

PRACH RESOURCE ADAPTATION

TECHNICAL FIELD

[0001] The present disclosure relates to a user equipment (UE), a base station, processors for wireless communication and methods for physical random access channel (PRACH) resource adaptation.

BACKGROUND

[0002] A wireless communications system may include one or multiple network communication devices, such as base stations, which may be otherwise known as an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. Each network communication devices, such as a base station may support wireless communications for one or multiple user communication devices, which may be otherwise known as user equipment (UE), or other suitable terminology. The wireless communications system may support wireless communications with one or multiple user communication devices by utilizing resources of the wireless communication system (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers). Additionally, the wireless communications system may support wireless communications across various radio access technologies including third generation (3G) radio access technology, fourth generation (4G) radio access technology, fifth generation (5G) radio access technology, among other suitable radio access technologies beyond 5G (e.g., sixth generation (6G)).

[0003] In 5G new radio (NR) systems, the random-access procedure is utilized for various purposes. For example, the random-access procedure may be utilized by a UE in initial access to find a cell to camp on; or utilized by a radio resource control (RRC) IDLE/INACTIVE UE to switch to a RRC Connected mode to start data transmission/reception; or utilized by a RRC Connected UE to re-establish the uplink (UL) synchronization, etc. Enhancements are still needed on the random-access procedure, especially on techniques related to the adaptation of PRACH resources.

SUMMARY

[0004] The present disclosure relates to methods, apparatuses, and systems that support PRACH resource adaptation. By dynamically configuring or activating at least

one additional random access channel (RACH) occasion (RO), the RACH procedure may be performed on additional PRACH resources in addition to the PRACH resources configured by SIB1. In this way, the latency of the RACH procedure may be reduced, especially for low load scenarios where sparse PRACH resources are configured for the sake of network energy saving.

[0005] In a first aspect of the solution, a UE receives, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO. The UE performs a RACH procedure based on the at least one additional RO. In this way, the PRACH resources may be dynamically adapted and the RACH procedure may be performed on additional PRACH resources in addition to the PRACH resources configured by SIB1. Thus, the latency of the RACH procedure may be reduced without significantly increasing the power consumption on the network side.

[0006] In some implementations of the method and apparatuses described herein, the at least one additional RO may include one additional RO, the additional RO is configured or activated by the PDCCH order, the additional RO is associated with a synchronization signal and physical broadcast channel (PBCH) block (SSB) indicated in the PDCCH order.

[0007] In some implementations of the method and apparatuses described herein, the PDCCH order may include resource configurations for the additional RO.

[0008] Some implementations of the method and apparatuses described herein may further include: receiving, from the base station, resource configurations for the additional RO. The resource configurations are carried in a medium access control (MAC) control element (CE) signaling or a radio resource control (RRC) signaling. The PDCCH order may include an indication of activating the additional RO.

[0009] In some implementations of the method and apparatuses described herein, the additional RO is a first additional RO, and performing the RACH procedure may include: transmitting, to the base station, a preamble on the first additional RO, wherein a time offset between the PDCCH order and a first slot with the first additional RO is configured

by the base station or predefined; and monitoring, in a RAR window, a random access response (RAR) message indicating reception of the preamble.

[0010] Some implementations of the method and apparatuses described herein may further include: in the case that no RAR message is received in the RAR window, performing a second RACH procedure based on a second additional RO. A time offset between an end of the RAR window and a second slot with the second additional RO is configured by the base station or predefined.

[0011] In some implementations of the method and apparatuses described herein, the at least one additional ROs may include a set of additional ROs, the set of additional RO is configured or activated by the paging signaling, the paging signaling is one of the following: a paging message; a paging DCI for scheduling the paging message; or a paging early indication (PEI) indicative of a presence of the paging message.

[0012] Some implementations of the method and apparatuses described herein may further include: transmitting, to a network device, an indication of a capability of supporting physical RACH (PRACH) resource adaptation triggered by the paging signaling.

[0013] In some implementations of the method and apparatuses described herein, the paging signaling may include resource configurations for the set of additional ROs.

[0014] Some implementations of the method and apparatuses described herein may further include: receiving, from the base station, the SIB1, wherein the SIB1 may include resource configurations for the set of additional ROs. The paging signaling may include an indication of activating the set of additional ROs.

[0015] Some implementations of the method and apparatuses described herein may further include: receiving, from the base station, the SIB1, wherein the SIB1 may include resource configurations for at least one set of additional ROs, the at least one set of additional ROs may include the set of additional ROs. The paging signaling may include an indication of the set of additional ROs, the set of additional ROs is activated by the paging signaling.

[0016] In some implementations of the method and apparatuses described herein, a time offset between a last monitoring occasion for the paging DCI and a first slot with the set of additional ROs is configured by the base station or predefined.

[0017] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the paging message and a first slot with the set of additional ROs is configured by the base station or predefined.

[0018] In some implementations of the method and apparatuses described herein, the at least one additional RO may include a set of additional ROs, the set of additional RO is activated by the DCI for scheduling the SIB1, the DCI for scheduling the SIB1 may include an indication of an availability of a set of additional ROs. The SIB1 may include resource configurations for the set of additional ROs.

[0019] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the DCI for scheduling the SIB1 and a first slot with the set of additional ROs is configured by the base station or predefined.

[0020] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the SIB1 and a first slot with the set of additional ROs is configured by the base station or predefined.

[0021] In some implementations of the method and apparatuses described herein, the at least one additional RO is available in a time window. The time window is configured by the base station or predefined.

[0022] Some implementations of the method and apparatuses described herein may further include: receiving, from a base station, the SIB1; determining the set of ROs based on the SIB1; and performing a unified SSB-to-RO association for the set of ROs and the at least one additional RO.

[0023] In some implementations of the method and apparatuses described herein, the at least one additional RO may include a set of additional ROs, and performing the unified SSB-to-RO association may include: performing a first SSB-to-RO association for the set of ROs; and determining a second SSB-to-RO association for the set of additional ROs based on the first SSB-to-RO association.

[0024] In some implementations of the method and apparatuses described herein, determining the second SSB-to-RO association may include: causing the second SSB-to-RO association to follow the first SSB-to-RO association in a sequential and wrap round way.

[0025] In some implementations of the method and apparatuses described herein, determining the second SSB-to-RO association further may include: determining one or more of the set of additional ROs as invalid. The one or more additional ROs and at least one of the set of ROs subsequent to the one or more additional ROs cannot form a SSB-to-RO mapping cycle.

[0026] Some implementations of the method and apparatuses described herein may further include: determining one of the at least one additional RO as invalid. The additional RO is overlapped with one of the set of ROs.

[0027] In a second aspect of the solution, a base station transmits, to a UE, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO. The base station monitors a preamble on the at least one additional RO. In this way, the base station is able to dynamically configure or activate additional PRACH resources. Thus, the latency of the RACH procedure may be reduced without significantly increasing the power consumption on the network side.

[0028] In some implementations of the method and apparatuses described herein, the at least one additional RO may include one additional RO, the additional RO is configured or activated by the PDCCH order, the additional RO is associated with a synchronization signal and PBCH block (SSB) indicated in the PDCCH order.

[0029] In some implementations of the method and apparatuses described herein, the PDCCH order may include resource configurations for the additional RO.

[0030] Some implementations of the method and apparatuses described herein may further include: transmitting, to the UE, an indication of resource configurations for the additional RO, wherein the resource configurations are carried in a medium access control (MAC) control element (CE) signaling or a radio resource control (RRC) signaling. The PDCCH order may include an indication of activating the additional RO.

[0031] In some implementations of the method and apparatuses described herein, the additional RO is a first additional RO, a time offset between the PDCCH order and a first

slot with the first additional RO is predefined or associated with a configuration from the base station to the UE. Some implementations of the method and apparatuses described herein may further include: in the case that the preamble is received on the additional RO, transmitting, in a RAR window, a random access response (RAR) message indicating reception of the preamble.

[0032] Some implementations of the method and apparatuses described herein may further include: in the case that no preamble is received on the additional RO, monitoring the preamble on a second additional RO. A time offset between an end of the RAR window and a second slot with the second additional RO is predefined or associated with a configuration from the base station to the UE.

[0033] In some implementations of the method and apparatuses described herein, the at least one additional ROs may include a set of additional ROs, the set of additional RO is configured or activated by the paging signaling, the paging signaling is one of the following: a paging message; a paging DCI for scheduling the paging message; or a paging early indication (PEI) indicative of a presence of the paging message.

[0034] Some implementations of the method and apparatuses described herein may further include: receiving, from a network device, an indication of a capability of the UE supporting physical RACH (PRACH) resource adaptation triggered by the paging signaling.

[0035] In some implementations of the method and apparatuses described herein, the paging signaling may include resource configurations for the set of additional ROs.

[0036] Some implementations of the method and apparatuses described herein may further include: transmitting, to the UE, the SIB1, wherein the SIB1 may include resource configurations for the set of additional ROs. The paging signaling may include an indication of activating the set of additional ROs.

[0037] Some implementations of the method and apparatuses described herein may further include: transmitting, to the UE, the SIB1, wherein the SIB1 may include resource configurations for at least one set of additional ROs, the at least one set of additional ROs may include the set of additional ROs. The paging signaling may include an indication of the set of additional ROs, the set of additional ROs is activated by the paging signaling.

[0038] In some implementations of the method and apparatuses described herein, a time offset between a last monitoring occasion for the paging DCI and a first slot with the set of additional ROs is predefined or associated with a configuration from the base station to the UE.

[0039] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the paging message and a first slot with the set of additional ROs is predefined or associated with a configuration from the base station to the UE.

[0040] In some implementations of the method and apparatuses described herein, the at least one additional RO may include a set of additional ROs, the set of additional ROs is activated by the DCI for scheduling the SIB1, the DCI for scheduling the SIB1 may include an indication of an availability of a set of additional ROs. The SIB1 may include resource configurations for the set of additional ROs.

[0041] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the DCI for scheduling the SIB1 and a first slot with the set of additional ROs is predefined or associated with a configuration from the base station to the UE.

[0042] In some implementations of the method and apparatuses described herein, a time offset between a last slot with the SIB1 and a first slot with the set of additional ROs is predefined or associated with a configuration from the base station to the UE.

[0043] In some implementations of the method and apparatuses described herein, the at least one additional RO is available in a time window, wherein the time window is predefined or associated with a configuration from the base station to the UE.

[0044] Some implementations of the method and apparatuses described herein may further include: transmitting, to a UE, the SIB1, and

[0045] wherein a unified SSB-to-RO association is formed for the set of ROs and the at least one additional RO.

[0046] In some implementations of the method and apparatuses described herein, the at least one additional RO may include a set of additional ROs, the unified SSB-to-RO association may include a first SSB-to-RO association for the set of ROs and a second

SSB-to-RO association for the set of additional ROs, the second SSB-to-RO association is based on the first SSB-to-RO association.

[0047] In some implementations of the method and apparatuses described herein, the second SSB-to-RO association follows the first SSB-to-RO association in a sequential and wrap round way.

[0048] In some implementations of the method and apparatuses described herein, one or more of the set of additional ROs are invalid, wherein the one or more additional ROs and at least one of the set of ROs subsequent to the one or more additional ROs cannot form a SSB-to-RO mapping cycle.

[0049] In some implementations of the method and apparatuses described herein, one of the at least one additional RO is invalid, wherein the additional RO is overlapped with one of the set of ROs.

[0050] In a third aspect of the solution, an apparatus for performing an access and mobility management function (AMF) receives, from a UE, an indication of a capability of the UE supporting physical random access channel (PRACH) resource adaptation triggered by a paging signaling; and transmits, to a base station, an indication of a capability of the UE supporting the PRACH resource adaptation triggered by the paging signaling. In this way, the base station is able to identify a UE that supports additional PRACH resource allocation. As a result, the base station is able to dynamically trigger PRACH resource adaptation when paging the UE, thus reducing the latency of the RACH procedure.

[0051] In some implementations of the method and apparatuses described herein, the paging signaling is one of the following: a paging message; paging downlink control information (DCI) for scheduling the paging message; or a paging early indication (PEI) indicative of a presence of the paging message.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052] FIG. 1A illustrates an example of a wireless communications system that supports PRACH resource adaptation in accordance with aspects of the present disclosure.

[0053] FIG. 1B illustrates an example of an NR 4-step random-access procedure that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure.

[0054] FIG. 1C illustrates an example of an NR random-access procedure that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure.

[0055] FIG. 2 illustrates an example signaling chart of a communication process that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure.

[0056] FIG. 3 illustrates an example of PRACH resource adaptation by a PDCCH order in accordance with some example embodiments of the present disclosure.

[0057] FIG. 4 illustrates an example signaling chart of a communication process that supports PRACH resource adaptation by a paging signaling in accordance with some example embodiments of the present disclosure.

[0058] FIG. 5 illustrates an example of PRACH resource adaptation by a paging signaling in accordance with some example embodiments of the present disclosure.

[0059] FIG. 6 illustrates an example of a SSB-to-RO association in accordance with some example embodiments of the present disclosure.

[0060] FIG. 7 illustrates another example of a SSB-to-RO association in accordance with some example embodiments of the present disclosure.

[0061] FIG. 8 illustrates an example of a device that supports PRACH resource adaptation in accordance with aspects of the present disclosure.

[0062] FIG. 9 illustrates an examples of a processor that supports PRACH resource adaptation in accordance with aspects of the present disclosure.

[0063] FIGS. 10 through 12 illustrate flowcharts of methods that support PRACH resource adaptation in accordance with aspects of the present disclosure.

[0064] Throughout the drawings, the same or similar reference numerals represent the same or similar elements.

DETAILED DESCRIPTION

[0065] Principles of the present disclosure will now be described with reference to some embodiments. It is to be understood that these embodiments are described only for the purpose of illustration and help those skilled in the art to understand and implement the present disclosure, without suggesting any limitation as to the scope of the disclosure. The disclosure described herein may be implemented in various manners other than the ones described below.

[0066] In the following description and claims, unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skills in the art to which this disclosure belongs.

[0067] References in the present disclosure to “one embodiment,” “an example embodiment,” “an embodiment,” “some embodiments,” and the like indicate that the embodiment(s) described may include a particular feature, structure, or characteristic, but it is not necessary that every embodiment includes the particular feature, structure, or characteristic. Moreover, such phrases do not necessarily refer to the same embodiment(s). Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0068] It shall be understood that although the terms “first” and “second” or the like may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another element. For example, a first element could also be termed as a second element, and similarly, a second element could also be termed as a first element, without departing from the scope of embodiments. As used herein, the term “and/or” includes any and all combinations of one or more of the listed terms.

[0069] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “has,” “having,” “includes” and/or “including”, when used herein, specify the presence of stated features, elements, and/or components etc., but do not preclude the presence or addition of one or more other features, elements,

components and/ or combinations thereof. For example, the term “includes” and its variants are to be read as open terms that mean “includes, but is not limited to.” The term “based on” is to be read as “based at least in part on.” The term “one embodiment” and “an embodiment” are to be read as “at least one embodiment.” The term “another embodiment” is to be read as “at least one other embodiment.” The use of an expression such as “A and/or B” can mean either “only A” or “only B” or “both A and B.” Other definitions, explicit and implicit, may be included below.

[0070] As used herein, the term “communication network” refers to a network following any suitable communication standards, such as, 5G NR, long term evolution (LTE), LTE-advanced (LTE-A), wideband code division multiple access (WCDMA), high-speed packet access (HSPA), narrow band internet of things (NB-IoT), and so on. Further, the communications between a terminal device and a network device in the communication network may be performed according to any suitable generation communication protocols, including but not limited to, the first generation (1G), the second generation (2G), 2.5G, 2.75G, the third generation (3G), the fourth generation (4G), 4.5G, the fifth generation (5G) communication protocols, and/or any other protocols either currently known or to be developed in the future. Embodiments of the present disclosure may be applied in various communication systems. Given the rapid development in communications, there will also be future type communication technologies and systems in which the present disclosure may be embodied. It should not be seen as limiting the scope of the present disclosure to only the aforementioned systems.

[0071] As used herein, the term “network device” generally refers to a node in a communication network via which a terminal device can access the communication network and receive services therefrom. The network device may refer to a base station (BS) or an access point (AP), for example, a node B (NodeB or NB), a radio access network (RAN) node, an evolved NodeB (eNodeB or eNB), an NR NB (also referred to as a gNB), a remote radio unit (RRU), a radio header (RH), an infrastructure device for a V2X (vehicle-to-everything) communication, a transmission and reception point (TRP), a reception point (RP), a remote radio head (RRH), a relay, an integrated access and backhaul (IAB) node, a low power node such as a femto BS, a pico BS, and so forth, depending on the applied terminology and technology.

[0072] As used herein, the term “terminal device” generally refers to any end device that may be capable of wireless communications. By way of example rather than a limitation, a terminal device may also be referred to as a communication device, a user equipment (UE), an end user device, a subscriber station (SS), an unmanned aerial vehicle (UAV), a portable subscriber station, a mobile station (MS), or an access terminal (AT). The terminal device may include, but is not limited to, a mobile phone, a cellular phone, a smart phone, a voice over IP (VoIP) phone, a wireless local loop phone, a tablet, a wearable terminal device, a personal digital assistant (PDA), a portable computer, a desktop computer, an image capture terminal device such as a digital camera, a gaming terminal device, a music storage and playback appliance, a vehicle-mounted wireless terminal device, a wireless endpoint, a mobile station, laptop-embedded equipment (LEE), laptop-mounted equipment (LME), a USB dongle, a smart device, wireless customer-premises equipment (CPE), an internet of things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical device (for example, a remote surgery device), an industrial device (for example, a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. In the following description, the terms: “terminal device,” “communication device,” “terminal,” “user equipment” and “UE,” may be used interchangeably.

[0073] Network energy saving (NES) is of great importance for environmental sustainability, to reduce environmental impact (greenhouse gas emissions), and for operational cost savings. One method to achieve NES is to introduce PRACH resource adaptation in time domain. From a high level, this means that the PRACH resources could be configured based on needs. For example, dense PRACH resources are configured for high load scenarios while sparse PRACH resources are configured for low load scenarios. With this way, the number of PRACH receptions in network side is reduced and network energy saving is achieved.

[0074] On the other hand, in low load scenarios when sparse PRACH resources are configured (e.g., PRACH resources are configured with a long periodicity), when a RACH procedure is to be initiated by a UE, the UE may need to wait a long time to start the RACH procedure. Besides, if the first RACH attempt fails, the UE needs to wait a

long time to restart the RACH procedure. Thus, there is a need to reduce the latency in RACH procedures.

[0075] In view of the above, embodiments of the present disclosure provide solutions to dynamically configure or activate additional PRACH resources for the RACH procedure based on actual needs while maintaining the configuration of PRACH resources with a long periodicity. In an aspect of the solution, additional PRACH resource(s) can be configured or activated by at least one of a PDCCH order, a paging signaling, or a DCI for scheduling a SIB1. Thus, the base station would know about when a UE needs the PRACH resource for starting a RACH procedure, and is able to dynamically configure or activate the additional PRACH resources for the UE. The latency of the RACH procedure may be reduced correspondingly. Aspects of the present disclosure are described in the context of a wireless communications system.

[0076] FIG. 1A illustrates an example of a wireless communications system 100 that supports PRACH resource adaptation in accordance with aspects of the present disclosure. The wireless communications system 100 may include one or more network entities 102 (also referred to as network equipment (NE)), one or more UEs 104, a core network 106, and a packet data network 108. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a 4G network, such as an LTE network or an LTE-Advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be a 5G network, such as an NR network. In other implementations, the wireless communications system 100 may be a combination of a 4G network and a 5G network, or other suitable radio access technology including Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G. Additionally, the wireless communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

[0077] The one or more network entities 102 may be dispersed throughout a geographic region to form the wireless communications system 100. One or more of the network entities 102 described herein may be or include or may be referred to as a network node, a base station, a network element, a radio access network (RAN), a base transceiver

station, an access point, a NodeB, an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. A network entity 102 and a UE 104 may communicate via a communication link 110, which may be a wireless or wired connection. For example, a network entity 102 and a UE 104 may perform wireless communication (e.g., receive signaling, transmit signaling) over a Uu interface.

[0078] A network entity 102 may provide a geographic coverage area 112 for which the network entity 102 may support services (e.g., voice, video, packet data, messaging, broadcast, etc.) for one or more UEs 104 within the geographic coverage area 112. For example, a network entity 102 and a UE 104 may support wireless communication of signals related to services (e.g., voice, video, packet data, messaging, broadcast, etc.) according to one or multiple radio access technologies. In some implementations, a network entity 102 may be moveable, for example, a satellite associated with a non-terrestrial network. In some implementations, different geographic coverage areas 112 associated with the same or different radio access technologies may overlap, but the different geographic coverage areas 112 may be associated with different network entities 102. Information and signals described herein may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0079] The one or more UEs 104 may be dispersed throughout a geographic region of the wireless communications system 100. A UE 104 may include or may be referred to as a mobile device, a wireless device, a remote device, a remote unit, a handheld device, or a subscriber device, or some other suitable terminology. In some implementations, the UE 104 may be referred to as a unit, a station, a terminal, or a client, among other examples. Additionally, or alternatively, the UE 104 may be referred to as an Internet-of-Things (IoT) device, an Internet-of-Everything (IoE) device, or machine-type communication (MTC) device, among other examples. In some implementations, a UE 104 may be stationary in the wireless communications system 100. In some other implementations, a UE 104 may be mobile in the wireless communications system 100.

[0080] The one or more UEs 104 may be devices in different forms or having different capabilities. Some examples of UEs 104 are illustrated in FIG. 1A. A UE 104 may be

capable of communicating with various types of devices, such as the network entities 102, other UEs 104, or network equipment (e.g., the core network 106, the packet data network 108, a relay device, an integrated access and backhaul (IAB) node, or another network equipment), as shown in FIG. 1A. Additionally, or alternatively, a UE 104 may support communication with other network entities 102 or UEs 104, which may act as relays in the wireless communications system 100.

[0081] A UE 104 may also be able to support wireless communication directly with other UEs 104 over a communication link 114. For example, a UE 104 may support wireless communication directly with another UE 104 over a device-to-device (D2D) communication link. In some implementations, such as vehicle-to-vehicle (V2V) deployments, vehicle-to-everything (V2X) deployments, or cellular-V2X deployments, the communication link 114 may be referred to as a sidelink. For example, a UE 104 may support wireless communication directly with another UE 104 over a PC5 interface.

[0082] A network entity 102 may support communications with the core network 106, or with another network entity 102, or both. For example, a network entity 102 may interface with the core network 106 through one or more backhaul links 116 (e.g., via an S1, N2, N2, or another network interface). The network entities 102 may communicate with each other over the backhaul links 116 (e.g., via an X2, Xn, or another network interface). In some implementations, the network entities 102 may communicate with each other directly (e.g., between the network entities 102). In some other implementations, the network entities 102 may communicate with each other or indirectly (e.g., via the core network 106). In some implementations, one or more network entities 102 may include subcomponents, such as an access network entity, which may be an example of an access node controller (ANC). An ANC may communicate with the one or more UEs 104 through one or more other access network transmission entities, which may be referred to as a radio heads, smart radio heads, or transmission-reception points (TRPs).

[0083] In some implementations, a network entity 102 may be configured in a disaggregated architecture, which may be configured to utilize a protocol stack physically or logically distributed among two or more network entities 102, such as an integrated access backhaul (IAB) network, an open RAN (O-RAN) (e.g., a network configuration sponsored by the O-RAN Alliance), or a virtualized RAN (vRAN) (e.g., a cloud RAN (C-

RAN)). For example, a network entity 102 may include one or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a RAN Intelligent Controller (RIC) (e.g., a Near-Real Time RIC (Near-RT RIC), a Non-Real Time RIC (Non-RT RIC)), a Service Management and Orchestration (SMO) system, or any combination thereof.

[0084] An RU may also be referred to as a radio head, a smart radio head, a remote radio head (RRH), a remote radio unit (RRU), or a transmission reception point (TRP). One or more components of the network entities 102 in a disaggregated RAN architecture may be co-located, or one or more components of the network entities 102 may be located in distributed locations (e.g., separate physical locations). In some implementations, one or more network entities 102 of a disaggregated RAN architecture may be implemented as virtual units (e.g., a virtual CU (VCU), a virtual DU (VDU), a virtual RU (VRU)).

[0085] Split of functionality between a CU, a DU, and an RU may be flexible and may support different functionalities depending upon which functions (e.g., network layer functions, protocol layer functions, baseband functions, radio frequency functions, and any combinations thereof) are performed at a CU, a DU, or an RU. For example, a functional split of a protocol stack may be employed between a CU and a DU such that the CU may support one or more layers of the protocol stack and the DU may support one or more different layers of the protocol stack. In some implementations, the CU may host upper protocol layer (e.g., a layer 3 (L3), a layer 2 (L2)) functionality and signaling (e.g., Radio Resource Control (RRC), service data adaptation protocol (SDAP), Packet Data Convergence Protocol (PDCP)). The CU may be connected to one or more DUs or RUs, and the one or more DUs or RUs may host lower protocol layers, such as a layer 1 (L1) (e.g., physical (PHY) layer) or an L2 (e.g., radio link control (RLC) layer, medium access control (MAC) layer) functionality and signaling, and may each be at least partially controlled by the CU 160.

[0086] Additionally, or alternatively, a functional split of the protocol stack may be employed between a DU and an RU such that the DU may support one or more layers of the protocol stack and the RU may support one or more different layers of the protocol stack. The DU may support one or multiple different cells (e.g., via one or more RUs). In some implementations, a functional split between a CU and a DU, or between a DU and an RU may be within a protocol layer (e.g., some functions for a protocol layer may be

performed by one of a CU, a DU, or an RU, while other functions of the protocol layer are performed by a different one of the CU, the DU, or the RU).

[0087] A CU may be functionally split further into CU control plane (CU-CP) and CU user plane (CU-UP) functions. A CU may be connected to one or more DUs via a midhaul communication link (e.g., F1, F1-c, F1-u), and a DU may be connected to one or more RUs via a fronthaul communication link (e.g., open fronthaul (FH) interface). In some implementations, a midhaul communication link or a fronthaul communication link may be implemented in accordance with an interface (e.g., a channel) between layers of a protocol stack supported by respective network entities 102 that are in communication via such communication links.

[0088] The core network 106 may support user authentication, access authorization, tracking, connectivity, and other access, routing, or mobility functions. The core network 106 may be an evolved packet core (EPC), or a 5G core (5GC), which may include a control plane entity that manages access and mobility (e.g., a mobility management entity (MME), an access and mobility management functions (AMF)) and a user plane entity that routes packets or interconnects to external networks (e.g., a serving gateway (S-GW), a Packet Data Network (PDN) gateway (P-GW), or a user plane function (UPF)). In some implementations, the control plane entity may manage non-access stratum (NAS) functions, such as mobility, authentication, and bearer management (e.g., data bearers, signal bearers, etc.) for the one or more UEs 104 served by the one or more network entities 102 associated with the core network 106.

[0089] The core network 106 may communicate with the packet data network 108 over one or more backhaul links 116 (e.g., via an S1, N2, N2, or another network interface). The packet data network 108 may include an application server 118. In some implementations, one or more UEs 104 may communicate with the application server 118. A UE 104 may establish a session (e.g., a protocol data unit (PDU) session, or the like) with the core network 106 via a network entity 102. The core network 106 may route traffic (e.g., control information, data, and the like) between the UE 104 and the application server 118 using the established session (e.g., the established PDU session). The PDU session may be an example of a logical connection between the UE 104 and the core network 106 (e.g., one or more network functions of the core network 106).

[0090] In the wireless communications system 100, the network entities 102 and the UEs 104 may use resources of the wireless communications system 100 (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers)) to perform various operations (e.g., wireless communications). In some implementations, the network entities 102 and the UEs 104 may support different resource structures. For example, the network entities 102 and the UEs 104 may support different frame structures. In some implementations, such as in 4G, the network entities 102 and the UEs 104 may support a single frame structure. In some other implementations, such as in 5G and among other suitable radio access technologies, the network entities 102 and the UEs 104 may support various frame structures (i.e., multiple frame structures). The network entities 102 and the UEs 104 may support various frame structures based on one or more numerologies.

[0091] One or more numerologies may be supported in the wireless communications system 100, and a numerology may include a subcarrier spacing and a cyclic prefix. A first numerology (e.g., $\mu=0$) may be associated with a first subcarrier spacing (e.g., 15 kHz) and a normal cyclic prefix. In some implementations, the first numerology (e.g., $\mu=0$) associated with the first subcarrier spacing (e.g., 15 kHz) may utilize one slot per subframe. A second numerology (e.g., $\mu=1$) may be associated with a second subcarrier spacing (e.g., 30 kHz) and a normal cyclic prefix. A third numerology (e.g., $\mu=2$) may be associated with a third subcarrier spacing (e.g., 60 kHz) and a normal cyclic prefix or an extended cyclic prefix. A fourth numerology (e.g., $\mu=3$) may be associated with a fourth subcarrier spacing (e.g., 120 kHz) and a normal cyclic prefix. A fifth numerology (e.g., $\mu=4$) may be associated with a fifth subcarrier spacing (e.g., 240 kHz) and a normal cyclic prefix.

[0092] A time interval of a resource (e.g., a communication resource) may be organized according to frames (also referred to as radio frames). Each frame may have a duration, for example, a 10 millisecond (ms) duration. In some implementations, each frame may include multiple subframes. For example, each frame may include 10 subframes, and each subframe may have a duration, for example, a 1 ms duration. In some implementations, each frame may have the same duration. In some implementations, each subframe of a frame may have the same duration.

[0093] Additionally or alternatively, a time interval of a resource (e.g., a communication resource) may be organized according to slots. For example, a subframe may include a number (e.g., quantity) of slots. The number of slots in each subframe may also depend on the one or more numerologies supported in the wireless communications system 100. For instance, the first, second, third, fourth, and fifth numerologies (i.e., $\mu=0$, $\mu=1$, $\mu=2$, $\mu=3$, $\mu=4$) associated with respective subcarrier spacings of 15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz may utilize a single slot per subframe, two slots per subframe, four slots per subframe, eight slots per subframe, and 16 slots per subframe, respectively. Each slot may include a number (e.g., quantity) of symbols (e.g., OFDM symbols). In some implementations, the number (e.g., quantity) of slots for a subframe may depend on a numerology. For a normal cyclic prefix, a slot may include 14 symbols. For an extended cyclic prefix (e.g., applicable for 60 kHz subcarrier spacing), a slot may include 12 symbols. The relationship between the number of symbols per slot, the number of slots per subframe, and the number of slots per frame for a normal cyclic prefix and an extended cyclic prefix may depend on a numerology. It should be understood that reference to a first numerology (e.g., $\mu=0$) associated with a first subcarrier spacing (e.g., 15 kHz) may be used interchangeably between subframes and slots.

[0094] In the wireless communications system 100, an electromagnetic (EM) spectrum may be split, based on frequency or wavelength, into various classes, frequency bands, frequency channels, etc. By way of example, the wireless communications system 100 may support one or multiple operating frequency bands, such as frequency range designations FR1 (410 MHz – 7.125 GHz), FR2 (24.25 GHz – 52.6 GHz), FR3 (7.125 GHz – 24.25 GHz), FR4 (52.6 GHz – 114.25 GHz), FR4a or FR4-1 (52.6 GHz – 71 GHz), and FR5 (114.25 GHz – 300 GHz). In some implementations, the network entities 102 and the UEs 104 may perform wireless communications over one or more of the operating frequency bands. In some implementations, FR1 may be used by the network entities 102 and the UEs 104, among other equipment or devices for cellular communications traffic (e.g., control information, data). In some implementations, FR2 may be used by the network entities 102 and the UEs 104, among other equipment or devices for short-range, high data rate capabilities.

[0095] FR1 may be associated with one or multiple numerologies (e.g., at least three numerologies). For example, FR1 may be associated with a first numerology (e.g., $\mu=0$), which includes 15 kHz subcarrier spacing; a second numerology (e.g., $\mu=1$), which

includes 30 kHz subcarrier spacing; and a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing. FR2 may be associated with one or multiple numerologies (e.g., at least 2 numerologies). For example, FR2 may be associated with a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g., $\mu=3$), which includes 120 kHz subcarrier spacing.

[0096] As mentioned above, in 5G NR systems, the random-access procedure may be utilized for various purposes. For example, the random-access procedure may be utilized by a UE in initial access to find a cell to camp on; or utilized by a RRC IDLE/INACTIVE UE to switch to a RRC CONNECTED mode to start data transmission/reception; or utilized by a RRC CONNECTED UE to re-establish the lost UL synchronization, etc.

[0097] An NR 4-step random-access procedure may be used for RRC IDLE/INACTIVE UEs to access to the network. FIG. 1B illustrates an example of an NR 4-step random-access procedure 120 that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure. For the purpose of discussion, the procedure 120 will be described with reference to FIG. 1A. The procedure 120 may involve a UE 104 and a base station 102 as illustrated in FIG. 1A. It is noted that the 4-step random-access procedure 120 is merely for illustration, and not for limitation. Embodiments of the present disclosure may apply to other random-access procedures.

[0098] In the random-access procedure 120, the UE 104 may firstly transmit 122 a Msg1 including a preamble to the base station 102. After receiving the Msg1, the base station 102 may transmit 124 a Random-Access Response (RAR) in Msg2 to the UE 104, indicating the reception of the preamble and providing necessary information for the transmission of Msg3. The RAR may be received by the UE 104 in a configured time window (RAR window), which starts after a time gap after the UE 104 transmits the Msg1. The UE 104 may then transmit 126 a Msg3 to the base station 102. The base station 102 may transmit 128 a Msg4 to the UE 104. The Msg3 and Msg4 may be used to solve potential collisions due to simultaneous transmissions of the same preamble from different UEs to the base station 102. If the UE 104 does not receive the Msg2 including the RAR after transmitting the Msg1, the UE 104 will treat the random access unsuccessful and may restart the RACH procedure.

[0099] In RACH procedures, the PRACH Msg1 transmission takes place in RACH occasions (ROs), each of which occupies multiple consecutive resource blocks in frequency domain. The ROs may be configured in system information block type 1 (SIB1). The ROs are configured in both time domain and frequency domain. In time domain, the ROs are configured in every PRACH configuration period, which contains a set of radio frames. Within a PRACH configuration period, a subset of subframes is indicated to contain a set of PRACH slots, and within each PRACH slot, there might be one or more available ROs for PRACH transmission. Besides, in frequency domain, the BS may configure a number of frequency-division-multiplexed (FDMed) ROs multiplexed in a same time occasion.

[0100] Each RO is associated with an SSB that is transmitted with a specific beam. The SSBs are transmitted in a beam sweeping way. The UE may measure the channel status of each SSB, select the one with good channel quality, and transmit preamble in an RO that is associated with the selected SSB. Using the beam with good channel quality for preamble transmission is beneficial in terms of preamble reception in the base station side.

[0101] A random-access procedure may be used for RRC CONNECTED UEs to re-establish UL synchronization. FIG. 1C illustrates an example of the random-access procedure 130 that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure. For the purpose of discussion, the procedure 120 will be described with reference to FIG. 1A. The procedure 120 may involve a UE 104 and a base station 102 as illustrated in FIG. 1A. It is noted that the random-access procedure 130 is merely for illustration, and not for limitation. Embodiments of the present disclosure may apply to other random-access procedures.

[0102] In the random-access procedure 130, the base station 102 may transmit 131 a PDCCH order to the UE 104 if the UL synchronization is lost in the network side. The PDCCH order is provided using DCI format 1_0 with the frequency domain assignment set to be all ones (1), indicating that the DCI is not providing a downlink scheduling assignment but rather as a PDCCH order to initiate a RACH procedure. The DCI indicates a dedicated RO and a dedicated preamble index for the UE to transmit PRACH Msg1. The DCI includes an SSB index, indicating that the SSB that should be used to determine the RO for the PRACH transmission (based on SSB to RO association). The

indicated SSB corresponds to the best of beam of the UE. It should be noted that, in legacy, the DCI does not configure ROs but only indicates which RO of the ROs configured in SIB1 is used for PRACH transmission. After receiving the PDCCH order, the UE 104 may transmit 132 a Msg1 including the preamble indicated in the PDCCH order to the base station 102 using the determined RO. After receiving the Msg1, the base station 102 may transmit 134 a RAR in Msg2 to the UE 104, indicating the reception of the preamble.

[0103] Reference is now made to FIG. 2, which illustrates an example signaling chart of a communication process 200 that supports PRACH resource adaptation in accordance with some example embodiments of the present disclosure. For the purpose of discussion, the process 200 will be described with reference to FIG. 1A. The process 200 may involve the UE 104 and the base station 102. It is to be understood that the steps and the order of the steps in FIG. 2 are merely for illustration, and not for limitation. It is to be understood that process 200 may further include additional blocks not shown and/or omit some shown blocks, and the scope of the present disclosure is not limited in this regard.

[0104] As shown in FIG. 2, the base station 102 transmits 201 one of a PDCCH order 202, a paging signaling 203, or a DCI 204 for scheduling a SIB1 to the UE 104. Accordingly, the UE 104 receives 203, from a base station 102, one of the PDCCH order 202, the paging signaling 203, or the DCI 204 for scheduling a SIB1. The received one of the PDCCH order 202, the paging signaling 203, or the DCI 204 for scheduling the SIB1 configures or activates at least one additional RO. In other words, in addition to a set of ROs configured in the SIB1, at least one additional RO is configured or activated by the base station 102. The UE 104 performs 206 a RACH procedure based on the at least one additional RO. The base station 207 monitors 207 a preamble one the at least one additional RO.

[0105] Hereinbefore, some embodiments of the PRACH resource adaptation are described in general terms. Hereinafter, some implementations of the PRACH resource adaptation will be further detailed in regard to various specific aspects.

[0106] A first specific aspect is about triggering a PRACH resource adaptation by the PDCCH order. For example, when the UE 104 is in a RRC CONNECTED mode, if the UL synchronization is lost, a PDCCH order may be transmitted to the UE 104 requesting the UE 104 to start a RACH procedure to re-establish the UL synchronization. If PRACH

resources with a long periodicity are configured, the UE 104 might need to wait a long time to start or restart the RACH procedure. This would lead to a high latency to re-establish UL synchronization.

[0107] In some embodiments of the present disclosure, the at least one additional RO may include one additional RO. The additional RO is configured or activated by the PDCCH order 202. In some implementations, the PRACH format of the additional PRACH resource can be always same with that configured in SIB1 or it is indicated by PDCCH order 202 as well.

[0108] In some implementations, the PDCCH order 202 may include resource configurations or resource allocations for the additional RO. For example, an additional RO may be configured in the PDCCH order 202. When the UE 104 receives a PDCCH order 202, the UE 104 could start the RACH procedure in the additional RO configured by the PDCCH order 202. The PDCCH order 202 allocates at least the time domain and frequency domain resources of the additional RO. For example, the starting OFDM symbol and the starting PRB of the additional RO are indicated in the PDCCH order 202. It should be noted that the number of OFDM symbols and physical resource blocks (PRBs) might not be indicated but determined by the PRACH format. The reserved bits (12bits) in the PDCCH order 202 could be reused for allocation of the time domain and frequency domain resources.

[0109] In some implementations, the UE 104 may receive, from the base station 102, resource configurations for the additional RO carried in a medium access control (MAC) control element (CE) signaling or a radio resource control (RRC) signaling. The PDCCH order 202 may include an indication of activating the additional RO. For example, the additional PRACH resource may be configured semi-statically by RRC/MAC signaling, and is activated by an information element in the PDCCH order 202.

[0110] In some implementations, the additional RO is associated with a SSB indicated in the PDCCH order 202. The indicated SSB is already the one corresponding to the best of beam of the UE, so there is no need to associate the additional ROs with other SSBs. This further reduces the power consumption in the base station side on the PRACH detection.

[0111] In some implementations, the additional RO is a first additional RO. When performing the RACH procedure, the UE 104 may transmit a preamble on the first

additional RO to the base station 102 and monitor a RAR message indicating reception of the preamble in a RAR window. A time offset between the PDCCH order 202 and a first slot with the first additional RO may be configured by the base station 102 or predefined. In other words, there could be a predefined or configured timing offset between PDCCH order 202 (i.e., the DCI) and the first slot with additional RO. Based on this timing, the UE 104 could know when the additional RO is available.

[0112] In some implementations, if no RAR message is received in the RAR window, the UE 104 may perform a second RACH procedure based on a second additional RO. A time offset between the end of the RAR window and a second slot with the second additional RO is configured by the base station 102 or predefined. The second additional RO may have the same configurations with the first additional RO. In other words, the additional RO may be available if a preamble is transmitted in the additional RO but no RAR message is received. In a more specific example, if a PRACH preamble is transmitted in the additional RO but a RAR is not received by the UE 104, the UE 104 may assume that the additional RO is still available after a predefined or configured time offset from the end of the RAR window. The UE 104 may transmit the PRACH again in the additional RO with a higher transmission power.

[0113] Reference is now made to FIG. 3, which illustrates an example 300 of PRACH resource adaptation by a PDCCH order in accordance with some example embodiments of the present disclosure. In the example 300, a set of PRACH resources are configured in SIB1. The legacy ROs correspond to the PRACH resources configured in SIB1 and has a long period. In other words, the legacy ROs are used by the UEs not supporting additional ROs or not supporting PRACH resource adaptation. In addition to the legacy ROs, an additional RO is configured or triggered by the PDCCH order. Upon receiving the PDCCH order, the UE supporting the additional PRACH adaptation may start the RACH procedure from the additional RO, instead of waiting a long time to start the procedure in the legacy ROs. The latency of the PRACH procedure may thus be reduced.

[0114] Returning back to FIG. 2, a second specific aspect is about triggering a PRACH resource adaptation by a paging signaling. The UE will start RACH procedure after receiving a paging message. The paging of a UE mostly happens when DL data is arrived in the network for the UE. If only RACH resources with a long periodicity are available when the UE is paged in a paging occasion (PO), and if the available ROs are

far away from the PO, the UE needs to wait a long time to start the RACH procedure. Besides, even the available ROs are near the PO, if the first PRACH attempt fails, the UE might need to wait a long time to restart the RACH procedure. This would result in a high latency of the UE accessing the network when the UE is paged.

[0115] In some implementations, the at least one additional ROs may include a set of additional ROs. The set of additional RO is configured or activated by the paging signaling 203. The paging signaling 203 may be one of a paging message, a paging DCI for scheduling the paging message, or a paging early indication (PEI) indicative of a presence of the paging message. In other words, additional PRACH resources for a UE 104 could be configured or activated by a paging signaling, which is either paging DCI or PEI or paging message. When the UE 104 is paged, the UE 104 could start or re-start the RACH procedure in the additional PRACH resources.

[0116] In some implementations, the UE 104 may transmit, to a network device, an indication of a capability of supporting PRACH resource adaptation triggered by the paging signaling. The network device may be implemented as an apparatus for performing an access and mobility management function (AMF). The network device may transmit, to the base station 102, an indication of a capability of the UE 104 supporting the PRACH resource adaptation triggered by the paging signaling. In this way, the base station is able to identify the UEs supporting additional PRACH resource allocation, such that when a UE supporting additional PRACH resource allocation is paged, the base station could configure the additional PRACH resource for the UE.

[0117] FIG. 4 illustrates an example signaling chart of a communication process 400 that supports PRACH resource adaptation by a paging signaling in accordance with some example embodiments of the present disclosure. For the purpose of discussion, the process 400 will be described with reference to FIG. 1A. The process 400 may involve the UE 104 and the base station 102 as shown in FIG. 1A and an AMF 106-1 not shown in FIG. 1A. The AMF 106-1 may be a network function in the core network 106 in FIG. 1A. It is to be understood that the steps and the order of the steps in FIG. 4 are merely for illustration, and not for limitation. It is to be understood that process 400 may further include additional blocks not shown and/or omit some shown blocks, and the scope of the present disclosure is not limited in this regard. The process 400 may be regarded as a specific example of the process 200 in FIG. 2.

[0118] In the process 400, at 401, the UE 104 reports to the AMF 106-1 about its capability of supporting configuring additional PRACH resources. The reporting could be performed through NAS signaling when the UE 104 registers in the network. At 402, the AMF 106-1 indicates the base station 102 about which UEs support PRACH resource adaptation. When the base station 102 pages a UE with such capability, the base station 102 can trigger additional PRACH resources to be available in the paging signaling. For example, at 403, the base station 102 obtains a paging message for the UE 104. Since the base station 102 is aware about the UE's capability of supporting configuring additional PRACH resources, at 404, the base station 102 may transmit a paging message to the UE 104 to activate additional PRACH resources. At 405, the UE 104 may transmit a PRACH preamble in the additional PRACH resources.

[0119] In some implementations, the paging signaling 203 may include resource configurations for the set of additional ROs. In other words, the additional ROs may be configured by the paging signaling.

[0120] In some implementations, the UE 104 may receive the SIB1 from the base station 102. The SIB1 may include resource configurations for the set of additional ROs. The paging signaling 203 may include an indication of activating the set of additional ROs. In other words, in addition to configuring the PRACH resources with a PRACH configuration period, the SIB1 may further configure a set of additional PRACH resources. The set of additional PRACH resources may be configured in SIB1 and activated by an indicator in the paging signaling. In one embodiment, the indicator may be a 1-bit indicator, which is either newly added to the paging signaling or reuses the reserved bit in the paging signaling, e.g., the short message indicator.

[0121] In some implementations, the UE 104 may receive the SIB1 from the base station 102. The SIB1 may include resource configurations for at least one set of additional ROs. The at least one set of additional ROs may include the set of additional ROs. The paging signaling 203 may include an indication of the set of additional ROs. The set of additional ROs is activated by the paging signaling 203. In other words, in addition to configuring the PRACH resources with a PRACH configuration period, the SIB1 may further configure multiple sets of additional PRACH resources, and the paging signalling may indicate which set of additional PRACH resources will be activated.

[0122] In some implementations, a time offset between a last monitoring occasion for the paging DCI and a first slot with the set of additional ROs may be configured by the base station 102 or predefined. Alternatively, a time offset between a last slot with the paging message and a first slot with the set of additional ROs may be configured by the base station 102 or predefined. In some implementations, the at least one additional RO is available in a time window, wherein the time window is configured by the base station 102 or predefined.

[0123] Reference is now made to FIG. 5, which illustrates an example 500 of PRACH resource adaptation by a paging signaling in accordance with some example embodiments of the present disclosure. In the example 500, a PO#0 521 contains four PDCCH monitoring occasions 521-1, 521-2, 521-3 and 521-4 for the paging DCI. Each monitoring occasion is associated with a specific beam. Upon receiving a paging DCI in a monitoring occasion (e.g., the PDCCH monitoring occasion 521-3), the UE supporting PRACH resource adaptation may determine a set of additional PRACH resources. There could be a predefined or configured time offset t between the last PDCCH monitoring occasion (e.g., the PDCCH monitoring occasion 521-4) for the paging DCI and the first slot with additional PRACH resources or between the last slot with paging message and the first slot with additional PRACH resources. Based on this timing, the UE would know when the additional PRACH resources are available. Besides, a time window may be configured within which the additional PRACH resources are available. In the example 500, additional PRACH resources 511-1, 511-2, 511-3, 511-4 and 512-1, 512-2, 512-3, 512-4 are available. The PDCCH monitoring occasions and the additional ROs associated with the same beam are shown with the same shadow in FIG. 5. When the UE is paged, the UE may start the RACH procedure in an additional RO instead of waiting a long time to start the procedure in a legacy RO. For example, if the UE receives the paging DCI in the PDCCH monitoring occasion 521-3, the UE may start the RACH procedure in the first additional RO 511-3 associated with the same beam with the PDCCH monitoring occasion 521-3.

[0124] Returning back to FIG. 2, a third specific aspect is about triggering a PRACH resource adaptation by a DCI for scheduling SIB1. In some implementations, the at least one additional RO may include a set of additional ROs. The set of additional RO is activated by the DCI 204 for scheduling the SIB1. The DCI 204 for scheduling the SIB1

may include an indication of an availability of a set of additional ROs. The SIB1 may include resource configurations for the set of additional ROs.

[0125] In other words, additional PRACH resources could be triggered in the DCI for scheduling a SIB1, which is transmitted periodically using a beam sweeping way. Using the DCI for scheduling a SIB1 to trigger the activation of additional PRACH resources may avoid frequent changing of SIB1 and is thus beneficial in terms of SIB1 detection and avoiding frequent signaling of system information modification. An information element in the SIB1 DCI may be used to indicate the availability of the additional PRACH resources. For example, the reserved bit in the SIB1 DCI can be used for the indication. From the point of view of the UE 104, when the UE 104 receives the SIB1 and gets the indication, it reads the SIB1 and gets the configured additional PRACH resources.

[0126] In some implementations, a time offset between a last slot with the DCI 204 for scheduling the SIB1 and a first slot with the set of additional ROs is configured by the base station 102 or predefined. Alternatively, a time offset between a last slot with the SIB1 and a first slot with the set of additional ROs is configured by the base station 102 or predefined. In some implementations, the at least one additional RO is available in a time window, wherein the time window is configured by the base station 102 or predefined. In other words, there could be a predefined or configured time offset between the last slot with the DCI for scheduling the SIB1 and the first slot with additional PRACH resources or between the last slot with SIB1 and the first slot with additional PRACH resources. Based on this timing, the UE 104 would know when the additional PRACH resources are available. Besides, a time window may be configured within which the additional PRACH resources are available.

[0127] A fourth specific aspect is about SSB-to-RO association for the additional ROs. As mentioned above, for the additional RO configured or activated by PDCCH order 202, which is used by a RRC CONNECTED UE, the additional RO is associated with the indicated SSB in the PDCCH order 202. While for additional ROs configured or activated by the paging signaling or the DCI for scheduling SIB1, which are mostly used for RRC IDLE/INACTIVE UEs, the additional ROs should be associated with all the available SSBs (indicated in the SIB) since the base station has no knowledge on which beam will be selected by the UE 104 for the preamble transmission. In order not to impact the SSB to RO association for legacy ROs, the SSB to RO association for the additional ROs can

be separately determined. However, this means that the UE supporting the additional PRACH adaptation needs to maintain two association relationships, one for legacy ROs configured in SIB1 and the other for the additional ROs. This might lead to a higher complexity at the UE side.

[0128] In some implementations, the UE 104 may receive the SIB1 from a base station 102, determine the set of ROs based on the SIB1, and perform a unified SSB-to-RO association for the set of ROs and the at least one additional RO. In other words, a unified SSB-to-RO association may be implemented for the legacy ROs and the additional ROs without changing the SSB-to-RO association of legacy ROs.

[0129] In some implementations, the at least one additional RO may include a set of additional ROs. To perform the unified SSB-to-RO association, the UE may perform a first SSB-to-RO association for the set of legacy ROs, and determine a second SSB-to-RO association for the set of additional ROs based on the first SSB-to-RO association. In some examples, the second SSB-to-RO association may follow the first SSB-to-RO association in a sequential and wrap round way. In other words, in the unified SSB-to-RO association, the UE 104 may perform the SSB-to-RO association of legacy ROs, then the SSB-to-RO association for the additional ROs may be determined based on the SSB-to-RO association of the legacy ROs. As one embodiment, the additional ROs are associated with the SSBs in a sequential and wrap round way.

[0130] For example, assuming the available SSBs in the network is $\{\text{SSB}\#k_1, \text{SSB}\#k_2, \text{SSB}\#k_3, \dots, \text{SSB}\#k_N\}$, where $k_1 < k_2 < k_3 < \dots < k_N$. If the SSBs and the legacy ROs are one-to-one mapped or one-to-M mapped, and the last legacy RO before a set of additional ROs maps to $\text{SSB}\#k_n$, the first additional RO of the set of additional ROs would map to $\text{SSB}\#k_n+1$. If the SSBs and the legacy ROs are one-to-one mapped or one-to-M mapped, and the last legacy RO before a set of additional ROs maps to $\text{SSB}\#k_N$, the first additional RO of the set of additional ROs would map to $\text{SSB}\#k_1$. If the SSBs and legacy ROs are M-to-one mapped, and the last legacy RO before a set of additional ROs maps to $\text{SSB}\#k_n-M+1$ to $\text{SSB}\#k_n$, the first additional RO of the set of additional ROs would map to $\text{SSB}\#k_n+1$ to $\text{SSB}\#k_n+M$. If the SSBs and legacy ROs are M-to-one mapped, and the last legacy RO before a set of additional ROs maps to $\text{SSB}\#k_N-M+1$ to $\text{SSB}\#k_N$, the first additional RO of the set of additional ROs would map to $\text{SSB}\#k_1$ to $\text{SSB}\#k_M$.

[0131] Reference is now made to FIG. 6, which illustrates an example 600 of a SSB-to-RO association in accordance with some example embodiments of the present disclosure. In the example 600, the SSBs and the legacy ROs are one-to-one mapped. The last legacy RO 601 before the configured set of additional set of ROs maps to SSB#3, and the first additional RO 611 of the configured set of additional ROs maps to SSB#4. The SSBs are sequentially mapped to the additional ROs and the legacy ROs.

[0132] Returning back to FIG. 2, in some implementations, the UE 104 may determine one of the at least one additional RO as invalid if the additional RO is overlapped with one of the set of ROs. In other words, the configured additional RO(s) collides with the legacy ROs in a slot, the UE 104 and base station 102 may treat the additional RO(s) colliding with the legacy ROs as invalid ROs and cannot be used for PRACH transmission.

[0133] In some implementations, the UE 104 may determine one or more of the set of additional ROs as invalid if the one or more additional ROs and at least one of the set of ROs subsequent to the one or more additional ROs cannot form a SSB-to-RO mapping cycle. Reference is now made to FIG. 7, which illustrates another example 700 of a SSB-to-RO association in accordance with some example embodiments of the present disclosure. In the example 700, after performing a unified SSB-to-RO association, four additional ROs 711, 712, 713 and 714 cannot form a mapping cycle. These ROs are invalid ROs and cannot be used for PRACH transmission.

[0134] FIG. 8 illustrates an example of a device 800 that supports PRACH resource adaptation in accordance with aspects of the present disclosure. The device 800 may be an example of a UE 104 or a base station 102 as described herein. The device 800 may support wireless communication with one or more network entities 102, UEs 104, or any combination thereof. The device 800 may include components for bi-directional communications including components for transmitting and receiving communications, such as a processor 802, a memory 804, a transceiver 806, and, optionally, an I/O controller 808. These components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0135] The processor 802, the memory 804, the transceiver 806, or various combinations thereof or various components thereof may be examples of means for

performing various aspects of the present disclosure as described herein. For example, the processor 802, the memory 804, the transceiver 806, or various combinations or components thereof may support a method for performing one or more of the operations described herein.

[0136] In some implementations, the processor 802, the memory 804, the transceiver 806, or various combinations or components thereof may be implemented in hardware (e.g., in communications management circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA) or other programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure. In some implementations, the processor 802 and the memory 804 coupled with the processor 802 may be configured to perform one or more of the functions described herein (e.g., executing, by the processor 802, instructions stored in the memory 804).

[0137] In an example, the processor 802 may support wireless communication at the device 800 in accordance with examples as disclosed herein. The processor 802 may be configured to operable to support a means for receiving, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and a means for performing a RACH procedure based on the at least one additional RO.

[0138] In another example, the processor 802 may support wireless communication at the device 800 in accordance with examples as disclosed herein. The processor 802 may be configured to operable to support a means for transmitting, to a user equipment (UE), one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and a means for monitoring a preamble on the at least one additional RO.

[0139] The processor 802 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, a microcontroller, an ASIC, an FPGA, a programmable logic device, a discrete gate or transistor logic component, a discrete hardware component, or any combination thereof). In some implementations, the processor 802 may be configured to operate a memory array using a memory controller. In some other implementations, a memory controller may be integrated into the processor 802. The processor 802 may be configured to execute computer-readable instructions stored in a memory (e.g., the memory 804) to cause the device 800 to perform various functions of the present disclosure such that the device 800 may perform any process of the disclosure as discussed with reference to FIGS. 2 to 7B.

[0140] The memory 804 may include random access memory (RAM) and read-only memory (ROM). The memory 804 may store computer-readable, computer-executable code including instructions that, when executed by the processor 802 cause the device 800 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. In some implementations, the code may not be directly executable by the processor 802 but may cause a computer (e.g., when compiled and executed) to perform functions described herein. In some implementations, the memory 804 may include, among other things, a basic I/O system (BIOS) which may control basic hardware or software operation such as the interaction with peripheral components or devices.

[0141] The I/O controller 808 may manage input and output signals for the device 800. The I/O controller 808 may also manage peripherals not integrated into the device 800. In some implementations, the I/O controller 808 may represent a physical connection or port to an external peripheral. In some implementations, the I/O controller 808 may utilize an operating system such as iOS®, ANDROID®, MS-WINDOWS®, OS/2®, UNIX®, LINUX®, or another known operating system. In some implementations, the I/O controller 808 may be implemented as part of a processor, such as the processor 802. In some implementations, a user may interact with the device 800 via the I/O controller 808 or via hardware components controlled by the I/O controller 808.

[0142] In some implementations, the device 800 may include a single antenna 810. However, in some other implementations, the device 800 may have more than one

antenna 810 (i.e., multiple antennas), including multiple antenna panels or antenna arrays, which may be capable of concurrently transmitting or receiving multiple wireless transmissions. The transceiver 806 may communicate bi-directionally, via the one or more antennas 810, wired, or wireless links as described herein. For example, the transceiver 806 may represent a wireless transceiver and may communicate bi-directionally with another wireless transceiver. The transceiver 806 may also include a modem to modulate the packets, to provide the modulated packets to one or more antennas 810 for transmission, and to demodulate packets received from the one or more antennas 810. The transceiver 806 may include one or more transmit chains, one or more receive chains, or a combination thereof.

[0143] A transmit chain may be configured to generate and transmit signals (e.g., control information, data, packets). The transmit chain may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmit chain may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmit chain may also include one or more antennas 810 for transmitting the amplified signal into the air or wireless medium.

[0144] A receive chain may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receive chain may include one or more antennas 810 for receive the signal over the air or wireless medium. The receive chain may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receive chain may include at least one demodulator configured to demodulate the receive signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receive chain may include at least one decoder for decoding the processing the demodulated signal to receive the transmitted data.

[0145] FIG. 9 illustrates an example of a processor 900 that supports PRACH resource adaptation in accordance with aspects of the present disclosure. The processor 900 may be an example of a processor configured to perform various operations in

accordance with examples as described herein. The processor 900 may be implemented in a device or its components as described herein. For example, the device may be an example of a UE 104 or a base station 102 as described herein. The processor 900 may include a controller 902 configured to perform various operations in accordance with examples as described herein. The processor 900 may optionally include at least one memory 904, such as L1/L2/L3 cache. Additionally, or alternatively, the processor 900 may optionally include one or more arithmetic-logic units (ALUs) 900. One or more of these components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0146] The processor 900 may be a processor chipset and include a protocol stack (e.g., a software stack) executed by the processor chipset to perform various operations (e.g., receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) in accordance with examples as described herein. The processor chipset may include one or more cores, one or more caches (e.g., memory local to or included in the processor chipset (e.g., the processor 900) or other memory (e.g., random access memory (RAM), read-only memory (ROM), dynamic RAM (DRAM), synchronous dynamic RAM (SDRAM), static RAM (SRAM), ferroelectric RAM (FeRAM), magnetic RAM (MRAM), resistive RAM (RRAM), flash memory, phase change memory (PCM), and others).

[0147] The controller 902 may be configured to manage and coordinate various operations (e.g., signaling, receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) of the processor 900 to cause the processor 900 to support various operations in accordance with examples as described herein. For example, the controller 902 may operate as a control unit of the processor 900, generating control signals that manage the operation of various components of the processor 900. These control signals include enabling or disabling functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

[0148] The controller 902 may be configured to fetch (e.g., obtain, retrieve, receive) instructions from the memory 904 and determine subsequent instruction(s) to be executed to cause the processor 900 to support various operations in accordance with examples as

described herein. The controller 902 may be configured to track memory address of instructions associated with the memory 904. The controller 902 may be configured to decode instructions to determine the operation to be performed and the operands involved. For example, the controller 902 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 900 to cause the processor 900 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 902 may be configured to manage flow of data within the processor 900. The controller 902 may be configured to control transfer of data between registers, arithmetic logic units (ALUs), and other functional units of the processor 900.

[0149] The memory 904 may include one or more caches (e.g., memory local to or included in the processor 900 or other memory, such RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc. In some implementation, the memory 904 may reside within or on a processor chipset (e.g., local to the processor 900). In some other implementations, the memory 904 may reside external to the processor chipset (e.g., remote to the processor 900).

[0150] The memory 904 may store computer-readable, computer-executable code including instructions that, when executed by the processor 900, cause the processor 900 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. The controller 902 and/or the processor 900 may be configured to execute computer-readable instructions stored in the memory 904 to cause the processor 900 to perform various functions. For example, the processor 900 and/or the controller 902 may be coupled with or to the memory 904, and the processor 900, the controller 902, and the memory 904 may be configured to perform various functions described herein. In some examples, the processor 900 may include multiple processors and the memory 904 may include multiple memories. One or more of the multiple processors may be coupled with one or more of the multiple memories, which may, individually or collectively, be configured to perform various functions herein.

[0151] The one or more ALUs 900 may be configured to support various operations in accordance with examples as described herein. In some implementation, the one or more ALUs 900 may reside within or on a processor chipset (e.g., the processor 900). In

some other implementations, the one or more ALUs 900 may reside external to the processor chipset (e.g., the processor 900). One or more ALUs 900 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 900 may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 900 be configured with a variety of logical and arithmetic circuits, including adders, subtractors, shifters, and logic gates, to process and manipulate the data according to the operation. Additionally, or alternatively, the one or more ALUs 900 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 900 to handle conditional operations, comparisons, and bitwise operations.

[0152] In an example, the processor 900 may support wireless communication in accordance with examples as disclosed herein. The processor 900 may be configured to or operable to support a means for receiving, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and a means for performing a RACH procedure based on the at least one additional RO.

[0153] In another example, the processor 900 may support wireless communication in accordance with examples as disclosed herein. The processor 900 may be configured to or operable to support a means for transmitting, to a user equipment (UE), one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and a means for monitoring a preamble on the at least one additional RO.

[0154] FIG. 10 illustrates a flowchart of a method 1000 that supports PRACH resource adaptation in accordance with aspects of the present disclosure. The operations of the method 1000 may be implemented by a device or its components as described herein. For example, the operations of the method 1000 may be performed by a UE 104

as described herein. In some implementations, the device may execute a set of instructions to control the function elements of the device to perform the described functions. Additionally, or alternatively, the device may perform aspects of the described functions using special-purpose hardware.

[0155] At 1005, the method may include receiving, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO. The operations of 1005 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1005 may be performed by a device as described with reference to FIG. 1A.

[0156] At 1010, the method may include performing a RACH procedure based on the at least one additional RO. The operations of 1010 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1010 may be performed by a device as described with reference to FIG. 1A.

[0157] FIG. 11 illustrates a flowchart of a method 1100 that supports requests for PRACH resources in accordance with aspects of the present disclosure. The operations of the method 1100 may be implemented by a device or its components as described herein. For example, the operations of the method 1100 may be performed by a base station 102 as described herein. In some implementations, the device may execute a set of instructions to control the function elements of the device to perform the described functions. Additionally, or alternatively, the device may perform aspects of the described functions using special-purpose hardware.

[0158] At 1105, the method may include transmitting, to a user equipment (UE), one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO. The operations of 1105 may be performed in accordance with examples as described herein. In some implementations,

aspects of the operations of 1105 may be performed by a device as described with reference to FIG. 1A.

[0159] At 1110, the method may include monitoring a preamble on the at least one additional RO. The operations of 1110 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1110 may be performed by a device as described with reference to FIG. 1A.

[0160] FIG. 12 illustrates a flowchart of a method 1200 that supports PRACH resource adaptation in accordance with aspects of the present disclosure. The operations of the method 1200 may be implemented by a device or its components as described herein. For example, the operations of the method 1200 may be performed by an AMF 106-1 as described herein. In some implementations, the device may execute a set of instructions to control the function elements of the device to perform the described functions. Additionally, or alternatively, the device may perform aspects of the described functions using special-purpose hardware.

[0161] At 1205, the method may include receiving, from a user equipment (UE), an indication of a capability of the UE supporting physical random access channel (PRACH) resource adaptation triggered by a paging signaling. The operations of 1205 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1205 may be performed by a device as described with reference to FIG. 1A.

[0162] At 1210, the method may include transmitting, to a base station, an indication of a capability of the UE supporting the PRACH resource adaptation triggered by the paging signaling. The operations of 1210 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1210 may be performed by a device as described with reference to FIG. 1A.

[0163] It should be noted that the methods described herein describes possible implementations, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible. Further, aspects from two or more of the methods may be combined.

[0164] The various illustrative blocks and components described in connection with the disclosure herein may be implemented or performed with a general-purpose processor,

a DSP, an ASIC, a CPU, an FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

[0165] The functions described herein may be implemented in hardware, software executed by a processor, firmware, or any combination thereof. If implemented in software executed by a processor, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Other examples and implementations are within the scope of the disclosure and appended claims. For example, due to the nature of software, functions described herein may be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations.

[0166] Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer. By way of example, non-transitory computer-readable media may include RAM, ROM, electrically erasable programmable ROM (EEPROM), flash memory, compact disk (CD) ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other non-transitory medium that may be used to carry or store desired program code means in the form of instructions or data structures and that may be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor.

[0167] As used herein, including in the claims, an article “a” before an element is unrestricted and understood to refer to “at least one” of those elements or “one or more” of those elements. The terms “a,” “at least one,” “one or more,” and “at least one of one

or more” may be interchangeable. As used herein, including in the claims, “or” as used in a list of items (e.g., a list of items prefaced by a phrase such as “at least one of” or “one or more of” or “one or both of”) indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Also, as used herein, the phrase “based on” shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as “based on condition A” may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase “based on” shall be construed in the same manner as the phrase “based at least in part on. Further, as used herein, including in the claims, a “set” may include one or more elements.

[0168] The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

CLAIMS

What is claimed is:

1. A user equipment comprising:
a processor; and
a transceiver coupled to the processor,
wherein the processor is configured to:
receive, via the transceiver from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and
perform a RACH procedure based on the at least one additional RO.
2. The UE of claim 1, wherein the at least one additional RO comprises one additional RO, the additional RO is configured or activated by the PDCCH order, the additional RO is associated with a synchronization signal and physical broadcast channel (PBCH) block (SSB) indicated in the PDCCH order.
3. The UE of claim 2, wherein the PDCCH order comprises resource configurations for the additional RO.
4. The UE of claim 2, wherein the additional RO is a first additional RO, and performing the RACH procedure comprises:
transmitting, via the transceiver to the base station, a preamble on the first additional RO, wherein a time offset between the PDCCH order and a first slot with the first additional RO is configured by the base station or predefined; and
monitoring, in a RAR window, a random access response (RAR) message indicating reception of the preamble.
5. The UE of claim 4, wherein the processor is further configured to:
in the case that no RAR message is received in the RAR window, perform a second RACH procedure based on a second additional RO,

wherein a time offset between an end of the RAR window and a second slot with the second additional RO is configured by the base station or predefined.

6. The UE of claim 1, wherein the at least one additional ROs comprises a set of additional ROs, the set of additional RO is configured or activated by the paging signaling, the paging signaling is one of the following:

- a paging message;
- a paging DCI for scheduling the paging message; or
- a paging early indication (PEI) indicative of a presence of the paging message.

7. The UE of claim 6, wherein the processor is further configured to:
transmit, via the transceiver to a network device, an indication of a capability of supporting physical RACH (PRACH) resource adaptation triggered by the paging signaling.

8. The UE of claim 6, wherein the processor is further configured to:
receive, via the transceiver from the base station, the SIB1, wherein the SIB1 comprises resource configurations for the set of additional ROs;
wherein the paging signaling comprises an indication of activating the set of additional ROs.

9. The UE of claim 6, wherein the processor is further configured to:
receive, via the transceiver from the base station, the SIB1, wherein the SIB1 comprises resource configurations for at least one set of additional ROs, the at least one set of additional ROs comprises the set of additional ROs;
wherein the paging signaling comprises an indication of the set of additional ROs, the set of additional ROs is activated by the paging signaling.

10. The UE of claim 6, wherein one of the following:
a time offset between a last monitoring occasion for the paging DCI and a first slot with the set of additional ROs is configured by the base station or predefined; or
a time offset between a last slot with the paging message and a first slot with the set of additional ROs is configured by the base station or predefined.

11. The UE of claim 1, wherein the at least one additional RO comprises a set of additional ROs, the set of additional RO is activated by the DCI for scheduling the SIB1, the DCI for scheduling the SIB1 comprises an indication of an availability of a set of additional ROs, and

wherein the SIB1 comprises resource configurations for the set of additional ROs.

12. The UE of claim 11, wherein one of the following:

a time offset between a last slot with the DCI for scheduling the SIB1 and a first slot with the set of additional ROs is configured by the base station or predefined; or

a time offset between a last slot with the SIB1 and a first slot with the set of additional ROs is configured by the base station or predefined.

13. The UE of claim 1, wherein the at least one additional RO is available in a time window, wherein the time window is configured by the base station or predefined.

14. The UE of claim 1, wherein the processor is further configured to:

receive, via the transceiver from a base station, the SIB1;

determine the set of ROs based on the SIB1; and

perform a unified SSB-to-RO association for the set of ROs and the at least one additional RO.

15. The UE of claim 14, wherein the at least one additional RO comprises a set of additional ROs, and performing the unified SSB-to-RO association comprises:

performing a first SSB-to-RO association for the set of ROs; and

determining a second SSB-to-RO association for the set of additional ROs based on the first SSB-to-RO association.

16. The UE of claim 15, wherein determining the second SSB-to-RO association comprises:

causing the second SSB-to-RO association to follow the first SSB-to-RO association in a sequential and wrap round way.

17. The UE of claim 1, wherein the processor is further configured to:

determine one of the at least one additional RO as invalid, wherein the additional RO is overlapped with one of the set of ROs.

18. A base station comprising:

a processor; and

a transceiver coupled to the processor,

wherein the processor is configured to:

transmit, via the transceiver to a user equipment (UE), one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and

monitor a preamble on the at least one additional RO.

19. A method performed by a user equipment, comprising:

receiving, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and

performing a RACH procedure based on the at least one additional RO.

20. A processor for wireless communication, comprising:

at least one memory; and

a controller coupled with the at least one memory and configured to cause the controller to:

receive, from a base station, one of the following: a physical downlink control channel (PDCCH) order, a paging signaling, or downlink control information (DCI) for scheduling a system information block 1 (SIB1), wherein the SIB1 configures a set of random access channel (RACH) occasions (ROs), and the one of the PDCCH order, the paging signaling, or the DCI for scheduling the SIB1 configures or activates at least one additional RO; and

perform a RACH procedure based on the at least one additional RO.