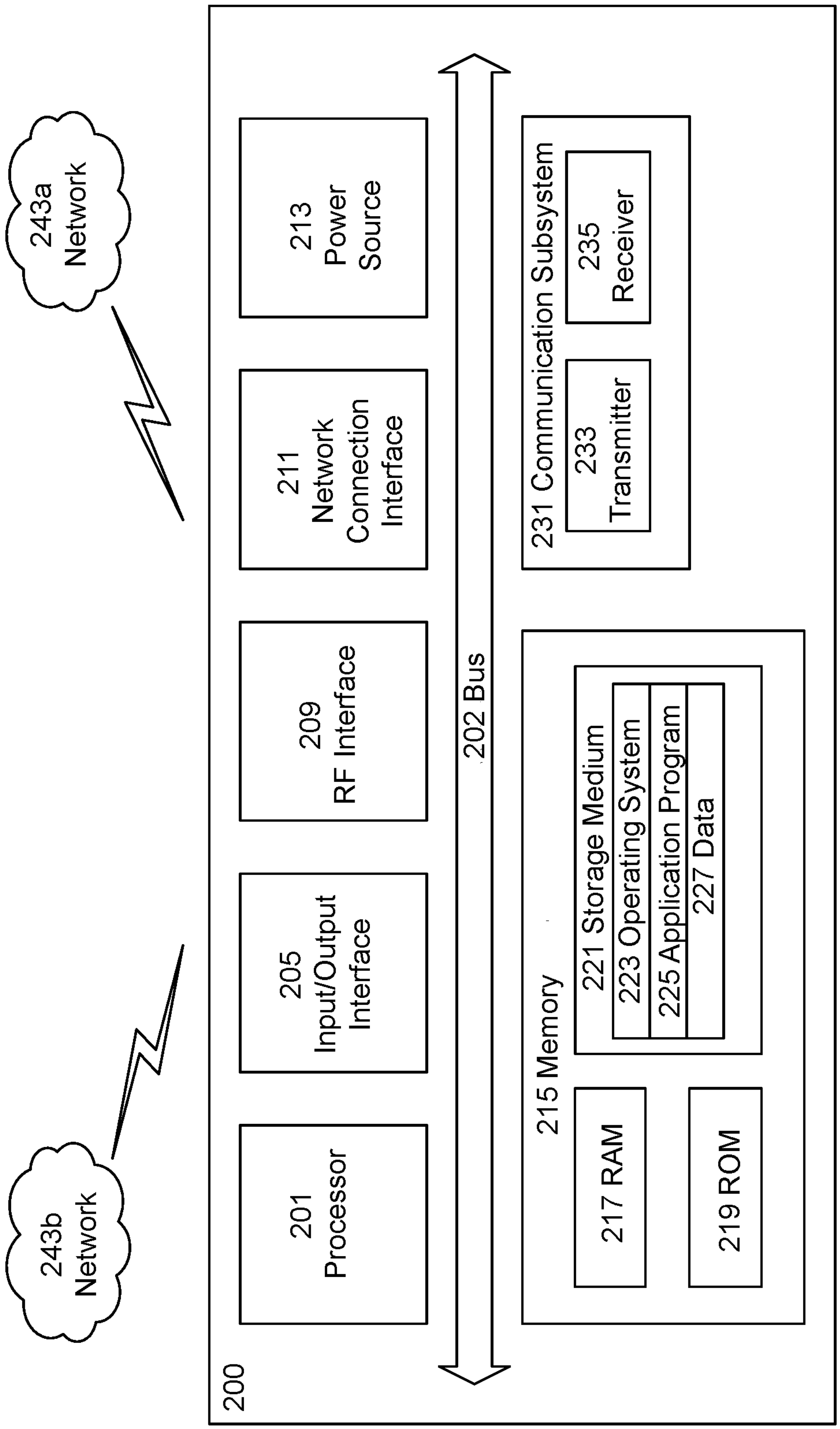

243a Network
243b Network
200
201 Processor
205 Input/Output Interface
209 RF Interface
211 Network Connection Interface
213 Power Source
202 Bus
215 Memory
217 RAM
219 ROM
221 Storage Medium
223 Operating System
225 Application Program
227 Data
231 Communication Subsystem
233 Transmitter
235 Receiver

FIGURE 5

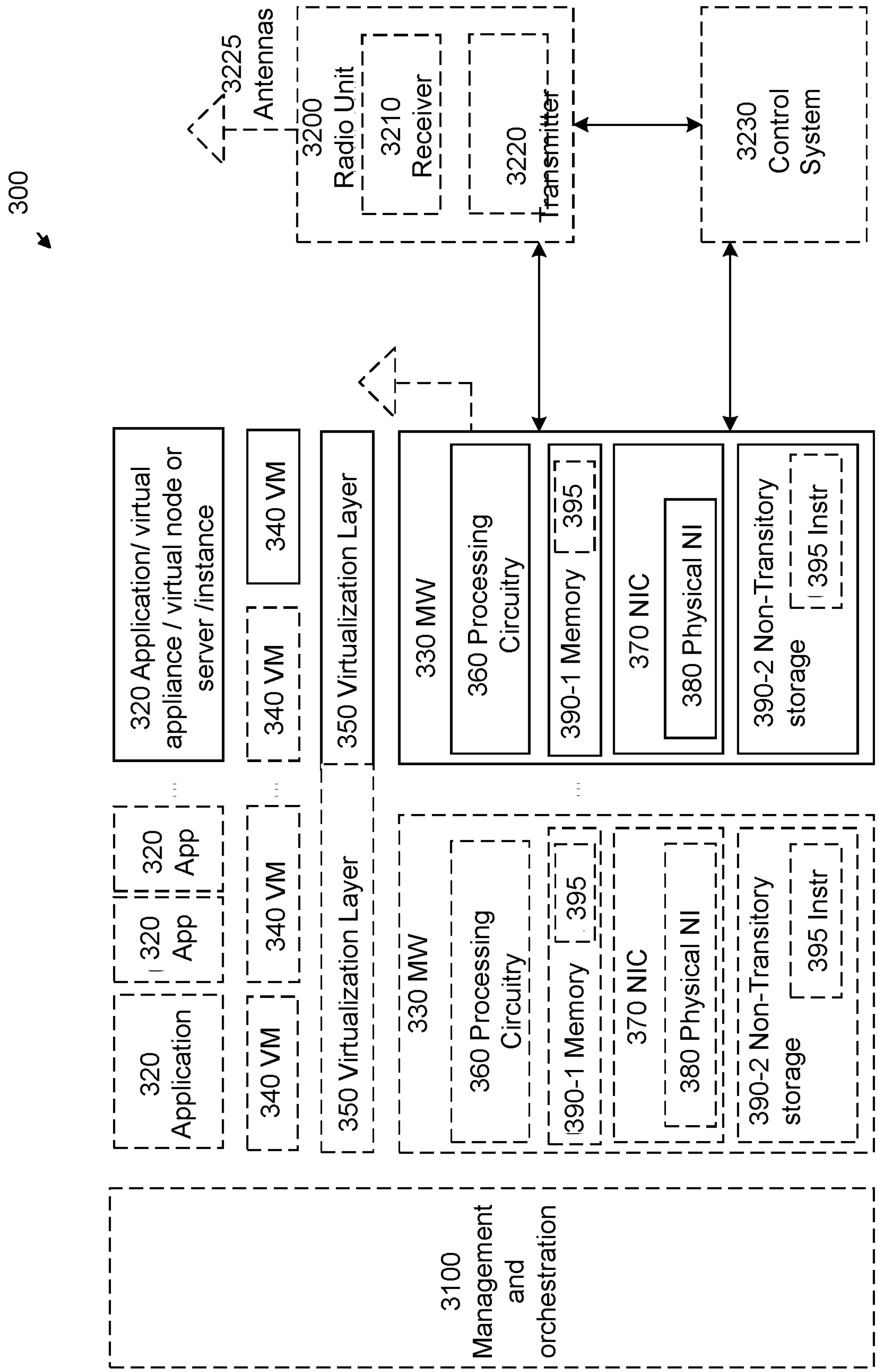

300
3225
Antennas
3200
Radio Unit
3210
Receiver
3220
Transmitter
3230
Control
System
320 Application/ virtual appliance / virtual node or server /instance
340 VM
340 VM
350 Virtualization Layer
330 MW
360 Processing Circuitry
390-1 Memory
395
370 NIC
380 Physical NI
390-2 Non-Transitory storage
395 Instr
320 Application
320 App
320 App
340 VM
340 VM
350 Virtualization Layer
330 MW
360 Processing Circuitry
390-1 Memory
395
370 NIC
380 Physical NI
390-2 Non-Transitory storage
395 Instr
3100
Management
and
orchestration

FIGURE 6

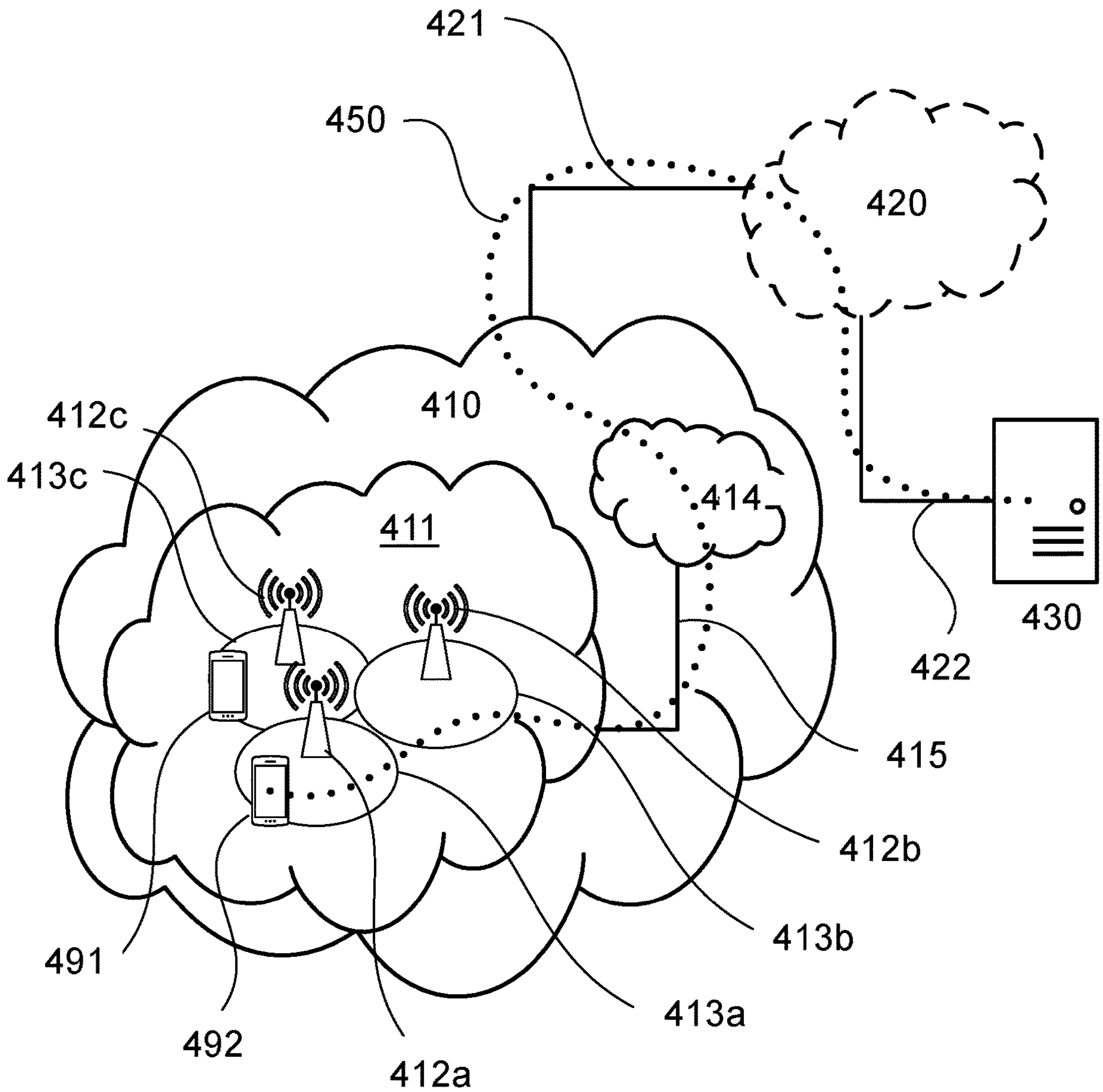

421
450
420
410
412c
413c
414
411
430
422
415
412b
413b
491
413a
492
412a

FIGURE 7

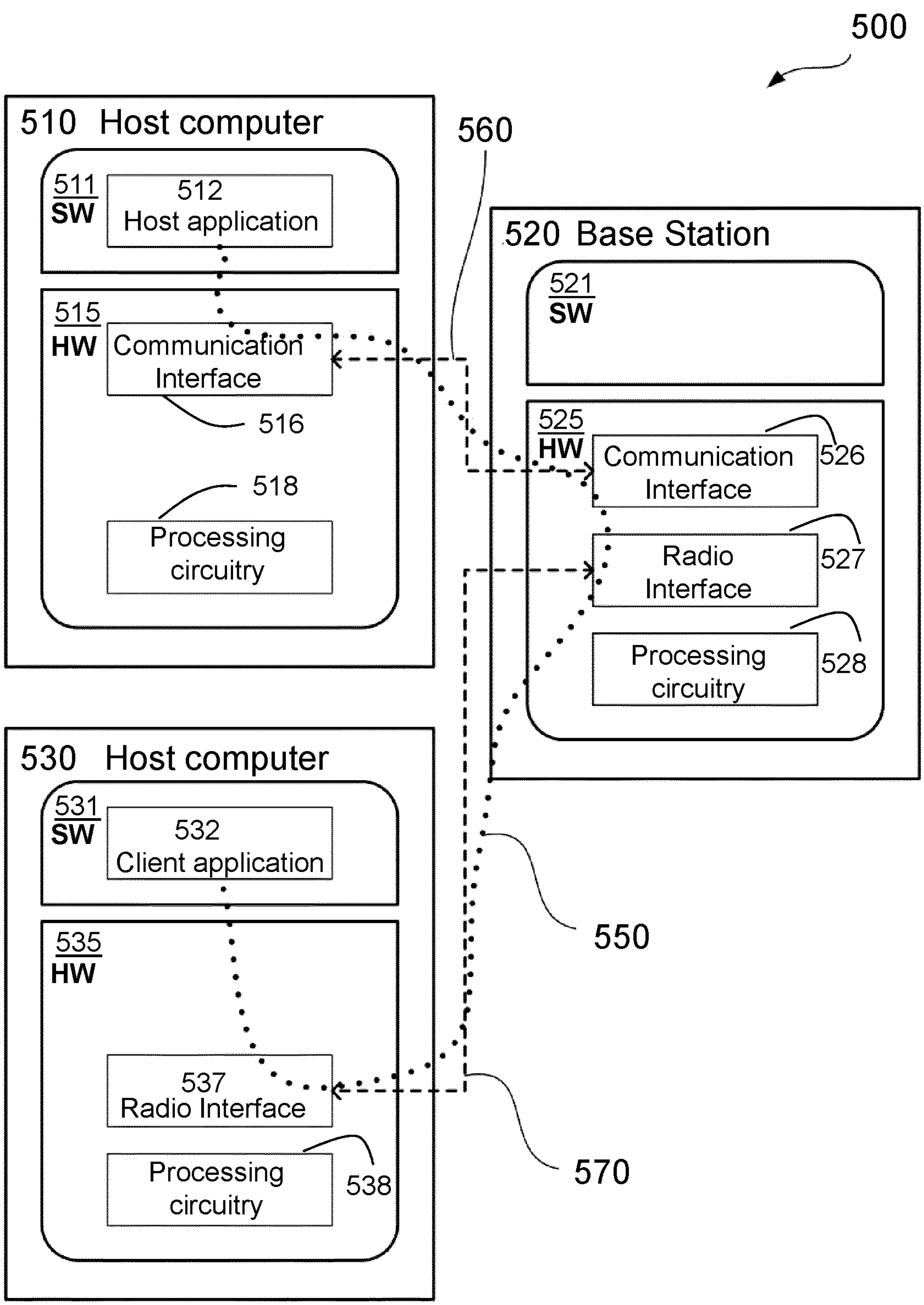

500
510 Host computer
511
SW
512
Host application
515
HW
Communication Interface
516
518
Processing circuitry
560
520 Base Station
521
SW
525
HW
Communication Interface
526
Radio Interface
527
Processing circuitry
528
530 Host computer
531
SW
532
Client application
535
HW
537
Radio Interface
Processing circuitry
538
550
570

FIGURE 8

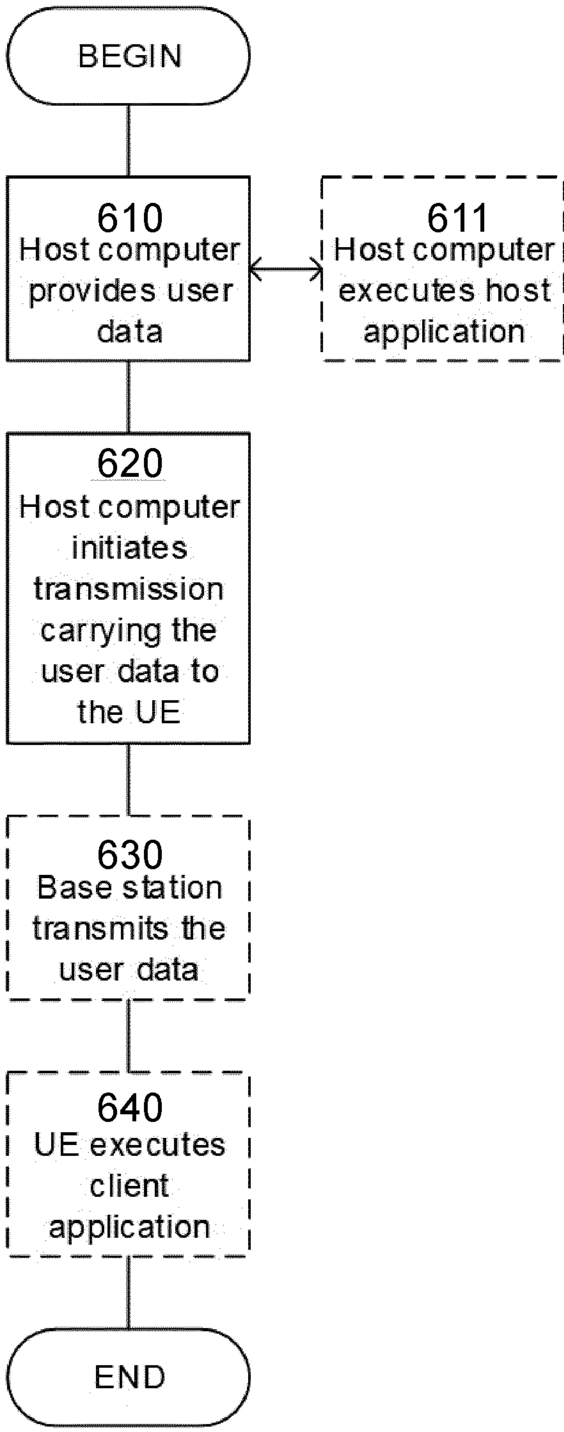


FIGURE 9

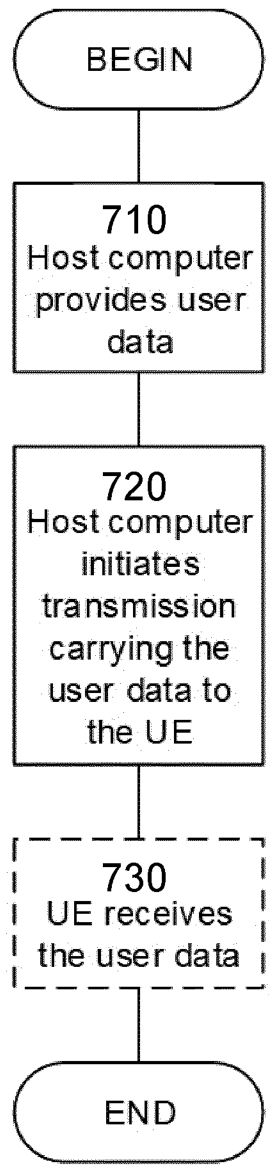


FIGURE 10

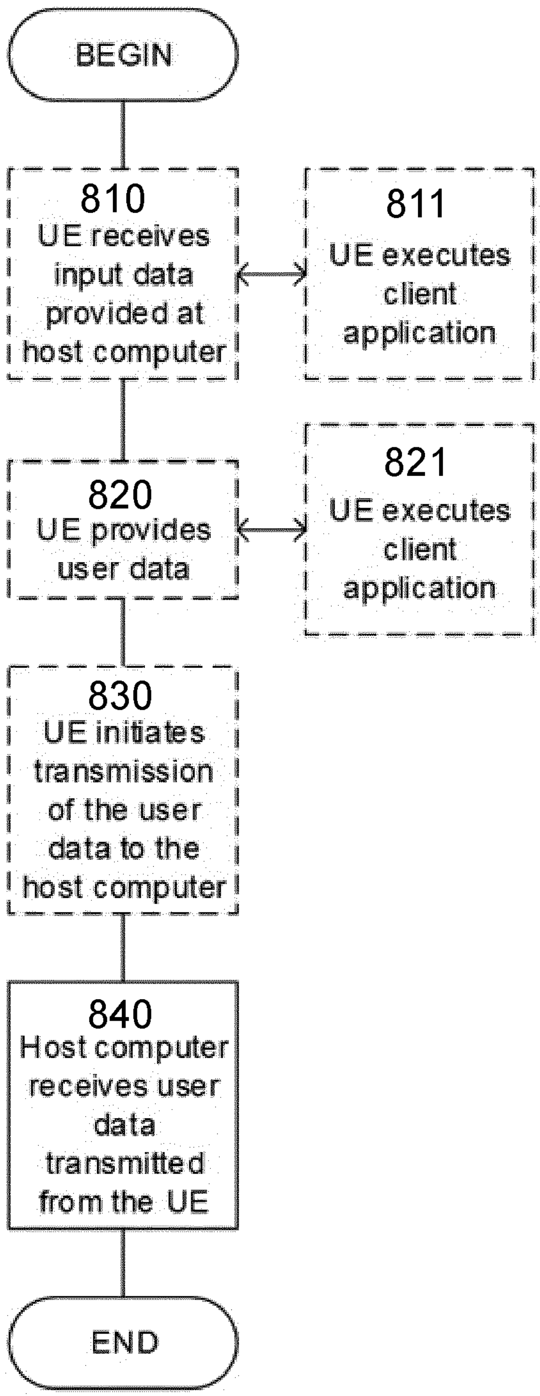


FIGURE 11

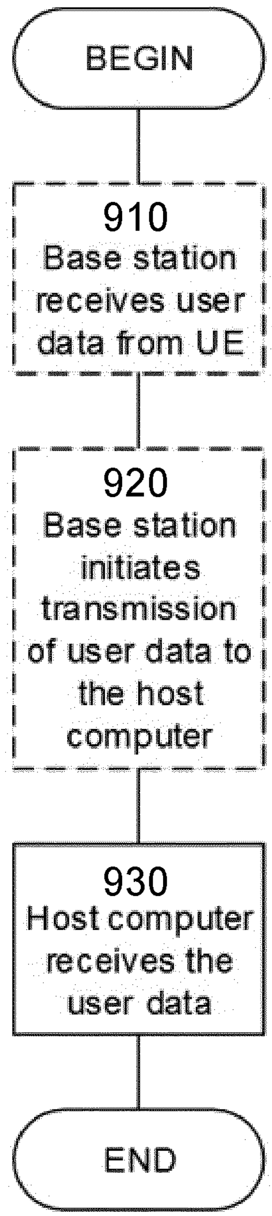


FIGURE 12

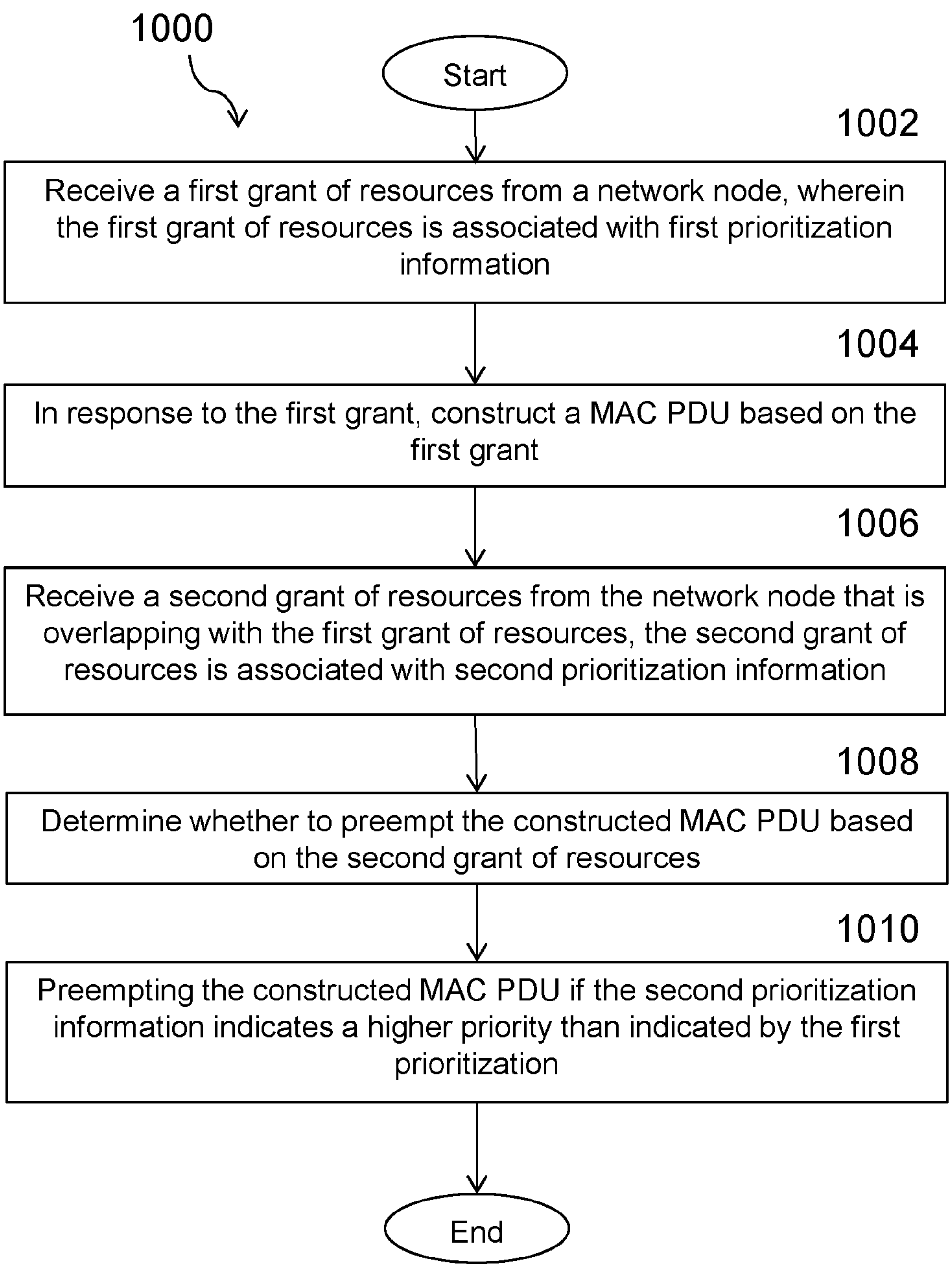

1000
Start
1002
Receive a first grant of resources from a network node, wherein the first grant of resources is associated with first prioritization information
1004
In response to the first grant, construct a MAC PDU based on the first grant
1006
Receive a second grant of resources from the network node that is overlapping with the first grant of resources, the second grant of resources is associated with second prioritization information
1008
Determine whether to preempt the constructed MAC PDU based on the second grant of resources
1010
Preempting the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization
End

FIGURE 13

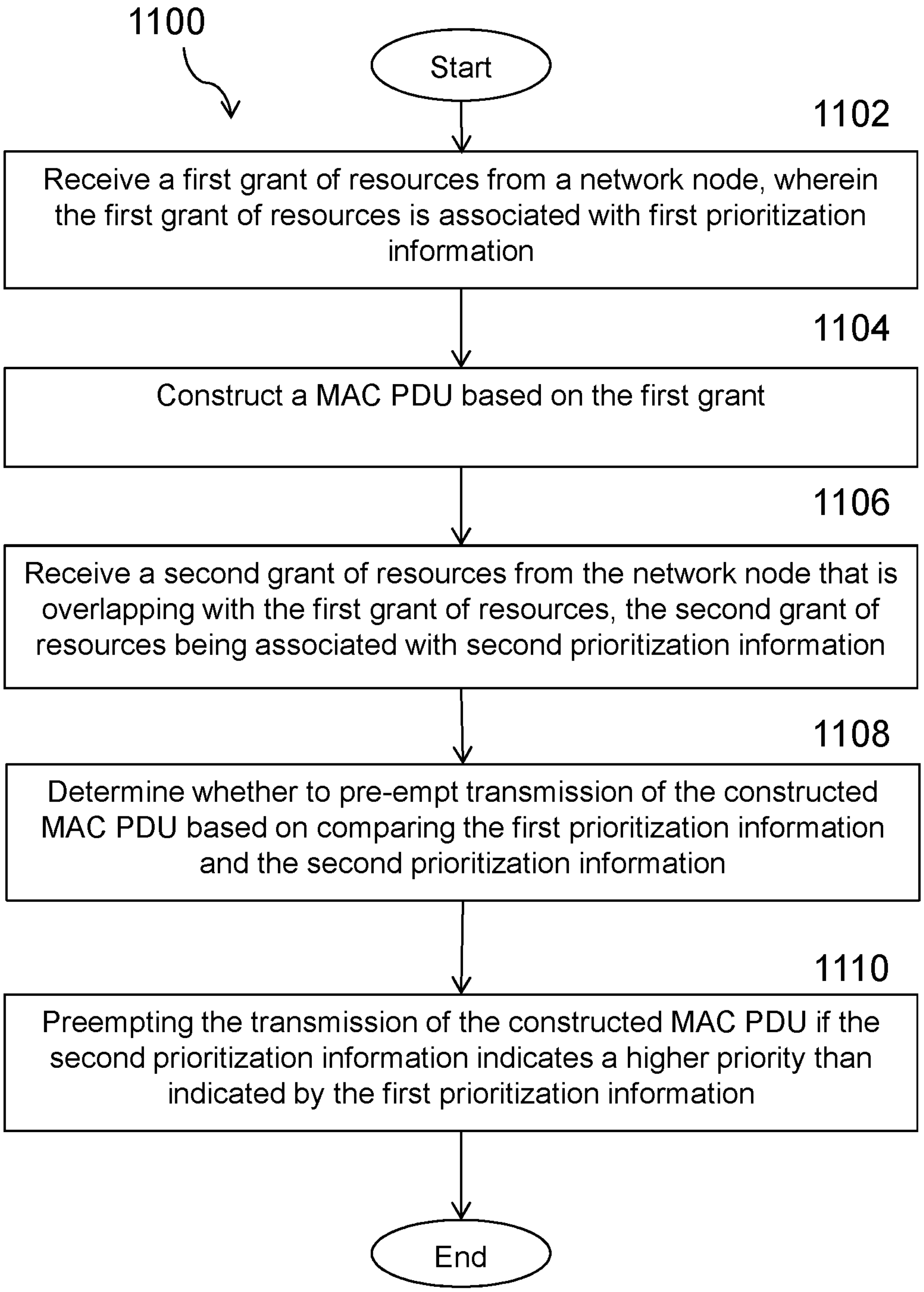

1100
Start
1102
Receive a first grant of resources from a network node, wherein the first grant of resources is associated with first prioritization information
1104
Construct a MAC PDU based on the first grant
1106
Receive a second grant of resources from the network node that is overlapping with the first grant of resources, the second grant of resources being associated with second prioritization information
1108
Determine whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and the second prioritization information
1110
Preempting the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information
End

FIGURE 14

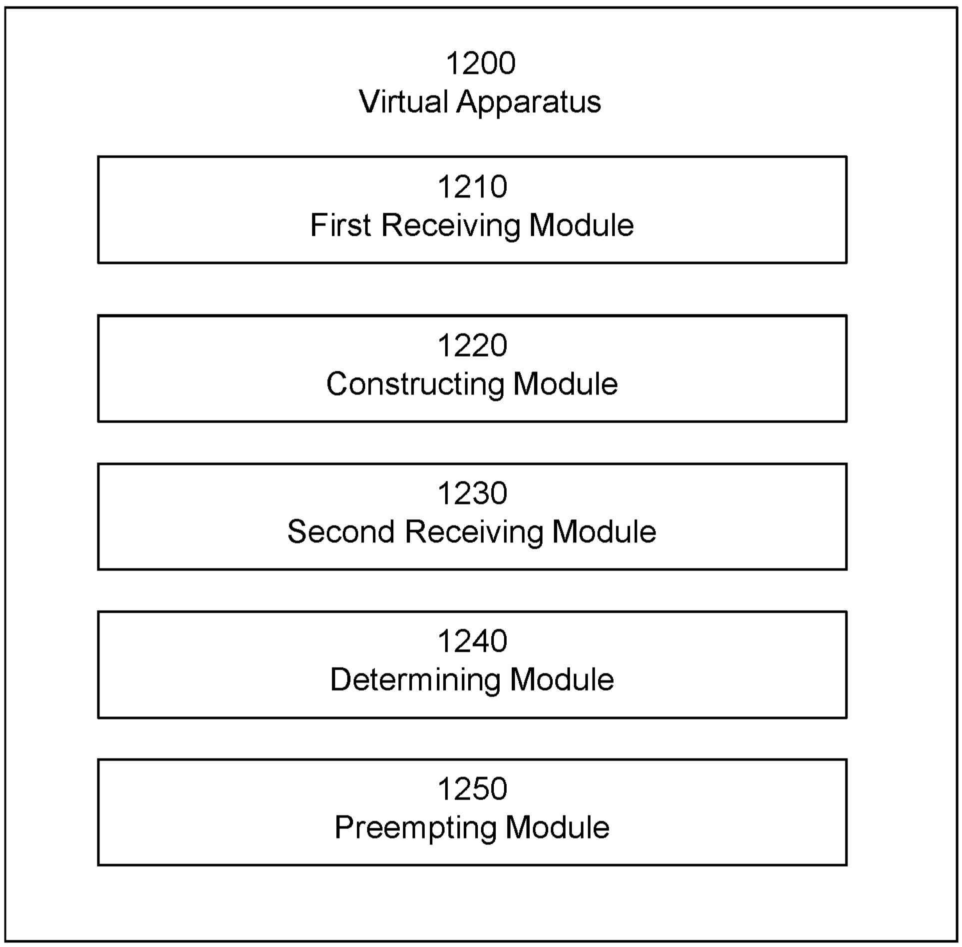

1200
Virtual Apparatus
1210
First Receiving Module
1220
Constructing Module
1230
Second Receiving Module
1240
Determining Module
1250
Preempting Module

FIGURE 15

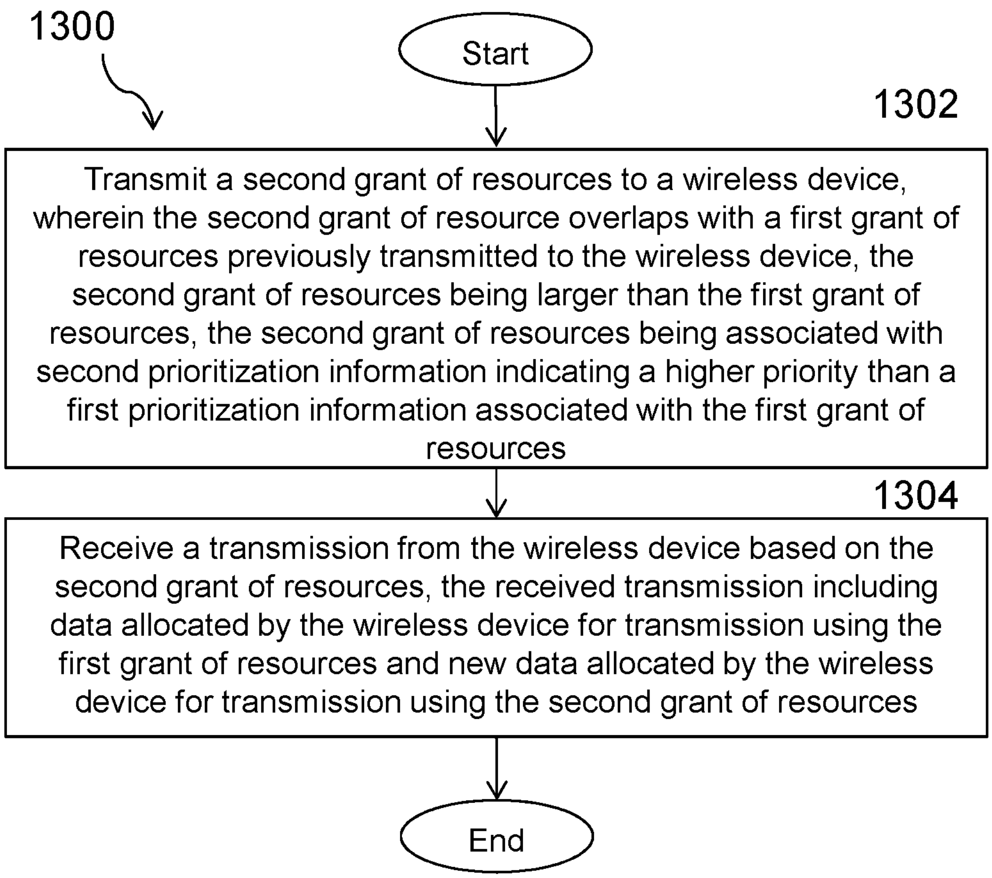


FIGURE 16

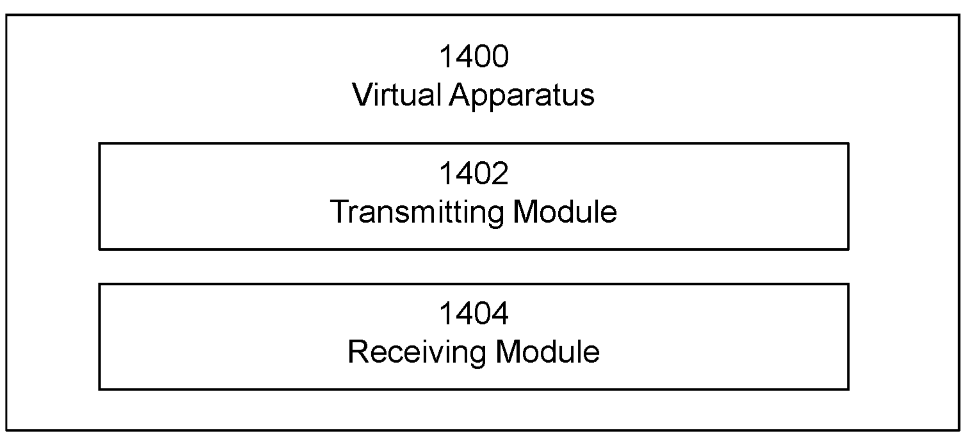


FIGURE 17

LOGICAL CHANNEL PRIORITIZATION FOR PRE-EMPTION

BACKGROUND

[0001] In the 3rd Generation Partnership Project (3GPP) study item, RP-182090, Revised SID: Study on New Radio Industrial Internet of Things (NR-IoT), New Radio (NR) technology enhancements are studied with the target of providing more deterministic low-latency delivery of data. This traffic is also referred to as time sensitive networking (TSN) traffic with typically periodic packet occurrences per cycle time.

[0002] Uplink (UL) traffic can be scheduled with dynamic UL grants or configured UL grants. In case of dynamic grants, a network node such as, for example, a base station such as a NR base station (gNodeB) provides an UL grant to the UE for each UL transmission. By contrast, configured grants are pre-allocated such that the configured grants are provided once to the UE. Thereafter, the configured UL grant is valid for usage for UL transmissions according to a configured periodicity. The UE does not need to transmit padding on those UL resources if no UL data is available for transmission. Rather, the UE may skip an UL transmission on such grants.

[0003] A typical NR-IoT device would handle communication for multiple service types, which may include multiple periodic Ultra-Reliable Low-Latency Communication (URLLC) type robot control messages (also referred to as time-sensitive networking (TSN)-like traffic), URLLC type of occasional alarm signals (for which periodic resources would need to be configured or relying on UE to send scheduling request for each occasional alarm message), occasional sensor data transmission (can be time-critical or non-time-critical), and/or other Enhanced Mobile Broadband (eMBB) or Mobile Broadband (MBB) best-effort type traffic such as occasional video transmissions or software updates. It would lead to a traffic mix to be multiplexed by the UE for UL transmissions on multiple Medium Access Control (MAC) logical channels with different priorities. In such a traffic mix scenario, it is crucial to treat URLLC-type of traffic with high priority.

[0004] The 3GPP study from RP-182090 concluded among other things that it is deemed beneficial to support enhanced prioritization between different intra-UE traffic types and priorities and it is recommended to specify in a later work item phase: Specification of grant prioritization in MAC based on Logical Channel (LCH) priorities and Logical Channel Prioritization (LCP) restrictions for the cases where MAC prioritizes the grant.

[0005] However, there currently exist certain challenges. As discussed above, there are two type of grants, i.e., dynamic UL grants and configured UL grants, which can be allocated to either URLLC traffic or eMBB traffic. The eMBB and URLLC traffic can be periodic or a-periodic. This is further complicated by the need to support multiple periodic URLLC flows where each flow is served by one configured grant. In conclusion, there are many possibilities that the allocated dynamic and/or configured grants might overlap. Yet, there does not exist an overall framework to treat all these cases. Mere guidelines to focus on logical channel prioritization (LCP) restrictions when specifying those decisions as provided in 3GPP are not sufficient to address these challenges. As one example, it is unclear how the UE decides when employing LCP to select among multiple available grants. In particular, it is not clear how the UE decides whether or not to pre-empt an already ongoing transmission according to one of the grants by another grant.

SUMMARY

[0006] Certain aspects of the present disclosure and their embodiments may provide solutions to these or other challenges. According to this disclosure, a wireless device such as a user equipment (UE) may make use of a logical channel prioritization (LCP) based decision for pre-emption of an existing transmission, including taking into account not only new data becoming available in logical channels but also data of logical channels already undergoing transmission. For example, when deciding which new data to multiplex by pre-empting an ongoing transmission (i.e., interrupting an ongoing transmission), the data associated with the pre-empted transmission is not discarded but may be re-considered by the wireless device after the pre-empting transmission is complete.

[0007] According to certain embodiments, a method performed by a wireless device includes receiving a first grant of resources from a network node. The first grant of resources is associated with first prioritization information. The wireless device constructs a Medium Access Control Protocol Data Unit (MAC PDU) based on the first grant. A second grant of resources that overlaps with the first grant of resources is received from the network node, and the second grant of resources is associated with second prioritization information. The wireless device determines whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information and pre-empts the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

[0008] According to certain embodiments, a wireless device includes processing circuitry configured to receive a first grant of resources from a network node. The first grant of resources is associated with first prioritization information. The processing circuitry is configured to construct a MAC PDU based on the first grant. A second grant of resources that overlaps with the first grant of resources is received from the network node, and the second grant of resources is associated with second prioritization information. The processing circuitry is configured to determine whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information and pre-empt the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

[0009] According to certain embodiments, a method performed by a network node includes transmitting a second grant of resources to a wireless device. The second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, and the second grant of resources is larger than the first grant of resources. The second grant of resources is associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources. The network node receives a transmission from the wireless device based on the second grant of resources, and the received transmission includes data allocated by the wireless device for transmission using the first grant of resources and new data allocated by the wireless device for transmission using the second grant of resources.

[0010] According to certain embodiments, a network node includes processing circuitry configured to transmit a second grant of resources to a wireless device. The second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, and the second grant of resources is larger than the first grant of resources. The second grant of resources is associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources. The processing circuitry is configured to receive a transmission from the wireless device based on the second grant of resources, and the received transmission includes data allocated by the wireless device for transmission using the first grant of resources and new data allocated by the wireless device for transmission using the second grant of resources.

[0011] Certain embodiments may provide one or more of the following technical advantages. For example, the UE may prevent wasting any given radio resources and instead utilizes allocated radio resources even when pre-empting an ongoing transmission in order to multiplex logical channel data according to their priority order correctly.

[0012] Other advantages may be readily apparent to one having skill in the art. Certain embodiments may have none, some, or all of the recited advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] For a more complete understanding of the disclosed embodiments and their features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

[0014] FIG. **1** illustrates scenarios where multiple uplink (UL) grants have overlapping resources, according to certain embodiments;

[0015] FIG. **2** illustrates an example wireless network, according to certain embodiments;

[0016] FIG. **3** illustrates an example network node, according to certain embodiments;

[0017] FIG. **4** illustrates an example wireless device, according to certain embodiments;

[0018] FIG. **5** illustrate an example user equipment, according to certain embodiments;

[0019] FIG. **6** illustrates a virtualization environment in which functions implemented by some embodiments may be virtualized, according to certain embodiments;

[0020] FIG. **7** illustrates a telecommunication network connected via an intermediate network to a host computer, according to certain embodiments;

[0021] FIG. **8** illustrates a generalized block diagram of a host computer communicating via a base station with a user equipment over a partially wireless connection, according to certain embodiments;

[0022] FIG. **9** illustrates a method implemented in a communication system, according to one embodiment;

[0023] FIG. **10** illustrates another method implemented in a communication system, according to one embodiment;

[0024] FIG. **11** illustrates another method implemented in a communication system, according to one embodiment;

[0025] FIG. **12** illustrates another method implemented in a communication system, according to one embodiment;

[0026] FIG. **13** illustrates an example method by a wireless device, according to certain embodiments;

[0027] FIG. **14** illustrates another example method by a wireless device, according to certain embodiments;

[0028] FIG. **15** illustrates an exemplary virtual computing device, according to certain embodiments;

[0029] FIG. **16** illustrates an example method by a network node, according to certain embodiments; and

[0030] FIG. **17** illustrates another exemplary virtual computing device, according to certain embodiments.

DETAILED DESCRIPTION

[0031] Some of the embodiments contemplated herein will now be described more fully with reference to the accompanying drawings. Other embodiments, however, are contained within the scope of the subject matter disclosed herein, the disclosed subject matter should not be construed as limited to only the embodiments set forth herein; rather, these embodiments are provided by way of example to convey the scope of the subject matter to those skilled in the art.

[0032] Generally, all terms used herein are to be interpreted according to their ordinary meaning in the relevant technical field, unless a different meaning is clearly given and/or is implied from the context in which it is used. All references to a/an/the element, apparatus, component, means, step, etc. are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any methods disclosed herein do not have to be performed in the exact order disclosed, unless a step is explicitly described as following or preceding another step and/or where it is implicit that a step must follow or precede another step. Any feature of any of the embodiments disclosed herein may be applied to any other embodiment, wherever appropriate. Likewise, any advantage of any of the embodiments may apply to any other embodiments, and vice versa. Other objectives, features, and advantages of the enclosed embodiments will be apparent from the following description.

[0033] The present disclosure is described within the context of 3rd Generation Partnership Project (3GPP) 5^{th} Generation (5G) New Radio (NR) radio technology as discussed in 3GPP TS 38.300 V15.2.0 (2018 June). It is understood that the problems and solutions described herein are equally applicable to wireless access networks and user-equipments (UEs) implementing other access technologies and standards. Additionally, New Radio (NR) is used as an example technology where the techniques and systems described herein are suitable, and using NR in the description therefore is particularly useful for understanding the problem and solutions solving the problem. However, the disclosure is applicable also to 3GPP Long-Term Evolution (LTE) or 3GPP LTE and NR integration, also denoted as non-standalone NR.

[0034] According to certain embodiments, a method may be provided for use in a UE Medium Access Control (MAC) entity for making a pre-emption decision such as, for example, when there are two or more overlapping grants. Further, a method for multiplexing data associated with a pre-empted transmission (e.g., multiplexing data associated with a transmission that has been targeted for pre-emption) into a pre-empting transmission may also be provided.

[0035] For example, a method in a wireless device may be provided in which the wireless device is able to determine whether to pre-empt a transmission associated with an earlier-received grant based on a later-received overlapping grant. In particular, the wireless device may determine to pre-empt a transmission after a Medium Access Control Protocol Data Unit (MAC PDU) is constructed based on the earlier-received grant and sent to the Physical Layer (PHY). This determination may be based on comparing prioritization information of the first grant and the second grant. In this manner, the grant with the highest priority may be used even if a MAC PDU is already constructed based on the earlier-received grant. In some embodiments, the pre-empting transmission may include multiplexed data meant for the pre-empted transmission associated with the earlier-received grant. Accordingly, the UE may reduce wasted resources and unnecessary padding.

[0036] The disclosure herein considers a scenario where multiple uplink (UL) grants with overlapping resources are available in the UE. The UL grants can be configured UL grants or dynamic UL grants in any combination. According to certain embodiments, two cases may be differentiated:

- **[0037]** Scenario 1: In a first set of examples, the MAC PDU of the pre-empted transmission has not been built, or is able to be re-built, when a second UL grant is received and processed. This can happen when knowledge of overlapping grants and their respective user data is available for processing in MAC before construction of the MAC PDU is initiated (e.g., the MAC has enough time prior to the start of transmission to decide what data to prioritize and formulate the corresponding MAC PDU). This may also occur when data for a grant becomes available when the MAC PDU corresponding to another grant has been submitted to the physical layer for transmission, but transmission has not yet started and it is possible to re-build that MAC PDU.
- **[0038]** Scenario 2: In a second set of examples, the MAC PDU of the pre-empted transmission has been built and submitted (to PHY) and therefore cannot be re-built (e.g., the transmission might have started), when a second UL grant is received and processed.

[0039] FIG. **1** illustrates scenarios where multiple UL grants include overlapping resources with the first scenario **50** being illustrated using the first two received grants **55** and **60** and the second scenario **65** being illustrated using the last two received grants **60** and **70**.

[0040] According to certain embodiments, in response to the UE receiving an UL grant where there is an overlap of resources with a previously received grant, the UE may select among the grants according to certain rules. For example, in a particular embodiment, if both grants are of type dynamic grant, the UE may always select the later grant as a rule and/or configuration. If, however, the grants are not both dynamic grants, the grant may be selected according to a grant selection procedure. For example, in a particular embodiment, the grant may be selected based on which type of resources the data of the logical channel with the highest priority is allowed to be transmitted on. For instance, it may involve considering logical channel transmission restrictions such as, for example, on grant type, duration, reliability, and other logical channel transmission restrictions.

[0041] The techniques described herein may apply to any scenario for any two overlapping UL grants (including dynamic versus dynamic, configured versus configured, and configured versus dynamic). Accordingly, the techniques discussed within may also consider the case of two overlapping dynamic grants.

[0042] According to a first set of example embodiments (based on scenario 1 discussed above in which the MAC PDU of the pre-empted transmission has not been built or can be re-built), the UE discards any ongoing MAC PDU building (or delays the start of MAC PDU building) related to the first grant (grant 1) after receiving the second overlapping grant (grant 2). Then, both grants (grants 1 and 2) are processed, assuming all available data can be multiplexed on it, and considering LCP restrictions such as the grant type, duration, and reliability. For example, the grant with a higher priority logical channel may have a higher priority, while the other grant is discarded. According to certain embodiments, if both grants have the same highest priority, the grant with the larger transport block (TB) size may be selected, while the other may be discarded.

[0043] According to a second set of example embodiments (based on scenario 2 discussed above in which the MAC PDU of the pre-empted transmission cannot be rebuilt such as, for example, because it has already been submitted to the physical layer), the MAC evaluation process for determining if the new data is to be prioritized also considers logical channels corresponding to the data in the already submitted MAC PDU, e.g., the MAC PDU created for grant 2. In particular, the MAC entity may remember the logical channel data, logical channels or logical channel priority of all or at least the highest priority logical channel for the data included in the MAC PDU that was already created (and/or submitted to PHY), according to certain embodiments. This may allow the MAC to evaluate the already submitted MAC PDU for grant 1 for possible pre-emption in light of the logical channels for which new data has become available for transmission using the further new grant (grant 2). In this manner, the MAC may be able to select between the further new grant (grant 2) and the previous grant (grant 1) according to which the MAC PDU sent to PHY was constructed. For example, in some embodiments, the priority of the logical channel data allowed to be transmitted on the further new grant (grant 2) and the priority of the highest priority logical channel data actually included in the MAC PDU already sent to PHY (grant 1) are compared and a prioritization decision is made by LCP.

[0044] According to another set of example embodiments (based on scenario 2 discussed above in which the MAC PDU of the pre-empted transmission cannot be rebuilt such as, for example, because the MAC PDU has already been submitted to the physical layer, the MAC logical channel prioritization (LCP) procedure not only considers the new logical channel data, but also logical channel data included within the MAC PDU already submitted to PHY (i.e. if resources available for transmission of the already submitted MAC PDU per grant 1 overlap with resources available for transmitting the new logical channel data per grant 2).

[0045] The decision during LCP to consider a logical channel data for which transmission was already started or at least submitted to PHY for transmission on the previously received grant can, for example, be based on detecting a new grant (grant 2) such as, for example, in a Physical Downlink Control Channel (PDCCH) occasion where grant 2 includes an UL time resource with a starting point (e.g. symbol offset) that occurs later than the start of the grant 1's UL Physical Uplink Shared Channel (PUSCH), but has a time duration that partially overlaps with that of grant 1. Accordingly, grant 2 may be considered overlapping with grant 1 if it meets this criteria.

[0046] In certain embodiments, the UE may consider the multiplexed (or not multiplexed) data on the pre-empted PUSCH when multiplexing the MAC control element (CE) for the pre-empting PUSCH. For example, the MAC CE multiplexing into the transmission of new data may be dependent of whether data from previous (pre-empted) transmission is again also multiplexed on the pre-empting transmission. For instance, if data associated with the pre-empted transmission could be multiplexed (all or part of it) into the pre-empting transmission, then a decision about potentially multiplexing a Buffer Status Report (BSR) MAC CE on the pre-empting transmission may be made taking into account the buffer status after multiplexing all or part of the data associated with the pre-empted transmission.

[0047] According to certain other embodiments, if the pre-empted resources corresponding to the first configured grant configuration (grant 1) were supposed to include the confirmation MAC CE, then a confirmation MAC CE pointing to the pre-empted confirmation MAC CE (i.e. referring to the same HARQ process ID as the pre-empted confirmation MAC CE) should be included in the MAC PDU sent using the resources associated with the pre-empting grant (grant 2).

[0048] According to still other embodiments, given that the HARQ process ID (HARQ PID) associated with the pre-empting grant (grant 2) is different than that of the pre-empted one (grant 1), the UE should expect the Hybrid Automatic Repeat Request (HARQ) feedback of the later transmission to inform the UE about the previous (pre-empted) data multiplexed on grant 2. Upon reception of ACK for the PID associated with grant 2, the UE may flush also the earlier HARQ process buffer in the case that all of its content was sent on the pre-empting transmission.

[0049] According to certain alternative embodiments, if the logical channel data included within a Medium Access Control Protocol Data Unit (MAC PDU) already submitted to PHY is a re-transmission of the logical channel data included in a previously built MAC PDU, then that logical channel data is not considered in the logical channel prioritization (LCP) procedure. A non-limiting example is provided below:

- **[0050]** Logical channel H has higher priority than logical channel L
- **[0051]** 100 byte of data of L were submitted in a PDU according to a previous uplink grant.
- **[0052]** Now, a new grant is received, overlapping with resources of the previous grant, on which H is allowed to transmit on, and H has 100 byte data available in this moment.

[0053] Therefore, according to certain embodiments, a PDU according to grant 2 should be constructed and submitted to PHY, and even including pre-empting the transmission (if a MAC PDU is already constructed and sent to PHY) according to grant 1. This results because the logical channel data H has higher priority than previously submitted data L.

[0054] Consider the situation where grant 2 has a size of 200 bytes.

According to certain embodiments, beside prioritizing the 100 byte data of H, the remaining space of the selected grant is utilized for the previously submitted data of L, i.e. 100 byte as considered in the LCP procedure.

[0055] From the example described above, certain advantages become clear. In particular, that data (or parts of it) of a pre-empted transmission need not be lost because it may be included in the pre-empting transmission. Moreover, if there is room in this pre-empting transmission, the space is not wasted such as, for example, by including padding, but instead the remaining MAC PDU space is filled up with the otherwise lost pre-empted data. As a result, a network node such as a gNB, for example, is provided additional scheduling flexibility to replace grants by larger grants without increase the amount of lost data or reissuance of grants.

[0056] FIG. **2** illustrates an example wireless network, in accordance with some embodiments. Although the subject matter described herein may be implemented in any appropriate type of system using any suitable components, the embodiments disclosed herein are described in relation to a wireless network, such as the example wireless network illustrated in FIG. **2**. For simplicity, the wireless network of FIG. **2** only depicts network **106**, network nodes **160** and **160***b*, and wireless devices **110**, **110***b*, and **110***c*. In practice, a wireless network may further include any additional elements suitable to support communication between wireless devices or between a wireless device and another communication device, such as a landline telephone, a service provider, or any other network node or end device. Of the illustrated components, network node **160** and wireless device **110** are depicted with additional detail. The wireless network may provide communication and other types of services to one or more wireless devices to facilitate the wireless devices' access to and/or use of the services provided by, or via, the wireless network.

[0057] The wireless network may comprise and/or interface with any type of communication, telecommunication, data, cellular, and/or radio network or other similar type of system. In some embodiments, the wireless network may be configured to operate according to specific standards or other types of predefined rules or procedures. Thus, particular embodiments of the wireless network may implement communication standards, such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), and/or other suitable 2G, 3G, 4G, or 5G standards; wireless local area network (WLAN) standards, such as the IEEE 802.11 standards; and/or any other appropriate wireless communication standard, such as the Worldwide Interoperability for Microwave Access (WiMax), Bluetooth, Z-Wave and/or ZigBee standards.

[0058] Network **106** may comprise one or more backhaul networks, core networks, IP networks, public switched telephone networks (PSTNs), packet data networks, optical networks, wide-area networks (WANs), local area networks (LANs), wireless local area networks (WLANs), wired networks, wireless networks, metropolitan area networks, and other networks to enable communication between devices.

[0059] Network node **160** and wireless device **110** comprise various components described in more detail below. These components work together in order to provide network node and/or wireless device functionality, such as providing wireless connections in a wireless network. In different embodiments, the wireless network may comprise any number of wired or wireless networks, network nodes, base stations, controllers, wireless devices, relay stations, and/or any other components or systems that may facilitate or participate in the communication of data and/or signals whether via wired or wireless connections.

[0060] FIG. **3** illustrates an example network node **160**, according to certain embodiments. As used herein, network node refers to equipment capable, configured, arranged and/or operable to communicate directly or indirectly with a wireless device and/or with other network nodes or equipment in the wireless network to enable and/or provide wireless access to the wireless device and/or to perform other functions (e.g., administration) in the wireless network. Examples of network nodes include, but are not limited to, access points (APs) (e.g., radio access points), base stations (BSs) (e.g., radio base stations, Node Bs, evolved Node Bs (eNBs) and NR NodeBs (gNBs)). Base stations may be categorized based on the amount of coverage they provide (or, stated differently, their transmit power level) and may then also be referred to as femto base stations, pico base stations, micro base stations, or macro base stations. A base station may be a relay node or a relay donor node controlling a relay. A network node may also include one or more (or all) parts of a distributed radio base station such as centralized digital units and/or remote radio units (RRUs), sometimes referred to as Remote Radio Heads (RRHs). Such remote radio units may or may not be integrated with an antenna as an antenna integrated radio. Parts of a distributed radio base station may also be referred to as nodes in a distributed antenna system (DAS). Yet further examples of network nodes include multi-standard radio (MSR) equipment such as MSR BSs, network controllers such as radio network controllers (RNCs) or base station controllers (BSCs), base transceiver stations (BTSs), transmission points, transmission nodes, multi-cell/multicast coordination entities (MCEs), core network nodes (e.g., Mobile Switching Centers (MS Cs), Mobile Management Entities (MMEs)), Operations & Maintenance (O&M) nodes, Operations Support System (OSS) nodes, Self Optimizing Network (SON) nodes, positioning nodes (e.g., Evolved-Serving Mobile Location Centers (E-SMLCs)), and/or Minimization of Drive Tests (MDTs). As another example, a network node may be a virtual network node as described in more detail below. More generally, however, network nodes may represent any suitable device (or group of devices) capable, configured, arranged, and/or operable to enable and/or provide a wireless device with access to the wireless network or to provide some service to a wireless device that has accessed the wireless network.

[0061] In FIG. **3**, network node **160** includes processing circuitry **170**, device readable medium **180**, interface **190**, auxiliary equipment **184**, power source **186**, power circuitry **187**, and antenna **162**. Although network node **160** illustrated in the example wireless network of FIG. **3** may represent a device that includes the illustrated combination of hardware components, other embodiments may comprise network nodes with different combinations of components. It is to be understood that a network node comprises any suitable combination of hardware and/or software needed to perform the tasks, features, functions and methods disclosed herein. Moreover, while the components of network node **160** are depicted as single boxes located within a larger box, or nested within multiple boxes, in practice, a network node may comprise multiple different physical components that make up a single illustrated component (e.g., device readable medium **180** may comprise multiple separate hard drives as well as multiple RAM modules).

[0062] Similarly, network node **160** may be composed of multiple physically separate components (e.g., a NodeB component and a RNC component, or a BTS component and a BSC component, etc.), which may each have their own respective components. In certain scenarios in which network node **160** comprises multiple separate components (e.g., BTS and BSC components), one or more of the separate components may be shared among several network nodes. For example, a single RNC may control multiple NodeB's. In such a scenario, each unique NodeB and RNC pair, may in some instances be considered a single separate network node. In some embodiments, network node **160** may be configured to support multiple radio access technologies (RATs). In such embodiments, some components may be duplicated (e.g., separate device readable medium **180** for the different RATs) and some components may be reused (e.g., the same antenna **162** may be shared by the RATs). Network node **160** may also include multiple sets of the various illustrated components for different wireless technologies integrated into network node **160**, such as, for example, GSM, Wide Code Division Multiplexing Access (WCDMA), Long Term Evolution (LTE), New Radio (NR), WiFi, or Bluetooth wireless technologies. These wireless technologies may be integrated into the same or different chip or set of chips and other components within network node **160**.

[0063] Processing circuitry **170** is configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being provided by a network node. These operations performed by processing circuitry **170** may include processing information obtained by processing circuitry **170** by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored in the network node, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

[0064] Processing circuitry **170** may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software and/or encoded logic operable to provide, either alone or in conjunction with other network node **160** components, such as device readable medium **180**, network node **160** functionality. For example, processing circuitry **170** may execute instructions stored in device readable medium **180** or in memory within processing circuitry **170**. Such functionality may include providing any of the various wireless features, functions, or benefits discussed herein. In some embodiments, processing circuitry **170** may include a system on a chip (SOC).

[0065] In some embodiments, processing circuitry **170** may include one or more of radio frequency (RF) transceiver circuitry **172** and baseband processing circuitry **174**. In some embodiments, RF transceiver circuitry **172** and baseband processing circuitry **174** may be on separate chips (or sets of chips), boards, or units, such as radio units and digital units. In alternative embodiments, part or all of RF transceiver circuitry **172** and baseband processing circuitry **174** may be on the same chip or set of chips, boards, or units

[0066] In certain embodiments, some or all of the functionality described herein as being provided by a network node, base station, eNB or other such network device may be performed by processing circuitry **170** executing instructions stored on device readable medium **180** or memory within processing circuitry **170**. In alternative embodiments, some or all of the functionality may be provided by processing circuitry **170** without executing instructions stored on a separate or discrete device readable medium, such as in a hard-wired manner. In any of those embodiments, whether executing instructions stored on a device readable storage medium or not, processing circuitry **170** can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry **170** alone or to other components of network node **160**, but are enjoyed by network node **160** as a whole, and/or by end users and the wireless network generally.

[0067] Device readable medium **180** may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid-state memory, remotely mounted memory, magnetic media, optical media, random access memory (RAM), read-only memory (ROM), mass storage media (for example, a hard disk), removable storage media (for example, a flash drive, a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer-executable memory devices that store information, data, and/or instructions that may be used by processing circuitry **170**. Device readable medium **180** may store any suitable instructions, data or information, including a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions capable of being executed by processing circuitry **170** and, utilized by network node **160**. Device readable medium **180** may be used to store any calculations made by processing circuitry **170** and/or any data received via interface **190**. In some embodiments, processing circuitry **170** and device readable medium **180** may be considered to be integrated.

[0068] Interface **190** is used in the wired or wireless communication of signalling and/or data between network node **160**, network **106**, and/or wireless devices **110**. As illustrated, interface **190** comprises port(s)/terminal(s) **194** to send and receive data, for example to and from network **106** over a wired connection. Interface **190** also includes radio front end circuitry **192** that may be coupled to, or in certain embodiments a part of, antenna **162**. Radio front end circuitry **192** comprises filters **198** and amplifiers **196**. Radio front end circuitry **192** may be connected to antenna **162** and processing circuitry **170**. Radio front end circuitry may be configured to condition signals communicated between antenna **162** and processing circuitry **170**. Radio front end circuitry **192** may receive digital data that is to be sent out to other network nodes or wireless devices via a wireless connection. Radio front end circuitry **192** may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters **198** and/or amplifiers **196**. The radio signal may then be transmitted via antenna **162**. Similarly, when receiving data, antenna **162** may collect radio signals which are then converted into digital data by radio front end circuitry **192**. The digital data may be passed to processing circuitry **170**. In other embodiments, the interface may comprise different components and/or different combinations of components.

[0069] In certain alternative embodiments, network node **160** may not include separate radio front end circuitry **192**, instead, processing circuitry **170** may comprise radio front end circuitry and may be connected to antenna **162** without separate radio front end circuitry **192**. Similarly, in some embodiments, all or some of RF transceiver circuitry **172** may be considered a part of interface **190**. In still other embodiments, interface **190** may include one or more ports or terminals **194**, radio front end circuitry **192**, and RF transceiver circuitry **172**, as part of a radio unit (not shown), and interface **190** may communicate with baseband processing circuitry **174**, which is part of a digital unit (not shown).

[0070] Antenna **162** may include one or more antennas, or antenna arrays, configured to send and/or receive wireless signals. Antenna **162** may be coupled to radio front end circuitry **190** and may be any type of antenna capable of transmitting and receiving data and/or signals wirelessly. In some embodiments, antenna **162** may comprise one or more omni-directional, sector or panel antennas operable to transmit/receive radio signals between, for example, 2 GHz and 66 GHz. An omni-directional antenna may be used to transmit/receive radio signals in any direction, a sector antenna may be used to transmit/receive radio signals from devices within a particular area, and a panel antenna may be a line of sight antenna used to transmit/receive radio signals in a relatively straight line. In some instances, the use of more than one antenna may be referred to as MIMO. In certain embodiments, antenna **162** may be separate from network node **160** and may be connectable to network node **160** through an interface or port.

[0071] Antenna **162**, interface **190**, and/or processing circuitry **170** may be configured to perform any receiving operations and/or certain obtaining operations described herein as being performed by a network node. Any information, data and/or signals may be received from a wireless device, another network node and/or any other network equipment. Similarly, antenna **162**, interface **190**, and/or processing circuitry **170** may be configured to perform any transmitting operations described herein as being performed by a network node. Any information, data and/or signals may be transmitted to a wireless device, another network node and/or any other network equipment.

[0072] Power circuitry **187** may comprise, or be coupled to, power management circuitry and is configured to supply the components of network node **160** with power for performing the functionality described herein. Power circuitry **187** may receive power from power source **186**. Power source **186** and/or power circuitry **187** may be configured to provide power to the various components of network node **160** in a form suitable for the respective components (e.g., at a voltage and current level needed for each respective component). Power source **186** may either be included in, or external to, power circuitry **187** and/or network node **160**. For example, network node **160** may be connectable to an external power source (e.g., an electricity outlet) via an input circuitry or interface such as an electrical cable, whereby the external power source supplies power to power circuitry **187**. As a further example, power source **186** may comprise a source of power in the form of a battery or battery pack which is connected to, or integrated in, power circuitry **187**. The battery may provide backup power should the external power source fail. Other types of power sources, such as photovoltaic devices, may also be used.

[0073] Alternative embodiments of network node **160** may include additional components beyond those shown in FIG. **3** that may be responsible for providing certain aspects of the network node's functionality, including any of the functionality described herein and/or any functionality necessary to support the subject matter described herein. For example, network node **160** may include user interface equipment to allow input of information into network node **160** and to allow output of information from network node **160**. This may allow a user to perform diagnostic, maintenance, repair, and other administrative functions for network node **160**.

[0074] FIG. **4** illustrates an example wireless device **110**, according to certain embodiments. As used herein, wireless device refers to a device capable, configured, arranged and/or operable to communicate wirelessly with network nodes and/or other wireless devices. Unless otherwise noted, the term wireless device may be used interchangeably herein with UE. Communicating wirelessly may involve transmitting and/or receiving wireless signals using electromagnetic waves, radio waves, infrared waves, and/or other types of signals suitable for conveying information through air. In some embodiments, a wireless device may be configured to transmit and/or receive information without direct human interaction. For instance, a wireless device may be designed to transmit information to a network on a predetermined schedule, when triggered by an internal or external event, or in response to requests from the network. Examples of a wireless device include, but are not limited to, a smart phone, a mobile phone, a cell phone, a voice over IP (VoIP) phone, a wireless local loop phone, a desktop computer, a personal digital assistant (PDA), a wireless cameras, a gaming console or device, a music storage device, a playback appliance, a wearable terminal device, a wireless endpoint, a mobile station, a tablet, a laptop, a laptop-embedded equipment (LEE), a laptop-mounted equipment (LME), a smart device, a wireless customer-premise equipment (CPE). a vehicle-mounted wireless terminal device, etc. A wireless device may support device-to-device (D2D) communication, for example by implementing a 3GPP standard for sidelink communication, vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-everything (V2X) and may in this case be referred to as a D2D communication device. As yet another specific example, in an Internet of Things (IoT) scenario, a wireless device may represent a machine or other device that performs monitoring and/or measurements, and transmits the results of such monitoring and/or measurements to another wireless device and/or a network node. The wireless device may in this case be a machine-to-machine (M2M) device, which may in a 3GPP context be referred to as an MTC device. As one particular example, the wireless device may be a UE implementing the 3GPP narrow band internet of things (NB-IoT) standard. Particular examples of such machines or devices are sensors, metering devices such as power meters, industrial machinery, or home or personal appliances (e.g. refrigerators, televisions, etc.) personal wearables (e.g., watches, fitness trackers, etc.). In other scenarios, a wireless device may represent a vehicle or other equipment that is capable of monitoring and/or reporting on its operational status or other functions associated with its operation. A wireless device as described above may represent the endpoint of a wireless connection, in which case the device may be referred to as a wireless terminal. Furthermore, a wireless device as described above may be mobile, in which case it may also be referred to as a mobile device or a mobile terminal.

[0075] As illustrated, wireless device **110** includes antenna **111**, interface **114**, processing circuitry **120**, device readable medium **130**, user interface equipment **132**, auxiliary equipment **134**, power source **136** and power circuitry **137**. Wireless device **110** may include multiple sets of one or more of the illustrated components for different wireless technologies supported by wireless device **110**, such as, for example, GSM, WCDMA, LTE, NR, WiFi, WiMAX, or Bluetooth wireless technologies, just to mention a few. These wireless technologies may be integrated into the same or different chips or set of chips as other components within wireless device **110**.

[0076] Antenna **111** may include one or more antennas or antenna arrays, configured to send and/or receive wireless signals, and is connected to interface **114**. In certain alternative embodiments, antenna **111** may be separate from wireless device **110** and be connectable to wireless device **110** through an interface or port. Antenna **111**, interface **114**, and/or processing circuitry **120** may be configured to perform any receiving or transmitting operations described herein as being performed by a wireless device. Any information, data and/or signals may be received from a network node and/or another wireless device. In some embodiments, radio front end circuitry and/or antenna **111** may be considered an interface.

[0077] As illustrated, interface **114** comprises radio front end circuitry **112** and antenna **111**. Radio front end circuitry **112** comprise one or more filters **118** and amplifiers **116**. Radio front end circuitry **114** is connected to antenna **111** and processing circuitry **120**, and is configured to condition signals communicated between antenna **111** and processing circuitry **120**. Radio front end circuitry **112** may be coupled to or a part of antenna **111**. In some embodiments, wireless device **110** may not include separate radio front end circuitry **112**; rather, processing circuitry **120** may comprise radio front end circuitry and may be connected to antenna **111**. Similarly, in some embodiments, some or all of RF transceiver circuitry **122** may be considered a part of interface **114**. Radio front end circuitry **112** may receive digital data that is to be sent out to other network nodes or wireless devices via a wireless connection. Radio front end circuitry **112** may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters **118** and/or amplifiers **116**. The radio signal may then be transmitted via antenna **111**. Similarly, when receiving data, antenna **111** may collect radio signals which are then converted into digital data by radio front end circuitry **112**. The digital data may be passed to processing circuitry **120**. In other embodiments, the interface may comprise different components and/or different combinations of components.

[0078] Processing circuitry **120** may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software, and/or encoded logic operable to provide, either alone or in conjunction with other wireless device **110** components, such as device readable medium **130**, wireless device **110** functionality. Such functionality may include providing any of the various wireless features or benefits discussed herein. For example, processing circuitry **120** may execute instructions stored in device readable medium **130** or in memory within processing circuitry **120** to provide the functionality disclosed herein.

[0079] As illustrated, processing circuitry **120** includes one or more of RF transceiver circuitry **122**, baseband processing circuitry **124**, and application processing circuitry **126**. In other embodiments, the processing circuitry may comprise different components and/or different combinations of components. In certain embodiments processing circuitry **120** of wireless device **110** may comprise a SOC. In some embodiments, RF transceiver circuitry **122**, baseband processing circuitry **124**, and application processing circuitry **126** may be on separate chips or sets of chips. In alternative embodiments, part or all of baseband processing circuitry **124** and application processing circuitry **126** may be combined into one chip or set of chips, and RF transceiver circuitry **122** may be on a separate chip or set of chips. In still alternative embodiments, part or all of RF transceiver circuitry **122** and baseband processing circuitry **124** may be on the same chip or set of chips, and application processing circuitry **126** may be on a separate chip or set of chips. In yet other alternative embodiments, part or all of RF transceiver circuitry **122**, baseband processing circuitry **124**, and application processing circuitry **126** may be combined in the same chip or set of chips. In some embodiments, RF transceiver circuitry **122** may be a part of interface **114**. RF transceiver circuitry **122** may condition RF signals for processing circuitry **120**.

[0080] In certain embodiments, some or all of the functionality described herein as being performed by a wireless device may be provided by processing circuitry **120** executing instructions stored on device readable medium **130**, which in certain embodiments may be a computer-readable storage medium. In alternative embodiments, some or all of the functionality may be provided by processing circuitry **120** without executing instructions stored on a separate or discrete device readable storage medium, such as in a hard-wired manner. In any of those particular embodiments, whether executing instructions stored on a device readable storage medium or not, processing circuitry **120** can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry **120** alone or to other components of wireless device **110**, but are enjoyed by wireless device **110** as a whole, and/or by end users and the wireless network generally.

[0081] Processing circuitry **120** may be configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being performed by a wireless device. These operations, as performed by processing circuitry **120**, may include processing information obtained by processing circuitry **120** by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored by wireless device **110**, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

[0082] Device readable medium **130** may be operable to store a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions capable of being executed by processing circuitry **120**. Device readable medium **130** may include computer memory (e.g., Random Access Memory (RAM) or Read Only Memory (ROM)), mass storage media (e.g., a hard disk), removable storage media (e.g., a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer executable memory devices that store information, data, and/or instructions that may be used by processing circuitry **120**. In some embodiments, processing circuitry **120** and device readable medium **130** may be considered to be integrated.

[0083] User interface equipment **132** may provide components that allow for a human user to interact with wireless device **110**. Such interaction may be of many forms, such as visual, audial, tactile, etc. User interface equipment **132** may be operable to produce output to the user and to allow the user to provide input to wireless device **110**. The type of interaction may vary depending on the type of user interface equipment **132** installed in wireless device **110**. For example, if wireless device **110** is a smart phone, the interaction may be via a touch screen; if wireless device **110** is a smart meter, the interaction may be through a screen that provides usage (e.g., the number of gallons used) or a speaker that provides an audible alert (e.g., if smoke is detected). User interface equipment **132** may include input interfaces, devices and circuits, and output interfaces, devices and circuits. User interface equipment **132** is configured to allow input of information into wireless device **110**, and is connected to processing circuitry **120** to allow processing circuitry **120** to process the input information. User interface equipment **132** may include, for example, a microphone, a proximity or other sensor, keys/buttons, a touch display, one or more cameras, a USB port, or other input circuitry. User interface equipment **132** is also configured to allow output of information from wireless device **110**, and to allow processing circuitry **120** to output information from wireless device **110**. User interface equipment **132** may include, for example, a speaker, a display, vibrating circuitry, a USB port, a headphone interface, or other output circuitry. Using one or more input and output interfaces, devices, and circuits, of user interface equipment **132**, wireless device **110** may communicate with end users and/or the wireless network, and allow them to benefit from the functionality described herein.

[0084] Auxiliary equipment **134** is operable to provide more specific functionality which may not be generally performed by wireless devices. This may comprise specialized sensors for doing measurements for various purposes, interfaces for additional types of communication such as wired communications etc. The inclusion and type of components of auxiliary equipment **134** may vary depending on the embodiment and/or scenario.

[0085] Power source **136** may, in some embodiments, be in the form of a battery or battery pack. Other types of power sources, such as an external power source (e.g., an electricity outlet), photovoltaic devices or power cells, may also be used. Wireless device **110** may further comprise power circuitry **137** for delivering power from power source **136** to the various parts of wireless device **110** which need power from power source **136** to carry out any functionality described or indicated herein. Power circuitry **137** may in certain embodiments comprise power management circuitry. Power circuitry **137** may additionally or alternatively be operable to receive power from an external power source; in which case wireless device **110** may be connectable to the external power source (such as an electricity outlet) via input circuitry or an interface such as an electrical power cable. Power circuitry **137** may also in certain embodiments be operable to deliver power from an external power source to power source **136**. This may be, for example, for the charging of power source **136**. Power circuitry **137** may perform any formatting, converting, or other modification to the power from power source **136** to make the power suitable for the respective components of wireless device **110** to which power is supplied.

[0086] FIG. **5** illustrates one embodiment of a UE in accordance with various aspects described herein. As used herein, a user equipment or UE may not necessarily have a user in the sense of a human user who owns and/or operates the relevant device. Instead, a UE may represent a device that is intended for sale to, or operation by, a human user but which may not, or which may not initially, be associated with a specific human user (e.g., a smart sprinkler controller). Alternatively, a UE may represent a device that is not intended for sale to, or operation by, an end user but which may be associated with or operated for the benefit of a user (e.g., a smart power meter). UE **200** may be any UE identified by the 3rd Generation Partnership Project (3GPP), including a NB-IoT UE, a machine type communication (MTC) UE, and/or an enhanced MTC (eMTC) UE. UE **200**, as illustrated in FIG. **5**, is one example of a wireless device configured for communication in accordance with one or more communication standards promulgated by the 3rd Generation Partnership Project (3GPP), such as 3GPP's GSM, UMTS, LTE, and/or 5G standards. As mentioned previously, the term wireless device and UE may be used interchangeable. Accordingly, although FIG. **5** is a UE, the components discussed herein are equally applicable to a wireless device, and vice-versa.

[0087] In FIG. **5**, UE **200** includes processing circuitry **201** that is operatively coupled to input/output interface **205**, radio frequency (RF) interface **209**, network connection interface **211**, memory **215** including random access memory (RAM) **217**, read-only memory (ROM) **219**, and storage medium **221** or the like, communication subsystem **231**, power source **233**, and/or any other component, or any combination thereof. Storage medium **221** includes operating system **223**, application program **225**, and data **227**. In other embodiments, storage medium **221** may include other similar types of information. Certain UEs may utilize all of the components shown in FIG. **5**, or only a subset of the components. The level of integration between the components may vary from one UE to another UE. Further, certain UEs may contain multiple instances of a component, such as multiple processors, memories, transceivers, transmitters, receivers, etc.

[0088] In FIG. **5**, processing circuitry **201** may be configured to process computer instructions and data. Processing circuitry **201** may be configured to implement any sequential state machine operative to execute machine instructions stored as machine-readable computer programs in the memory, such as one or more hardware-implemented state machines (e.g., in discrete logic, FPGA, ASIC, etc.); programmable logic together with appropriate firmware; one or more stored program, general-purpose processors, such as a microprocessor or Digital Signal Processor (DSP), together with appropriate software; or any combination of the above. For example, the processing circuitry **201** may include two central processing units (CPUs). Data may be information in a form suitable for use by a computer.

[0089] In the depicted embodiment, input/output interface **205** may be configured to provide a communication interface to an input device, output device, or input and output device. UE **200** may be configured to use an output device via input/output interface **205**. An output device may use the same type of interface port as an input device. For example, a USB port may be used to provide input to and output from UE **200**. The output device may be a speaker, a sound card, a video card, a display, a monitor, a printer, an actuator, an emitter, a smartcard, another output device, or any combination thereof. UE **200** may be configured to use an input device via input/output interface **205** to allow a user to capture information into UE **200**. The input device may include a touch-sensitive or presence-sensitive display, a camera (e.g., a digital camera, a digital video camera, a web camera, etc.), a microphone, a sensor, a mouse, a trackball, a directional pad, a trackpad, a scroll wheel, a smartcard, and the like. The presence-sensitive display may include a capacitive or resistive touch sensor to sense input from a user. A sensor may be, for instance, an accelerometer, a gyroscope, a tilt sensor, a force sensor, a magnetometer, an optical sensor, a proximity sensor, another like sensor, or any combination thereof. For example, the input device may be an accelerometer, a magnetometer, a digital camera, a microphone, and an optical sensor.

[0090] In FIG. **5**, RF interface **209** may be configured to provide a communication interface to RF components such as a transmitter, a receiver, and an antenna. Network connection interface **211** may be configured to provide a communication interface to network **243*a***. Network **243*a*** may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network **243*a*** may comprise a Wi-Fi network. Network connection interface **211** may be configured to include a receiver and a transmitter interface used to communicate with one or more other devices over a communication network according to one or more communication protocols, such as Ethernet, TCP/IP, SONET, ATM, or the like. Network connection interface **211** may implement receiver and transmitter functionality appropriate to the communication network links (e.g., optical, electrical, and the like). The transmitter and receiver functions may share circuit components, software or firmware, or alternatively may be implemented separately.

[0091] RAM **217** may be configured to interface via bus **202** to processing circuitry **201** to provide storage or caching of data or computer instructions during the execution of software programs such as the operating system, application programs, and device drivers. ROM **219** may be configured to provide computer instructions or data to processing circuitry **201**. For example, ROM **219** may be configured to store invariant low-level system code or data for basic system functions such as basic input and output (I/O), startup, or reception of keystrokes from a keyboard that are stored in a non-volatile memory. Storage medium **221** may be configured to include memory such as RAM, ROM, programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, or flash drives. In one example, storage medium **221** may be configured to include operating system **223**, application program **225** such as a web browser application, a widget or gadget engine or another application, and data file **227**. Storage medium **221** may store, for use by UE **200**, any of a variety of various operating systems or combinations of operating systems.

[0092] Storage medium **221** may be configured to include a number of physical drive units, such as redundant array of independent disks (RAID), floppy disk drive, flash memory, USB flash drive, external hard disk drive, thumb drive, pen drive, key drive, high-density digital versatile disc (HD-DVD) optical disc drive, internal hard disk drive, Blu-Ray optical disc drive, holographic digital data storage (HDDS) optical disc drive, external mini-dual in-line memory module (DIMM), synchronous dynamic random access memory (SDRAM), external micro-DIMM SDRAM, smartcard memory such as a subscriber identity module or a removable user identity (SIM/RUIM) module, other memory, or any combination thereof. Storage medium **221** may allow UE **200** to access computer-executable instructions, application programs or the like, stored on transitory or non-transitory memory media, to off-load data, or to upload data. An article of manufacture, such as one utilizing a communication system may be tangibly embodied in storage medium **221**, which may comprise a device readable medium.

[0093] In FIG. **5**, processing circuitry **201** may be configured to communicate with network **243*b*** using communication subsystem **231**. Network **243*a*** and network **243*b*** may be the same network or networks or different network or networks. Communication subsystem **231** may be configured to include one or more transceivers used to communicate with network **243*b***. For example, communication subsystem **231** may be configured to include one or more transceivers used to communicate with one or more remote transceivers of another device capable of wireless communication such as another wireless device, UE, or base station of a radio access network (RAN) according to one or more communication protocols, such as IEEE 802.2, CDMA, WCDMA, GSM, LTE, Universal Terrestrial Radio Access Network (UTRAN), WiMax, or the like. Each transceiver may include transmitter **233** and/or receiver **235** to implement transmitter or receiver functionality, respectively, appropriate to the RAN links (e.g., frequency allocations and the like). Further, transmitter **233** and receiver **235** of each transceiver may share circuit components, software or firmware, or alternatively may be implemented separately.

[0094] In the illustrated embodiment, the communication functions of communication subsystem **231** may include data communication, voice communication, multimedia communication, short-range communications such as Bluetooth, near-field communication, location-based communication such as the use of the global positioning system (GPS) to determine a location, another like communication function, or any combination thereof. For example, communication subsystem **231** may include cellular communication, Wi-Fi communication, Bluetooth communication, and GPS communication. Network **243*b*** may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network **243*b*** may be a cellular network, a Wi-Fi network, and/or a near-field network. Power source **213** may be configured to provide alternating current (AC) or direct current (DC) power to components of UE **200**.

[0095] The features, benefits and/or functions described herein may be implemented in one of the components of UE **200** or partitioned across multiple components of UE **200**. Further, the features, benefits, and/or functions described herein may be implemented in any combination of hardware, software or firmware. In one example, communication subsystem **231** may be configured to include any of the components described herein. Further, processing circuitry **201** may be configured to communicate with any of such components over bus **202**. In another example, any of such components may be represented by program instructions stored in memory that when executed by processing circuitry **201** perform the corresponding functions described herein. In another example, the functionality of any of such components may be partitioned between processing circuitry **201** and communication subsystem **231**. In another example, the non-computationally intensive functions of any of such components may be implemented in software or firmware and the computationally intensive functions may be implemented in hardware.

[0096] FIG. **6** is a schematic block diagram illustrating a virtualization environment **300** in which functions implemented by some embodiments may be virtualized. In the present context, virtualizing means creating virtual versions of apparatuses or devices which may include virtualizing hardware platforms, storage devices and networking resources. As used herein, virtualization can be applied to a node (e.g., a virtualized base station or a virtualized radio access node) or to a device (e.g., a UE, a wireless device or any other type of communication device) or components thereof and relates to an implementation in which at least a portion of the functionality is implemented as one or more virtual components (e.g., via one or more applications, components, functions, virtual machines or containers executing on one or more physical processing nodes in one or more networks).

[0097] In some embodiments, some or all of the functions described herein may be implemented as virtual components executed by one or more virtual machines implemented in one or more virtual environments **300** hosted by one or more of hardware nodes **330**. Further, in embodiments in which the virtual node is not a radio access node or does not require radio connectivity (e.g., a core network node), then the network node may be entirely virtualized.

[0098] The functions may be implemented by one or more applications **320** (which may alternatively be called software instances, virtual appliances, network functions, virtual nodes, virtual network functions, etc.) operative to implement some of the features, functions, and/or benefits of some of the embodiments disclosed herein. Applications **320** are run in virtualization environment **300** which provides hardware **330** comprising processing circuitry **360** and memory **390**. Memory **390** contains instructions **395** executable by processing circuitry **360** whereby application **320** is operative to provide one or more of the features, benefits, and/or functions disclosed herein.

[0099] Virtualization environment **300**, comprises general-purpose or special-purpose network hardware devices **330** comprising a set of one or more processors or processing circuitry **360**, which may be commercial off-the-shelf (COTS) processors, dedicated Application Specific Integrated Circuits (ASICs), or any other type of processing circuitry including digital or analog hardware components or special purpose processors. Each hardware device may comprise memory **390-1** which may be non-persistent memory for temporarily storing instructions **395** or software executed by processing circuitry **360**. Each hardware device may comprise one or more network interface controllers (NICs) **370**, also known as network interface cards, which include physical network interface **380**. Each hardware device may also include non-transitory, persistent, machine-readable storage media **390-2** having stored therein software **395** and/or instructions executable by processing circuitry **360**. Software **395** may include any type of software including software for instantiating one or more virtualization layers **350** (also referred to as hypervisors), software to execute virtual machines **340** as well as software allowing it to execute functions, features and/or benefits described in relation with some embodiments described herein.

[0100] Virtual machines **340**, comprise virtual processing, virtual memory, virtual networking or interface and virtual storage, and may be run by a corresponding virtualization layer **350** or hypervisor. Different embodiments of the instance of virtual appliance **320** may be implemented on one or more of virtual machines **340**, and the implementations may be made in different ways.

[0101] During operation, processing circuitry **360** executes software **395** to instantiate the hypervisor or virtualization layer **350**, which may sometimes be referred to as a virtual machine monitor (VMM). Virtualization layer **350** may present a virtual operating platform that appears like networking hardware to virtual machine **340**.

[0102] As shown in FIG. **6**, hardware **330** may be a standalone network node with generic or specific components. Hardware **330** may comprise antenna **3225** and may implement some functions via virtualization. Alternatively, hardware **330** may be part of a larger cluster of hardware (e.g. such as in a data center or customer premise equipment (CPE)) where many hardware nodes work together and are managed via management and orchestration (MANO) **3100**, which, among others, oversees lifecycle management of applications **320**.

[0103] Virtualization of the hardware is in some contexts referred to as network function virtualization (NFV). NFV may be used to consolidate many network equipment types onto industry standard high volume server hardware, physical switches, and physical storage, which can be located in data centers, and customer premise equipment.

[0104] In the context of NFV, virtual machine **340** may be a software implementation of a physical machine that runs programs as if they were executing on a physical, non-virtualized machine. Each of virtual machines **340**, and that part of hardware **330** that executes that virtual machine, be it hardware dedicated to that virtual machine and/or hardware shared by that virtual machine with others of the virtual machines **340**, forms a separate virtual network elements (VNE).

[0105] Still in the context of NFV, Virtual Network Function (VNF) is responsible for handling specific network functions that run in one or more virtual machines **340** on top of hardware networking infrastructure **330** and corresponds to application **320** in FIG. **6**.

[0106] In some embodiments, one or more radio units **3200** that each include one or more transmitters **3220** and one or more receivers **3210** may be coupled to one or more antennas **3225**. Radio units **3200** may communicate directly with hardware nodes **330** via one or more appropriate network interfaces and may be used in combination with the virtual components to provide a virtual node with radio capabilities, such as a radio access node or a base station.

[0107] In some embodiments, some signalling can be affected with the use of control system **3230** which may alternatively be used for communication between the hardware nodes **330** and radio units **3200**.

[0108] FIG. **7** illustrates a telecommunication network connected via an intermediate network to a host computer in accordance with some embodiments. With reference to FIG. **7**, in accordance with an embodiment, a communication system includes telecommunication network **410**, such as a 3GPP-type cellular network, which comprises access network **411**, such as a radio access network, and core network **414**. Access network **411** comprises a plurality of base stations **412***a*, **412***b*, **412***c*, such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area **413***a*, **413***b*, **413***c*. Each base station **412***a*, **412***b*, **412***c* is connectable to core network **414** over a wired or wireless connection **415**. A first UE **491** located in coverage area **413***c* is configured to wirelessly connect to, or be paged by, the corresponding base station **412***c*. A second UE **492** in coverage area **413***a* is wirelessly connectable to the corresponding base station **412***a*. While a plurality of UEs **491**, **492** are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole UE is in the coverage area or where a sole UE is connecting to the corresponding base station **412**.

[0109] Telecommunication network **410** is itself connected to host computer **430**, which may be embodied in the hardware and/or software of a standalone server, a cloud-implemented server, a distributed server or as processing resources in a server farm. Host computer **430** may be under the ownership or control of a service provider, or may be operated by the service provider or on behalf of the service provider. Connections **421** and **422** between telecommunication network **410** and host computer **430** may extend directly from core network **414** to host computer **430** or may go via an optional intermediate network **420**. Intermediate network **420** may be one of, or a combination of more than one of, a public, private or hosted network; intermediate network **420**, if any, may be a backbone network or the Internet; in particular, intermediate network **420** may comprise two or more sub-networks (not shown).

[0110] The communication system of FIG. **7** as a whole enables connectivity between the connected UEs **491**, **492** and host computer **430**. The connectivity may be described as an over-the-top (OTT) connection **450**. Host computer **430** and the connected UEs **491**, **492** are configured to communicate data and/or signaling via OTT connection **450**, using access network **411**, core network **414**, any intermediate network **420** and possible further infrastructure (not shown) as intermediaries. OTT connection **450** may be transparent in the sense that the participating communication devices through which OTT connection **450** passes are unaware of routing of uplink and downlink communications. For example, base station **412** may not or need not be informed about the past routing of an incoming downlink communication with data originating from host computer **430** to be forwarded (e.g., handed over) to a connected UE **491**. Similarly, base station **412** need not be aware of the future routing of an outgoing uplink communication originating from the UE **491** towards the host computer **430**.

[0111] FIG. **8** illustrates a host computer communicating via a base station with a user equipment over a partially wireless connection in accordance with some embodiments. Example implementations, in accordance with an embodiment, of the UE, base station and host computer discussed in the preceding paragraphs will now be described with reference to FIG. **8**. In communication system **500**, host computer **510** comprises hardware **515** including communication interface **516** configured to set up and maintain a wired or wireless connection with an interface of a different communication device of communication system **500**. Host computer **510** further comprises processing circuitry **518**, which may have storage and/or processing capabilities. In particular, processing circuitry **518** may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Host computer **510** further comprises software **511**, which is stored in or accessible by host computer **510** and executable by processing circuitry **518**. Software **511** includes host application **512**. Host application **512** may be operable to provide a service to a remote user, such as UE **530** connecting via OTT connection **550** terminating at UE **530** and host computer **510**. In providing the service to the remote user, host application **512** may provide user data which is transmitted using OTT connection **550**.

[0112] Communication system **500** further includes base station **520** provided in a telecommunication system and comprising hardware **525** enabling it to communicate with host computer **510** and with UE **530**. Hardware **525** may include communication interface **526** for setting up and maintaining a wired or wireless connection with an interface of a different communication device of communication system **500**, as well as radio interface **527** for setting up and maintaining at least wireless connection **570** with UE **530** located in a coverage area (not shown in FIG. **8**) served by base station **520**. Communication interface **526** may be configured to facilitate connection **560** to host computer **510**. Connection **560** may be direct or it may pass through a core network (not shown in FIG. **8**) of the telecommunication system and/or through one or more intermediate networks outside the telecommunication system. In the embodiment shown, hardware **525** of base station **520** further includes processing circuitry **528**, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Base station **520** further has software **521** stored internally or accessible via an external connection.

[0113] Communication system **500** further includes UE **530** already referred to. Its hardware **535** may include radio interface **537** configured to set up and maintain wireless connection **570** with a base station serving a coverage area in which UE **530** is currently located. Hardware **535** of UE **530** further includes processing circuitry **538**, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. UE **530** further comprises software **531**, which is stored in or accessible by UE **530** and executable by processing circuitry **538**. Software **531** includes client application **532**. Client application **532** may be operable to provide a service to a human or non-human user via UE **530**, with the support of host computer **510**. In host computer **510**, an executing host application **512** may communicate with the executing client application **532** via OTT connection **550** terminating at UE **530** and host computer **510**. In providing the service to the user, client application **532** may receive request data from host application **512** and provide user data in response to the request data. OTT connection **550** may transfer both the request data and the user data. Client application **532** may interact with the user to generate the user data that it provides.

[0114] It is noted that host computer **510**, base station **520** and UE **530** illustrated in FIG. **8** may be similar or identical to host computer **430**, one of base stations **412***a*, **412***b*, **412***c* and one of UEs **491**, **492** of FIG. **4**, respectively. This is to say, the inner workings of these entities may be as shown in FIG. **8** and independently, the surrounding network topology may be that of FIG. **4**.

[0115] In FIG. **8**, OTT connection **550** has been drawn abstractly to illustrate the communication between host computer **510** and UE **530** via base station **520**, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from UE **530** or from the service provider operating host computer **510**, or both. While OTT connection **550** is active, the network infrastructure may further take decisions by which it dynamically changes the routing (e.g., on the basis of load balancing consideration or reconfiguration of the network).

[0116] Wireless connection **570** between UE **530** and base station **520** is in accordance with the teachings of the embodiments described throughout this disclosure. One or more of the various embodiments improve the performance of OTT services provided to UE **530** using OTT connection **550**, in which wireless connection **570** forms the last segment. More precisely, the teachings of these embodiments may improve the data rate and latency and thereby provide benefits such as relaxed restriction on file sizes and better responsiveness.

[0117] A measurement procedure may be provided for the purpose of monitoring data rate, latency and other factors on which the one or more embodiments improve. There may further be an optional network functionality for reconfiguring OTT connection **550** between host computer **510** and UE **530**, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring OTT connection **550** may be implemented in software **511** and hardware **515** of host computer **510** or in software **531** and hardware **535** of UE **530**, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which OTT connection **550** passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above, or supplying values of other physical quantities from which software **511**, **531** may compute or estimate the monitored quantities. The reconfiguring of OTT connection **550** may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect base station **520**, and it may be unknown or imperceptible to base station **520**. Such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary UE signaling facilitating host computer **510**'s measurements of throughput, propagation times, latency and the like. The measurements may be implemented in that software **511** and **531** causes messages to be transmitted, in particular empty or 'dummy' messages, using OTT connection **550** while it monitors propagation times, errors etc.

[0118] FIG. **9** is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. **7** and **8**. For simplicity of the present disclosure, only drawing references to FIG. **9** will be included in this section. In step **610**, the host computer provides user data. In substep **611** (which may be optional) of step **610**, the host computer provides the user data by executing a host application. In step **620**, the host computer initiates a transmission carrying the user data to the UE. In step **630** (which may be optional), the base station transmits to the UE the user data which was carried in the transmission that the host computer initiated, in accordance with the teachings of the embodiments described throughout this disclosure. In step **640** (which may also be optional), the UE executes a client application associated with the host application executed by the host computer.

[0119] FIG. **10** is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. **7** and **8**. For simplicity of the present disclosure, only drawing references to FIG. **10** will be included in this section. In step **710** of the method, the host computer provides user data. In an optional substep (not shown) the host computer provides the user data by executing a host application. In step **720**, the host computer initiates a transmission carrying the user data to the UE. The transmission may pass via the base station, in accordance with the teachings of the embodiments described throughout this disclosure. In step **730** (which may be optional), the UE receives the user data carried in the transmission.

[0120] FIG. **11** is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. **7** and **8**. For simplicity of the present disclosure, only drawing references to FIG. **11** will be included in this section. In step **810** (which may be optional), the UE receives input data provided by the host computer. Additionally or alternatively, in step **820**, the UE provides user data. In substep **821** (which may be optional) of step **820**, the UE provides the user data by executing a client application. In substep **811** (which may be optional) of step **810**, the UE executes a client application which provides the user data in reaction to the received input data provided by the host computer. In providing the user data, the executed client application may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the UE initiates, in substep **830** (which may be optional), transmission of the user data to the host computer. In step **840** of the method, the host computer receives the user data transmitted from the UE, in accordance with the teachings of the embodiments described throughout this disclosure.

[0121] FIG. **12** is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGS. **7** and **8**. For simplicity of the present disclosure, only drawing references to FIG. **12** will be included in this section. In step **910** (which may be optional), in accordance with the teachings of the embodiments described throughout this disclosure, the base station receives user data from the UE. In step **920** (which may be optional), the base station initiates transmission of the received user data to the host computer. In step **930** (which may be optional), the host computer receives the user data carried in the transmission initiated by the base station.

[0122] Any appropriate steps, methods, features, functions, or benefits disclosed herein may be performed through one or more functional units or modules of one or more virtual apparatuses. Each virtual apparatus may comprise a number of these functional units. These functional units may be implemented via processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as read-only memory (ROM), random-access memory (RAM), cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein. In some implementations, the processing circuitry may be used to cause the respective functional unit to perform corresponding functions according one or more embodiments of the present disclosure.

[0123] The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

[0124] FIG. **13** depicts a method **1000** in accordance with particular embodiments, the method begins at step **1002** with receiving a first grant of resources from a network node **160**, wherein the first grant of resources is associated with first prioritization information. For example, a wireless device **110**, such as an UE **200**, may receive a grant of resources on which the UE **200** may transmit data. In response to the grant, the method may move to step **1004**, wherein the wireless device **110** may construct a medium access control (MAC) protocol data unit (PDU) based on the first grant. For example, the wireless device **110** may construct the MAC PDU to include at least some of the data it is waiting to transmit to the network node. At step **1006**, the wireless device **110** may receive a second grant of resources from the network node **160** that is overlapping with the first grant of resources. The second grant of resources is associated with second prioritization information. In some cases, the grants may be considered overlapping if the second indicated grant includes an UL time resource with a starting point (e.g., symbol offset) that occurs later than the start of the first grant's UL PUSCH, but has a time duration that partially overlaps with that of the first grant.

[0125] If the grants are overlapping, the method may move to step **1008**, wherein it is determined whether to pre-empt the constructed MAC PDU based on the second grant of resources. For example, the wireless device **110** may retain prioritization information of the first grant even after the construction of the MAC PDU. Then, the wireless device **110** may compare the prioritization information between the first grant and the second grant. The determination may be made based on this comparison to choose the grant that has the highest priority based on the associated prioritization information. At step **1010**, the constructed MAC PDU is pre-empted if the second prioritization information indicates a higher priority than indicated by the first prioritization information. Accordingly, the method depicted in FIG. **13** may provide a consistent method of determining whether to pre-empt previously constructed MAC PDUs in the case of overlapping grants.

[0126] In certain embodiments, the method in FIG. **13** may have one or more additional or optional steps. For example, in certain embodiments, if the constructed MAC PDU is pre-empted, the wireless device may construct another MAC PDU based on the second grant. As another example, the wireless device **110** may incorporate data intended for the pre-empted MAC PDU in the new MAC PDU based on the second grant. In particular, in certain embodiments, constructing a MAC PDU based on the second grant comprises multiplexing data from the pre-empted MAC PDU with new data in the MAC PDU based on the second grant. For example, if the second grant is larger than needed for the available data for the second grant, the wireless device **110** may multiplex the data intended for the pre-empted transmission with the available data for the second grant to maximize the use of resources. This may reduce padding in the transmission and increase utilization of granted resources.

[0127] In some embodiments a computer program, computer program product or computer readable storage medium comprises instructions which when executed on a computer perform any of the embodiments disclosed herein. In further examples the instructions are carried on a signal or carrier and which are executable on a computer wherein when executed perform any of the embodiments disclosed herein.

[0128] FIG. **14** depicts another method by a wireless device **110**, according to certain embodiments. At step **1102**, the wireless device **110** receives a first grant of resources from a network node **160**. The first grant of resources is associated with first prioritization information. At step **1104**, the wireless device **110** constructs a MAC PDU based on the first grant. At step **1106**, the wireless device **110** receives a second grant of resources from the network node that is overlapping with the first grant of resources, and the second grant of resources is associated with second prioritization information. At step **1108**, the wireless device **110** determines whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information. At step **1110**, the wireless device **110** pre-empts the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

[0129] In a particular embodiment, the first prioritization information is determined based on a highest priority of logical channel data allocated for transmission using the first grant and the second prioritization information is determined based on a priority of logical channel data to be transmitted using the second grant.

[0130] In a particular embodiment, when determining whether to pre-empt the transmission of the constructed MAC PDU based on the comparing of the first prioritization information and the second prioritization information, the wireless device **110** compares the priority of the highest priority of logical channel data for transmission using the first grant and the highest priority of the logical channel data to be transmitted using the second grant.

[0131] In a particular embodiment, the wireless device **110** constructs a MAC PDU based on the second grant. In a further particular embodiment, when constructing the MAC PDU based on the second grant, the wireless device **110** multiplexes data allocated for transmission using the first grant with new data to be transmitted using the second grant. In a further particular embodiment, the wireless device **110** determines whether to multiplex a MAC CE into the MAC PDU constructed based on the second grant, and the determining step may be based on a buffer status after multiplexing the data allocated for transmission using the first grant with the new data to be transmitted using the second grant.

[0132] In a particular embodiment, the constructed MAC PDU based on the first grant comprises a first confirmation MAC CE, and the MAC PDU constructed based on the second grant comprises a second confirmation MAC CE referring to a same HARQ process ID as the first confirmation MAC CE.

[0133] In a particular embodiment, the wireless device **110** receives HARQ feedback for the MAC PDU constructed and transmitted based on the second grant, and the HARQ feedback includes a HARQ status of data to be transmitted using the first grant multiplexed in the constructed and transmitted MAC PDU based on the second grant.

[0134] In a particular embodiment, at least one of the first grant of resources and the second grant of resources comprises a dynamic grant. In a further particular embodiment, both the first grant of resources and the second grant of resources comprises dynamic grants.

[0135] In a particular embodiment, at least one of the first grant and the second grant is a configured grant.

[0136] In a further particular embodiment, the step of determining whether to pre-empt the transmission of the constructed MAC PDU based on the comparing the first prioritization information and second prioritization information is performed after the constructed MAC PDU based on the first grant is transmitted to a PHY. In a further particular embodiment, the step of determining whether to pre-empt the transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information is performed after PHY has initiated the transmission of the constructed MAC PDU.

[0137] FIG. **15** illustrates a schematic block diagram of a virtual apparatus **1200** in a wireless network (for example, the wireless network shown in FIG. **2**). The apparatus may be implemented in a wireless device or network node (e.g., wireless device **110** or network node **160** shown in FIG. **2**). Apparatus **1200** is operable to carry out the example method described with reference to FIG. **15** and possibly any other processes or methods disclosed herein. It is also to be understood that the method of FIG. **15** is not necessarily carried out solely by apparatus **1200**. At least some operations of the method can be performed by one or more other entities.

[0138] Virtual Apparatus **1200** may comprise processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein, in several embodiments. In some implementations, the processing circuitry may be used to cause first receiving module **1210**, constructing module **1220**, second receiving module **1230**, determining module **1240**, pre-empting module **1250**, and any other suitable units of apparatus **1200** to perform corresponding functions according one or more embodiments of the present disclosure.

[0139] According to certain embodiments, first receiving module **1210** may perform certain of the receiving functions of the apparatus **1200**. For example, first receiving module **1210** may receive a first grant of resources from a network node **160**. The first grant of resources is associated with first prioritization information.

[0140] According to certain embodiments, constructing module **1220** may perform certain of the constructing functions of the apparatus **1200**. For example, constructing module **1220** may construct a MAC PDU based on the first grant.

[0141] According to certain embodiments, second receiving module **1230** may perform certain of the receiving functions of the apparatus **1200**. For example, second receiving module **1230** may receive a second grant of resources from the network node that is overlapping with the first grant of resources, and the second grant of resources is associated with second prioritization information.

[0142] According to certain embodiments, determining module **1240** may perform certain of the determining functions of the apparatus **1200**. For example, determining module **1240** may determine whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information.

[0143] According to certain embodiments, pre-empting module **1250** may perform certain of the pre-empting functions of the apparatus **1200**. For example, pre-empting module **1250** may pre-empt the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

[0144] The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

[0145] FIG. **16** depicts a method **1300** by a network node **160** such as, for example, a base station, according to certain embodiments. At step **1302**, the network node **160** transmits a second grant of resources to a wireless device **110**. The second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, and the second grant of resources is larger than the first grant of resources. Additionally, the second grant of resources is associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources. At step **1304**, network node **160** receives a transmission from the wireless device **110** based on the second grant of resources. The received transmission includes data allocated by the wireless device **110** for transmission using the first grant of resources and new data allocated by the wireless device **110** for transmission using the second grant of resources.

[0146] In a particular embodiment, the first prioritization information is determined based on a highest priority of logical channel data allocated for transmission using the first grant and the second prioritization information is determined based on a priority of logical channel data allocated for transmission using the second grant.

[0147] In a particular embodiment, the network node **160** transmits the second grant of resources being larger than the first grant of resources based on a comparison of the first prioritization information and the second prioritization information.

[0148] In a particular embodiment, the transmission from the wireless device **110** based on the second grant comprises a MAC PDU constructed based on the second grant. The MAC PDU includes a second confirmation MAC CE referring to a same HARQ process ID as a first confirmation MAC CE associated with the first grant.

[0149] In a particular embodiment, the network node **160** provides to the wireless device **110** the first prioritization information for the first grant and/or the second prioritization information for the second grant, and at least one of the first prioritization information and the second prioritization information includes logical channel priority information.

[0150] In a particular embodiment, the network node **160** transmits HARQ feedback to the wireless device **110**, and the HARQ feedback includes a HARQ status of data allocated for transmission using the first grant multiplexed in the constructed MAC PDU based on the second grant.

[0151] In a particular embodiment, at least one of the first grant of resources and the second grant of resources is a dynamic grant.

[0152] In a particular embodiment, both the first grant of resources and the second grant of resources comprises dynamic grants.

[0153] In a particular embodiment, at least one of the first grant of resources and the second grant of resources is a configured grant.

[0154] FIG. **17** illustrates a schematic block diagram of a virtual apparatus **1400** in a wireless network (for example, the wireless network shown in FIG. **2**). The apparatus may be implemented in a wireless device or network node (e.g., wireless device **110** or network node **160** shown in FIG. **2**). Apparatus **1400** is operable to carry out the example method described with reference to FIG. **16** and possibly any other processes or methods disclosed herein. It is also to be understood that the method of FIG. **17** is not necessarily carried out solely by apparatus **1400**. At least some operations of the method can be performed by one or more other entities.

[0155] Virtual Apparatus **1400** may comprise processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein, in several embodiments. In some implementations, the processing circuitry may be used to cause transmitting module **1410**, receiving 4module **1420**, and any other suitable units of apparatus **1400** to perform corresponding functions according one or more embodiments of the present disclosure.

[0156] According to certain embodiments, transmitting module **1410** may perform certain of the transmitting functions of the apparatus **1400**. For example, transmitting module **1410** may transmit a second grant of resources to a wireless device **110**. The second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, and the second grant of resources is larger than the first grant of resources. Additionally, the second grant of resources is associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources.

[0157] According to certain embodiments, receiving module **1420** may perform certain of the receiving functions of the apparatus **1400**. For example, receiving module **1420** may receive a transmission from the wireless device **110** based on the second grant of resources. The received transmission includes data allocated by the wireless device **110** for transmission using the first grant of resources and new data allocated by the wireless device **110** for transmission using the second grant of resources.

[0158] The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

EXAMPLE EMBODIMENTS

[0159] Example Embodiment 1. A method performed by a wireless device, the method comprising: receiving a first grant of resources from a network node, wherein the first grant of resources is associated with first prioritization information; constructing a MAC PDU based on the first grant; receiving a second grant of resources from the network node that is overlapping with the first grant of resources, wherein the second grant of resources is associated with second prioritization information; determining whether to preempt the constructed MAC PDU based on the second grant of resources; and preempting the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

[0160] Example Embodiment 2. The method of the previous embodiment, further comprising constructing a MAC PDU based on the second grant.

[0161] Example Embodiment 3. The method of the previous embodiment, wherein constructing a MAC PDU based on the second grant comprises multiplexing data from the preempted MAC PDU with new data in the MAC PDU based on the second grant.

[0162] Example Embodiment 4. The method of any of embodiments 2-3, further comprising providing HARQ feedback, wherein the HARQ feedback informs the HARQ status of data in the preempted MAC PDU based on the first grant of resources.

[0163] Example Embodiment 5. The method of any of the previous embodiments, wherein the first prioritization information and/or the second prioritization information comprises one or more of logical channel data information, logical channel information or logical channel priority information.

[0164] Example Embodiment 6. The method of any of the previous embodiments, further comprising: providing user data; and forwarding the user data to a host computer via the transmission to the base station.

[0165] Example Embodiment 7. A method performed by a base station, the method comprising: transmitting a second grant of resources to a wireless device, wherein the second grant of resources overlaps with a first grant of resources previously received at the wireless device; receiving a transmission from the wireless device using the second grant based on a comparison of prioritization information associated with each of the first grant and the second grant, respectively.

[0166] Example Embodiment 8. The method of the previous embodiment, further comprising: determining that the second grant of resources may be granted to the wireless device, wherein the second grant of resources is larger than the first grant of resources and is associated with prioritization information indicating a higher priority than the prioritization information of the first grant; wherein the received transmission using the second grant includes data allocated to transmit using the first grant of resources and new data allocated to transmit using the second grant of resources.

[0167] Example Embodiment 9. The method of any of the previous embodiments, further comprising providing to the wireless device the prioritization information for the first grant and/or the second grant.

[0168] Example Embodiment 10. The method of any of the previous embodiments, further comprising transmitting the first grant of resources to the wireless device prior to transmitting the second grant of resources.

[0169] Example Embodiment 11. The method of any of the previous embodiments, wherein at least one of the first grant and the second grant is a dynamic grant.

[0170] Example Embodiment 12. The method of any of the previous embodiments, wherein at least one of the first grant and the second grant is a configured grant.

[0171] Example Embodiment 13. The method of any of the previous embodiments, further comprising: obtaining user data; and forwarding the user data to a host computer or a wireless device.

[0172] Example Embodiment 14. A wireless device, the wireless device comprising: processing circuitry configured to perform any of the steps of any of Example Embodiments 1 to 6; and power supply circuitry configured to supply power to the wireless device.

[0173] Example Embodiment 15. A base station, the base station comprising: processing circuitry configured to perform any of the steps of any of Example Embodiments 7 to 13; power supply circuitry configured to supply power to the base station.

[0174] Example Embodiment 16. A user equipment (UE), the UE comprising: an antenna configured to send and receive wireless signals; radio front-end circuitry connected to the antenna and to processing circuitry, and configured to condition signals communicated between the antenna and the processing circuitry; the processing circuitry being configured to perform any of the steps of any of Example Embodiments 1 to 6; an input interface connected to the processing circuitry and configured to allow input of information into the UE to be processed by the processing circuitry; an output interface connected to the processing circuitry and configured to output information from the UE that has been processed by the processing circuitry; and a battery connected to the processing circuitry and configured to supply power to the UE.

[0175] Example Embodiment 17. A computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 1 to 6.

[0176] Example Embodiment 18. A computer program product comprising a computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 1 to 6.

[0177] Example Embodiment 19. A non-transitory computer-readable storage medium or carrier comprising a computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 1 to 6.

[0178] Example Embodiment 20. A computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 7 to 13.

[0179] Example Embodiment 21. A computer program product comprising a computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 7 to 13.

[0180] Example Embodiment 22. A non-transitory computer-readable storage medium or carrier comprising a computer program, the computer program comprising instructions which when executed on a computer perform any of the steps of any of Example Embodiments 7 to 13.

[0181] Example Embodiment 23. A communication system including a host computer comprising: processing circuitry configured to provide user data; and a communication interface configured to forward the user data to a cellular network for transmission to a user equipment (UE), wherein the cellular network comprises a base station having a radio interface and processing circuitry, the base station's processing circuitry configured to perform any of the steps of any of Example Embodiments 7 to 13.

[0182] Example Embodiment 24. The communication system of the pervious embodiment further including the base station.

[0183] Example Embodiment 25. The communication system of the previous 2 embodiments, further including the UE, wherein the UE is configured to communicate with the base station.

[0184] Example Embodiment 26. The communication system of the previous 3 embodiments, wherein: the processing circuitry of the host computer is configured to execute a host application, thereby providing the user data; and the UE comprises processing circuitry configured to execute a client application associated with the host application.

[0185] Example Embodiment 27. A method implemented in a communication system including a host computer, a base station and a user equipment (UE), the method comprising: at the host computer, providing user data; and at the host computer, initiating a transmission carrying the user data to the UE via a cellular network comprising the base station, wherein the base station performs any of the steps of any of Example Embodiments 7 to 13.

[0186] Example Embodiment 28. The method of the previous embodiment, further comprising, at the base station, transmitting the user data.

[0187] Example Embodiment 29. The method of the previous 2 embodiments, wherein the user data is provided at the host computer by executing a host application, the method further comprising, at the UE, executing a client application associated with the host application.

[0188] Example Embodiment 30. A user equipment (UE) configured to communicate with a base station, the UE comprising a radio interface and processing circuitry configured to performs the of the previous 3 embodiments.

[0189] Example Embodiment A communication system including a host computer comprising: processing circuitry configured to provide user data; and a communication interface configured to forward user data to a cellular network for transmission to a user equipment (UE), wherein the UE comprises a radio interface and processing circuitry, the UE's components configured to perform any of the steps of any of Example Embodiments 1 to 6.

[0190] Example Embodiment 32. The communication system of the previous embodiment, wherein the cellular network further includes a base station configured to communicate with the UE.

[0191] Example Embodiment 33. The communication system of the previous 2 embodiments, wherein: the processing circuitry of the host computer is configured to execute a host application, thereby providing the user data; and the UE's processing circuitry is configured to execute a client application associated with the host application.

[0192] Example Embodiment 34. A method implemented in a communication system including a host computer, a base station and a user equipment (UE), the method comprising: at the host computer, providing user data; and at the host computer, initiating a transmission carrying the user data to the UE via a cellular network comprising the base station, wherein the UE performs any of the steps of any of Example Embodiments 1 to 6.

[0193] Example Embodiment 35. The method of the previous embodiment, further comprising at the UE, receiving the user data from the base station.

[0194] Example Embodiment 36. A communication system including a host computer comprising: communication interface configured to receive user data originating from a transmission from a user equipment (UE) to a base station, wherein the UE comprises a radio interface and processing circuitry, the UE's processing circuitry configured to perform any of the steps of any of Example Embodiments 1 to 6.

[0195] Example Embodiment 37. The communication system of the previous embodiment, further including the UE.

[0196] Example Embodiment 38. The communication system of the previous 2 embodiments, further including the base station, wherein the base station comprises a radio interface configured to communicate with the UE and a communication interface configured to forward to the host computer the user data carried by a transmission from the UE to the base station.

[0197] Example Embodiment 39. The communication system of the previous 3 embodiments, wherein: the processing circuitry of the host computer is configured to execute a host application; and the UE's processing circuitry is configured to execute a client application associated with the host application, thereby providing the user data.

[0198] Example Embodiment 40. The communication system of the previous 4 embodiments, wherein: the processing circuitry of the host computer is configured to execute a host application, thereby providing request data; and the UE's processing circuitry is configured to execute a client application associated with the host application, thereby providing the user data in response to the request data.

[0199] Example Embodiment 41. A method implemented in a communication system including a host computer, a base station and a user equipment (UE), the method comprising: at the host computer, receiving user data transmitted to the base station from the UE, wherein the UE performs any of the steps of any of Example Embodiments 1 to 6.

[0200] Example Embodiment 42. The method of the previous embodiment, further comprising, at the UE, providing the user data to the base station.

[0201] Example Embodiment 43. The method of the previous 2 embodiments, further comprising: at the UE, executing a client application, thereby providing the user data to be transmitted; and at the host computer, executing a host application associated with the client application.

[0202] Example Embodiment 44. The method of the previous 3 embodiments, further comprising: at the UE, executing a client application; and at the UE, receiving input data to the client application, the input data being provided at the host computer by executing a host application associated with the client application, wherein the user data to be transmitted is provided by the client application in response to the input data.

[0203] Example Embodiment 45. A communication system including a host computer comprising a communication interface configured to receive user data originating from a transmission from a user equipment (UE) to a base station, wherein the base station comprises a radio interface and processing circuitry, the base station's processing circuitry configured to perform any of the steps of any of Example Embodiments 7 to 13.

[0204] Example Embodiment 46. The communication system of the previous embodiment further including the base station.

[0205] Example Embodiment 47. The communication system of the previous 2 embodiments, further including the UE, wherein the UE is configured to communicate with the base station.

[0206] Example Embodiment The communication system of the previous 3 embodiments, wherein: the processing circuitry of the host computer is configured to execute a host application; the UE is configured to execute a client application associated with the host application, thereby providing the user data to be received by the host computer.

[0207] Example Embodiment 49. A method implemented in a communication system including a host computer, a base station and a user equipment (UE), the method comprising: at the host computer, receiving, from the base station, user data originating from a transmission which the base station has received from the UE, wherein the UE performs any of the steps of any of Example Embodiments 1 to 6.

[0208] Example Embodiment 50. The method of the previous embodiment, further comprising at the base station, receiving the user data from the UE.

[0209] Example Embodiment 51. The method of the previous 2 embodiments, further comprising at the base station, initiating a transmission of the received user data to the host computer.

1. A method performed by a wireless device, the method comprising:

receiving a first grant of resources from a network node, wherein the first grant of resources is associated with first prioritization information;

constructing a Medium Access Control Protocol Data Unit, MAC PDU, based on the first grant;

receiving a second grant of resources from the network node that is overlapping with the first grant of resources, wherein the second grant of resources is associated with second prioritization information;

determining whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information; and

pre-empting the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

2. The method of claim **1**, wherein the first prioritization information is determined based on a highest priority of logical channel data allocated for transmission using the first grant and the second prioritization information is determined based on a priority of logical channel data to be transmitted using the second grant.

3. The method of claim **2**, wherein determining whether to pre-empt the transmission of the constructed MAC PDU based on the comparing of the first prioritization information and the second prioritization information comprises comparing the priority of the highest priority of logical channel data for transmission using the first grant and the highest priority of the logical channel data to be transmitted using the second grant.

4. The method of claim **1**, further comprising constructing a MAC PDU based on the second grant.

5. The method of claim **4**, wherein constructing the MAC PDU based on the second grant comprises multiplexing data allocated for transmission using the first grant with new data to be transmitted using the second grant.

6. The method of claim **4**, further comprising determining whether to multiplex a Medium Access Control-Control Element (MAC CE) into the MAC PDU constructed based on the second grant, wherein the determining is based on a buffer status after multiplexing the data allocated for transmission using the first grant with the new data to be transmitted using the second grant.

7. The method of claim **4**, wherein:

the constructed MAC PDU based on the first grant comprises a first confirmation MAC CE, and

the MAC PDU constructed based on the second grant comprises a second confirmation MAC CE referring to a same HARQ process ID as the first confirmation MAC CE.

8. The method of claim **1**, further comprising receiving Hybrid Automatic Repeat Request, HARQ, feedback for the MAC PDU constructed and transmitted based on the second grant, wherein the HARQ feedback includes a HARQ status of data to be transmitted using the first grant multiplexed in the constructed and transmitted MAC PDU based on the second grant.

9. The method of claim **1**, wherein at least one of the first grant of resources and the second grant of resources comprises a dynamic grant.

10. The method of claim **9**, wherein both the first grant of resources and the second grant of resources comprises dynamic grants.

11. The method of claim **1**, wherein at least one of the first grant and the second grant is a configured grant.

12. The method of claim **1**, wherein the step of determining whether to pre-empt the transmission of the constructed MAC PDU based on the comparing the first prioritization information and second prioritization information is performed after the constructed MAC PDU based on the first grant is transmitted to a physical layer, PHY.

13. The method of claim **12**, wherein the step of determining whether to pre-empt the transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information is performed after PHY has initiated the transmission of the constructed MAC PDU.

14. A method performed by a network node, the method comprising:

transmitting a second grant of resources to a wireless device, wherein the second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, the second grant of resources being larger than the first grant of resources, the second grant of resources being associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources; and

receiving a transmission from the wireless device based on the second grant of resources, the received transmission including data allocated by the wireless device for transmission using the first grant of resources and new data allocated by the wireless device for transmission using the second grant of resources.

15. The method of claim **14**, wherein the first prioritization information is determined based on a highest priority of logical channel data allocated for transmission using the first grant and the second prioritization information is determined based on a priority of logical channel data allocated for transmission using the second grant.

16. The method of claim **14**, further comprising transmitting the second grant of resources being larger than the first grant of resources based on a comparison of the first prioritization information and the second prioritization information.

17. The method of claim **14**, wherein the transmission from the wireless device based on the second grant comprises a MAC PDU constructed based on the second grant, the MAC PDU comprising a second confirmation Medium Access Control Control Element (MAC CE) referring to a same HARQ process ID as a first confirmation MAC CE associated with the first grant.

18. The method of claim **14**, further comprising providing to the wireless device the first prioritization information for the first grant and/or the second prioritization information for the second grant, and wherein at least one of the first prioritization information and the second prioritization information comprises logical channel priority information.

19. The method of claim **14**, further comprising transmitting Hybrid Automatic Repeat Request, HARQ, feedback to the wireless device, wherein the HARQ feedback includes a HARQ status of data allocated for transmission using the first grant multiplexed in the constructed MAC PDU based on the second grant.

20. The method of claim **14**, wherein at least one of the first grant of resources and the second grant of resources is a dynamic grant;

wherein both the first grant of resources and the second grant of resources comprises dynamic grants, or,

wherein at least one of the first grant of resources and the second grant of resources is a configured grant.

21. (canceled)

22. (canceled)

23. A wireless device comprising:

processing circuitry configured to:

receive a first grant of resources from a network node, wherein the first grant of resources is associated with first prioritization information;

construct a Medium Access Control Protocol Data Unit, MAC PDU, based on the first grant;

receive a second grant of resources from the network node that is overlapping with the first grant of resources, wherein the second grant of resources is associated with second prioritization information;

determine whether to pre-empt transmission of the constructed MAC PDU based on comparing the first prioritization information and second prioritization information; and

pre-empt the transmission of the constructed MAC PDU if the second prioritization information indicates a higher priority than indicated by the first prioritization information.

24. (canceled)

25. A network node comprising:

processing circuitry configured to:

transmit a second grant of resources to a wireless device, wherein the second grant of resources overlaps with a first grant of resources previously transmitted to the wireless device, the second grant of resources being larger than the first grant of resources, the second grant of resources being associated with second prioritization information indicating a higher priority than a first prioritization information associated with the first grant of resources; and receive a transmission from the wireless device based on the second grant of resources, the received transmission including data allocated by the wireless device for transmission using the first grant of resources and new data allocated by the wireless device for transmission using the second grant of resources.

26. (canceled)

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