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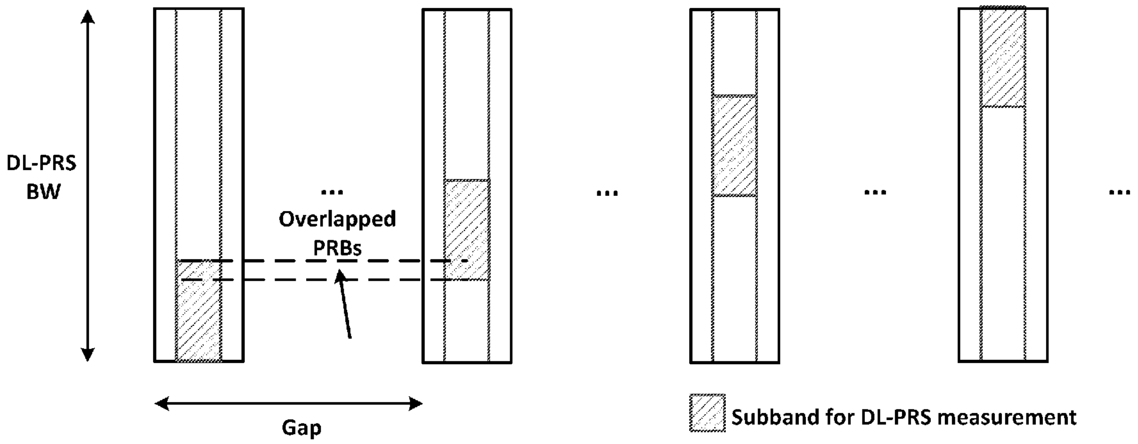

Figure 1

(57) **Abstract:** Various embodiments herein provide techniques for frequency hopping for positioning with reduced capability (RedCap) user equipments (UEs). For example, the RedCap UE may perform downlink positioning reference signal (DL-PRS) measurements using frequency hopping and bandwidth stitching. Additionally, or alternatively, the RedCap UE may transmit an uplink sounding reference signal (UL-SRS) using frequency hopping. Other embodiments may be described and claimed.

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SIGNALING MECHANISMS FOR POSITIONING FOR USER EQUIPMENTS WITH REDUCED CAPABILITY

CROSS REFERENCE TO RELATED APPLICATION

The present application claims priority to U.S. Provisional Patent Application No. 63/397,616, which was filed August 12, 2022; and to U.S. Provisional Patent Application No. 63/482,967, which was filed February 2, 2023.

FIELD

Various embodiments generally may relate to the field of wireless communications. For example, some embodiments may relate to techniques for positioning measurements for user equipments (UEs) with reduced capability.

BACKGROUND

Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. The next generation wireless communication system, 5G, or new radio (NR) will provide access to information and sharing of data anywhere, anytime by various users and applications. NR is expected to be a unified network/system that target to meet vastly different and sometime conflicting performance dimensions and services. Such diverse multi-dimensional requirements are driven by different services and applications. In general, NR will evolve based on 3GPP LTE-Advanced with additional potential new Radio Access Technologies (RATs) to enrich people lives with better, simple, and seamless wireless connectivity solutions. NR will enable everything connected by wireless and deliver fast, rich content and services.

NR supports highly precise positioning in the vertical and horizontal dimensions, which relies on timing-based, angle-based, power-based or hybrid techniques to estimate the user location in the network. With wide bandwidth for positioning signal and beamforming capability in mmWave frequency band, higher positioning accuracy can be achieved by RAT-dependent positioning techniques. Note that in 3GPP Release (Rel)-16, downlink positioning reference signal (DL-PRS) and uplink sounding reference signal (UL-SRS) for positioning were introduced as enablers to achieve target performance characteristics.

It has been identified as beneficial to support a class of NR user equipments (UEs) with complexity and power consumption levels lower than 3GPP Rel-15 NR UEs, catering to use cases like industrial wireless sensor networks (IWSN), certain class of wearables, and video surveillance, to fill the gap between current low power wide area (LPWA) solutions and enhanced mobile broadband (eMBB) solutions in NR and also to further facilitate a smooth migration from 3.5G and 4G technologies to 5G (NR) technology for currently deployed bands serving relevant use cases requiring relatively low-to-moderate reference (e.g., median) and peak user throughputs, low device complexity, small device form factors, and relatively long battery lifetimes.

Towards the above, in 3GPP Rel-17, a class of Reduced Capability (RedCap) NR UEs was introduced using the currently specified 5G NR framework with necessary adaptations and enhancements to limit device complexity and power consumption while minimizing any adverse impact to network resource utilization, system spectral efficiency, and operation efficiency. In particular, RedCap UEs typically support a maximum UE bandwidth (BW) of 20 MHz in frequency range 1 (FR1) bands and a maximum UE BW of 100 MHz in frequency range 2 (FR2) bands.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 illustrates an example of subband-based frequency hopping for downlink positioning reference signal (DL-PRS) measurement, in accordance with various embodiments.

Figure 2 illustrates another example of subband-based frequency hopping for DL-PRS measurement, in accordance with various embodiments.

Figure 3 illustrates an example of bandwidth part (BWP)-based frequency hopping for DL-PRS, in accordance with various embodiments.

Figure 4 illustrates another example of BWP-based frequency hopping for DL-PRS, in accordance with various embodiments.

Figure 5 illustrates an example of BWP-based frequency hopping for uplink (UL) sounding reference signal (SRS) for positioning, in accordance with various embodiments.

Figure 6 illustrates another example of BWP-based frequency hopping for UL SRS for positioning, in accordance with various embodiments.

Figure 7 illustrates an example of frequency hopping for reception of DL PRS for reduced capability (RedCap) user equipments (UEs), in accordance with various embodiments.

Figure 8 illustrates an example of frequency hopping for SRS for positioning for RedCap UEs

Figure 9 schematically illustrates a wireless network in accordance with various embodiments.

Figure 10 schematically illustrates components of a wireless network in accordance with various embodiments.

Figure 11 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

Figures 12, 13, and 14 depict example procedures for practicing the various embodiments discussed herein.

DETAILED DESCRIPTION

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

As mentioned above, NR supports highly precise positioning in the vertical and horizontal dimensions, which relies on timing-based, angle-based, power-based or hybrid techniques to estimate the user location in the network. For example, the following RAT-dependent positioning techniques may be used, which can meet the positioning requirements for various use cases, e.g., indoor, outdoor, Industrial internet of thing (IoT), etc:

- Downlink time difference of arrival (DL-TDOA);
- Uplink time difference of arrival (UL-TDOA);
- Downlink angle of departure (DL-AoD);
- Uplink angle of arrival (UL AoA);
- Multi-cell round trip time (multi-RTT);
- NR enhanced cell ID (E-CID).

With wide bandwidth for positioning signal and beamforming capability in mmWave frequency band, higher positioning accuracy can be achieved by RAT dependent positioning techniques. Note that in Rel-16, downlink positioning reference signal (DL-PRS) and uplink sounding reference signal (UL-SRS) for positioning were introduced as enablers to achieve target performance characteristics.

For reduced capability (RedCap) user equipments (UEs), bandwidth limitation may lead to insufficient resolution in time domain and affect the accuracy of the DL-TDOA, UL-TDOA, and Multi-RTT timing based positioning methods. Various embodiments herein may provide techniques for frequency hopping for DL-PRS and/or UL-SRS to improve the positioning accuracy. In some embodiments, two consecutive frequency hops may share a number of overlapped physical resource blocks (PRBs). In this case, multiple channel observations obtained with frequency hopping measurements can be processed at the receiver side to “stitch” them into a wideband channel realization, which would result in a sample time duration reduction and discrete Fourier size extension. The number of overlapping PRBs across two frequency hops can enable a receiver to estimate the frequency offset between two hops and compensate for the same to realize coherent combining processing gains.

Various embodiments herein provide systems and methods for frequency hopping for positioning support of RedCap UEs. For example, aspects of various embodiments may include:

- Frequency hopping with bandwidth stitching for DL-PRS transmission; and/or
- Frequency hopping with bandwidth stitching for UL-SRS transmission for positioning;
- Signaling mechanisms for DL-PRS transmission for RedCap UEs;
- Signaling mechanisms for UL-SRS transmission for positioning for RedCap UEs.

Frequency hopping with bandwidth stitching for DL-PRS transmission

Embodiments of frequency hopping with bandwidth stitching for DL-PRS transmission are described further below.

In one embodiment, wideband DL-PRS transmission may be configured to a RedCap UE for a DL-PRS resource such that the wideband DL-PRS transmission BW may exceed the maximum RedCap UE BW for the corresponding Frequency Range (FR). Further, for each DL-PRS transmission in the DL-PRS resource, multiple subbands for DL-PRS transmission in frequency can be configured by higher layers via radio resource control (RRC) signalling and the UE may be configured to perform frequency hopping across the configured multiple subbands. In some aspects, one or more subbands may overlap in frequency to allow coherent combining of the channel observations in multiple frequency hops at the receiver.

In one option, subband size and subband distance between two adjacent subbands in each DL-PRS transmission can be configured by higher layers via RRC signalling. In this case, UE determines a set of PRBs for positioning measurement in accordance with the subband size and subband distance in each DL-PRS repetition.

In another option, the subband size and number of overlapping PRBs between two subbands can be configured by higher layers via RRC signalling. In this case, UE determines a set of PRBs for positioning measurement in accordance with the subband size and number of overlapping PRBs between two subbands in each DL-PRS repetition.

In another example of the embodiment, a UE may not expect to be configured with a subband size in frequency dimension exceeding the maximum RedCap UE BW for the corresponding FR.

In another example of the embodiment, the repetitions of DL-PRS may be mapped in time domain such that one or more symbols or slots or a specified time gap (in absolute time units) are provisioned to accommodate any gaps necessary for a RedCap UE to retune from one subband to another. The symbols or slots may be defined using the numerology of the associated DL-PRS.

In another embodiment, a DL-PRS frequency hopping pattern may be pre-defined in the specification. In particular, the starting subband index for the frequency hopping can be configured by higher layers via RRC signalling. The subband index can be increased by 1 and modulo on total number of subbands for the subsequent DL-PRS repetition in a DL-PRS resource.

In this case, for i-th DL-PRS repetition, the starting PRB can be determined by

$$RB_{\text{start},i}^{\text{DL-PRS}} = RB_{\text{start},0}^{\text{DL-PRS}} + i \cdot \Delta_{\text{PRB}}^{\text{DL-PRS}}$$

Where $RB_{\text{start},0}^{\text{DL-PRS}}$ is provided by dl-PRS-StartPRB and $\Delta_{\text{PRB}}^{\text{DL-PRS}}$ is the subband distance between two adjacent subbands.

In another example of the embodiment, a UE may not expect to be configured with a subband size in frequency dimension exceeding the maximum RedCap UE BW for the corresponding FR.

In another example of the embodiment, the repetitions of DL-PRS may be mapped in time domain such that one or more symbols or slots are provisioned to accommodate any gaps necessary for a RedCap UE to retune from one subband to another. The symbols or slots may be defined using the numerology of the associated DL-PRS.

Figure 1 illustrates one example of subband based frequency hopping for DL-PRS measurement. In the figure, 4 repetitions are configured for DL-PRS resource. In addition, UE performs subband based frequency hopping on the DL-PRS measurement. The subband index for each DL-PRS repetition is increased by 1. In some aspects, adjacent subbands overlap in frequency domain for bandwidth stitching.

In another embodiment, a DL-PRS frequency hopping pattern may be defined in accordance with one or more following parameters: starting PRB for the first repetition, the subband index and DL-PRS repetition index.

In another embodiment, UE performs subband frequency hopping for positioning measurement on a group of every K DL-PRS repetitions. In particular, within the group of every K DL-PRS repetitions, same set of PRBs are used for DL-PRS measurement. In some aspects, K can be predefined in the specification or configured by higher layers via RRC signalling.

In some aspects, two gaps between DL-PRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K DL-PRS repetitions; and the second gap may be configured between two groups of every K DL-PRS repetitions. In some aspects, the gaps may be defined in accordance with a number of symbols or slots or absolute time. In the latter case, it can be determined based on the number of slots and numerology for DL-PRS transmission.

Figure 2 illustrates one example of subband based frequency hopping for DL-PRS measurement. In the figure, 4 repetitions are configured for DL-PRS resource and K = 2. In addition, UE performs subband based frequency hopping on every 2 repetitions for the DL-PRS measurement. Within 2 repetitions, same set of PRBs are used for DL-PRS measurement.

In another embodiment, DL-PRS repetitions for a DL-PRS resource may be transmitted in different DL bandwidth parts (BWPs) that may be configured to a RedCap UE for frequency hopping. Further, a gap may be configured between two DL-PRS repetitions for BWP switching. In some aspects, the gaps may be defined in accordance with a number of symbols or slots or absolute time. In the latter case, it can be determined based on the number of slots and numerology for DL-PRS transmission.

For this option, starting PRB for DL-PRS transmission may be defined in accordance with the starting PRB of an BWP. In some aspects, one or more DL-PRS repetitions or DL BWP for DL-PRS transmission may overlap in frequency to allow coherent combining of the channel observations in multiple frequency hops at the receiver.

Figure 3 illustrates one example of BWP based frequency hopping for DL-PRS. In the figure, DL-PRS fully occupies the DL BWP in frequency domain. Further, 3 repetitions are configured for DL-PRS transmission in a DL-PRS resource, where each DL-PRS repetition is transmitted in separate DL BWP.

In another embodiment, a group of every K DL-PRS repetitions for a DL-PRS resource may be transmitted in different DL BWPs configured to a RedCap UE for frequency hopping. In addition, same set of frequency resources may be used for DL-PRS repetitions within the group of every K DL-PRS repetitions. In some aspects, K can be predefined in the specification or configured by higher layers via RRC signalling.

Further, two gaps between DL-PRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K DL-PRS repetitions; and the second gap may be configured between two groups of every K DL-PRS repetitions. In some aspects, the gaps may be defined in accordance with a number of symbols or slots or absolute time. In the latter case, it can be determined based on the number of slots and numerology for DL-PRS transmission.

For this option, starting PRB for DL-PRS transmission may be defined in accordance with the starting PRB of an BWP.

Figure 4 illustrates one example of BWP based frequency hopping for DL-PRS. In the figure, DL-PRS fully occupies the DL BWP in frequency domain. Further, 4 repetitions are configured for DL-PRS transmission in a DL-PRS resource and K = 2. The gap between every 2 repetitions is 1 slot while the gap between the set of every 2 repetitions are 16 slots.

In another embodiment, a RedCap UE may be configured with a DL-PRS configuration such that the DL-PRS are mapped to one of N subbands or N DL BWPs across $r*N$ consecutive DL-PRS transmission occasions such that a pair of consecutive DL-PRS occasions may be separated by a time gap of a number of symbols or slots of absolute time, wherein r is an integer greater than or equal to one. Further, a set of $r*N$ consecutive-in-time DL-PRS transmission occasions spanning the N subbands or DL BWPs may be configured to repeat K times.

In contrast to the embodiments above that use a "repeat (within a hop)-then-hop" approach, this embodiment utilizes a "hop-then-repeat" approach, with possibility of $r \geq 1$ repetitions within each hop. Such a design may enable a trade-off between combining gains from combining repetitions for a frequency hop against accurate estimation of the frequency offset between the DL-PRS reception across two consecutive frequency hops for coherent combining across different frequency hops.

Frequency hopping with bandwidth stitching for UL-SRS transmission for positioning

Embodiments of frequency hopping with bandwidth stitching for UL-SRS transmission for described further below.

In one embodiment, UL SRS for positioning for a UL SRS resource are transmitted in different UL BWPs or UL subbands configured to a RedCap UE for frequency hopping. Further, a gap may be configured between two UL SRS transmissions for BWP switching. In some aspects, the gaps may be defined in accordance with a number of symbols or slots or absolute time. In the latter case, it can be determined based on the number of slots and numerology for UL SRS transmission.

In an example, the UL BWPs or UL subbands may be configured with the same numerology, BWP or subband size, and same shared and control channel configurations with exception of different starting PRBs.

In another example, the UL BWPs or UL subbands may be configured with the same numerology but may have different BWP or subband sizes, different shared and control channel configurations, and different starting PRBs.

For this option, starting PRB for UL SRS transmission may be defined in accordance with the starting PRB of an BWP or subband. In some aspects, one or more UL SRS repetitions or UL BWP or subband for UL SRS transmission may overlap in frequency to allow coherent combining of the channel observations in multiple frequency hops at the receiver.

Figure 5 illustrates one example of BWP based frequency hopping for UL SRS for positioning. In the figure, UL SRS for positioning fully occupies the UL BWP in frequency domain. Further, 3 repetitions are configured for UL SRS transmission in a SRS resource, where each SRS repetition is transmitted in separate UL BWP.

In another embodiment, a group of every K SRS repetitions for positioning for a SRS resource are transmitted in different UL BWP or subband for frequency hopping. In addition, same set of frequency resources are used for SRS repetitions within the group of every K SRS repetitions. In some aspects, K can be predefined in the specification or configured by higher layers via RRC signalling.

Further, two gaps between SRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K SRS repetitions; and the second gap may be configured between two groups of every K SRS repetitions. In some aspects, the gaps may be defined in accordance with a number of slots or absolute time. In the latter case, it can be determined based on the number of slots and numerology for SRS transmission.

For this option, starting PRB for SRS transmission may be defined in accordance with the starting PRB of an BWP or subband.

Figure 6 illustrates one example of BWP based frequency hopping for SRS for positioning. In the figure, SRS for positioning fully occupies the UL BWP in frequency domain. Further, 4 repetitions are configured for SRS transmission in an SRS resource and K = 2. The gap between every 2 repetitions is 1 slot while the gap between the set of every 2 repetitions are 16 slots.

In another embodiment, a RedCap UE may be configured with an SRS configuration such that the SRS are mapped to one of N UL BWPs or subbands across $r*N$ consecutive SRS transmission occasions such that a pair of consecutive SRS occasions may be separated by a time gap of a number of symbols or slots of absolute time, wherein r is an integer greater than or equal to one. Further, a set of $r*N$ consecutive-in-time SRS transmission occasions spanning the N UL BWPs or subbands may be configured to repeat K times.

In contrast to the embodiment above that use a “repeat (within hop)-then-hop” approach, this embodiment utilizes a “hop-then-repeat” approach, with possibility of $r \geq 1$ repetitions within each hop. Such a design may enable a trade-off between combining gains from combining repetitions for a frequency hop against accurate estimation of the frequency offset between the SRS reception across two consecutive frequency hops for coherent combining across different frequency hops at the gNB receiver.

Signalling mechanisms for DL-PRS transmission for RedCap UEs

As mentioned above, bandwidth limitation may lead to insufficient resolution in time domain and affects the accuracy of the downlink time difference of arrival (DL-TDOA), uplink time difference of arrival (UL-TDOA), and multi-cell round trip time (multi-RTT) timing based positioning methods. To improve the positioning accuracy, frequency hopping with bandwidth stitching method can be considered for the transmission of DL-PRS and/or UL-SRS for positioning, wherein two consecutive frequency hops share a number of overlapped PRBs. In this case, multiple channel observations obtained with frequency hopping measurements can be processed at the receiver side to “stitch” them into a wideband channel realization, which would result in a sample time duration reduction and discrete Fourier size extension.

Embodiments of signalling mechanisms for DL-PRS transmission for RedCap UEs are described further below.

In one embodiment, DL PRS sequence is generated in accordance with the DL PRS positioning frequency layer configuration that may exceed the maximum supported bandwidth by a RedCap UE. Further, DL PRS sequence may be mapped to the time-frequency resources allocated for DL PRS transmission in accordance with DL PRS positioning frequency layer configuration. In another option, DL PRS sequence may be mapped to the time-frequency resources in accordance with the frequency hopping pattern provided to a RedCap UE.

In another embodiment, DL PRS sequence may be mapped to the time-frequency resources allocated for DL PRS transmission in accordance with DL PRS positioning frequency layer configuration, however, a RedCap UE may assume that a DL PRS sequence is transmitted in the time-frequency resources confined to a frequency subband in accordance with a frequency hopping pattern provided to a RedCap UE. In this case, the assumption on DL PRS transmission by a RedCap UE can be decoupled from the actual transmission of DL PRS as long as DL PRS transmission includes the frequency subbands as per the frequency hopping pattern indicated to a RedCap UE. This allows a gNB to transparently choose between the option of transmitting a single common DL PRS that may be received by RedCap and non-RedCap UEs and the option of transmitting DL PRS for RedCap UEs separate from that for non-RedCap UEs.

In some aspects, multiple subbands for DL-PRS transmission in frequency can be configured by higher layers via radio resource control (RRC) signalling and the UE may be configured to perform frequency hopping across the configured multiple subbands.

In some aspects, one or more subbands may overlap in frequency to allow coherent combining of the channel observations in multiple frequency hops at the receiver. Further, subband size and subband distance between two adjacent subbands in each DL-PRS repetition can be configured by higher layers via RRC signalling. In this case, UE determines a set of PRBs for positioning measurement in accordance with the subband size and subband distance in each DL-PRS repetition.

Figure 7 illustrates one example of frequency hopping for reception of DL PRS for RedCap UEs. In the figure, DL PRS sequence is transmitted in the time frequency resource within a frequency subband or BWP based on frequency hopping pattern. In some aspects, gNB may transmit a single common DL PRS that can be received by both RedCap UEs and non-RedCap UEs, or gNB may only transmit DL PRS for RedCap UEs based on the frequency hopping pattern, while may not transmit the DL PRS in the remaining resources outside the frequency hopping pattern.

In some aspects, whether DL PRS sequence is mapped to the resource allocated for DL PRS transmission or the resource in accordance with the frequency hopping pattern may be configured by higher layers via RRC signalling.

In another embodiment, the starting PRB of the different hops may be configured by higher layers via RRC signalling. In addition, the reference point to indicate the starting PRB may be defined as Point A that corresponds to the lowest subcarrier of the common resource block (CRB) 0, or as starting PRB of DL PRS transmission in accordance with configuration of DL PRS positioning frequency layers, DL PRS resource set or DL PRS resource.

In another option, the reference point of the starting PRB may be defined as starting PRB of the configured BWP for RedCap UEs or the starting PRB of a subband defined above.

<u>Signalling mechanisms for UL-SRS transmission for positioning for RedCap UEs</u>

Embodiments of signalling mechanisms for UL-SRS transmission for positioning for RedCap UEs are described further below.

In one embodiment, an association between SRS resource set in a first UL BWP or subband and SRS resource set in a second UL BWP or subband may be configured by higher layers via RRC signalling. In this case, for periodic SRS transmission with frequency hopping, when the SRS resource set in the first UL BWP or subband is configured, SRS is also transmitted using the SRS resource set in the second UL BWP or subband in accordance with the association.

For semi-persistent SRS transmission with frequency hopping, when the SRS resource set in the first UL BWP or subband is activated or deactivated, SRS resource set in the second UL BWP or subband is also activated or deactivated in accordance with the association. For aperiodic

SRS transmission with frequency hopping, when the SRS resource set in the first UL BWP or subband is triggered, SRS resource set in the second UL BWP or subband is also triggered in accordance with the association.

In an example of the embodiment, an association between SRS resource set in a first UL BWP or subband and SRS resource set in a second UL BWP or subband may be defined via a schedule for SRS transmissions on one or more SRS resource(s) within each SRS resource set based on a frequency resource hopping pattern defined as a function of time resources (symbols and/or slots).

In another option, the association between periodic/semi-persistent SRS resource set and BWPs or subbands could be updated by MAC-CE.

Figure 8 illustrates one example of frequency hopping for SRS for positioning for RedCap UEs. In the figure, SRS resource set A in BWP#0 is associated with SRS resource set B in BWP#1 and SRS resource set C in BWP#2. When SRS resource set A in BWP#0 is activated or triggered, SRS resource set B in BWP#1 and SRS resource set C in BWP#2 are also activated or triggered, respectively.

In another embodiment, an association between SRS resource in a first UL BWP or subband and SRS resource in a second UL BWP or subband may be configured by higher layers via RRC signalling. In this case, for periodic SRS transmission with frequency hopping, when the SRS resource set including SRS resource in the first UL BWP or subband is configured, SRS is also transmitted using the SRS resource in the second BWP or subband in accordance with the association.

For semi-persistent SRS transmission with frequency hopping, when the SRS resource set including SRS resource in the first UL BWP or subband is activated or deactivated, SRS resource in the second UL BWP or subband is also activated or deactivated in accordance with the association. For aperiodic SRS transmission with frequency hopping, when the SRS resource set including SRS resource in the first UL BWP or subband is triggered, SRS resource in the second UL BWP or subband is also triggered in accordance with the association.

In an example of the embodiment, an association between SRS resource in a first UL BWP or subband and SRS resource in a second UL BWP or subband may be defined via configuration of a transmission schedule for SRS transmissions (e.g., an ordering/sequence of SRS transmissions) on the SRS resources based on a frequency resource hopping pattern defined as a function of time resources (symbols and/or slots).

In another embodiment, for semi-persistent SRS for positioning with frequency hopping for RedCap UEs, more than one SRS resources or resource sets in different UL BWPs or subbands in a carrier may be activated or deactivated via Medium Access Control - Control Element (MAC-

CE). In addition, a new extended logical channel ID (eLCID) may be defined for semi-persistent SRS for positioning with frequency hopping for RedCap UE.

In one option, a set of UL BWPs or subbands in a carrier may be included in the activation/deactivation MAC-CE. Further, activated or deactivated SRS resource set in each BWP or subband may be included in the MAC-CE.

In another embodiment, for aperiodic SRS for positioning with frequency hopping for RedCap UEs, more than one SRS resource sets in different BWPs or subbands in a carrier may be triggered via DCI format 0_1, 0_2, 1_1, 1_2 and/or DCI format for multi-cell scheduling. In particular, joint SRS request field may indicate a row of a table for SRS request in more than one BWP in a carrier, which is configured by RRC signalling.

In one option, more than one set of UL BWPs or subbands in a carrier may be configured by higher layers via RRC signalling. One UL BWP or subband set could contain one BWP/subband or multiple BWPs/subbands, and one BWP/subband could belong to one BWP/subband set or several BWP sets. A code point of SRS request field in the DCI may be used to indicate one of the more than one set of associated UL BWPs or subbands are used for SRS transmission for positioning with frequency hopping for RedCap UEs.

In some aspects, to differentiate the SRS request for positioning with frequency hopping and the SRS request for other purpose, one bit field may be included the DCI format 0_1, 0_2, 1_1, 1_2, and/or the DCI format for multi-cell scheduling. In one example, bit “1” may be used to indicate that the SRS request is used for SRS for positioning with frequency hopping, while bit “0” may be used to indicate that the SRS request is not used to SRS for positioning with frequency hopping for RedCap UEs.

In another option, to differentiate the SRS request for positioning with frequency hopping and the SRS request for other purpose, some unused state or fields may be repurposed to indicate the SRS request for positioning with frequency hopping.

In another option, to differentiate the SRS request for positioning with frequency hopping and the SRS request for other purpose, a separate search space set may be configured for monitoring the DCI format which includes the SRS request for positioning with frequency hopping.

In another option, to differentiate the SRS request for positioning with frequency hopping and the SRS request for other purpose, a separate search space set may be configured for monitoring the DCI format which includes the SRS request for positioning with frequency hopping.

In another embodiment, a group common DCI may be defined to trigger SRS transmission for positioning with frequency hopping in different BWPs or subbands for RedCap UEs.

In one option, existing DCI format 2_3 may be extended to support the triggering of SRS transmission for positioning with frequency hopping in different BWPs or subbands. In this case, a new configuration field may be configured, e.g., Type C to indicate that the DCI format 2_3 is used to trigger SRS transmission for positioning with frequency hopping. In some aspects, the TPC command field(s) may be absent in the DCI format 2_3 with Type C configuration. In another option, the presence/absence of TPC command field(s) in DCI format 2_3 with Type C configuration could be configured via RRC signaling. Further, the aforementioned embodiments for triggering SRS transmission using SRS request via UE specific DCI format can be applied for group common DCI.

In another option, a new group common DCI format may be defined to support the triggering of SRS transmission for positioning with frequency hopping in different BWPs. In this case, a new Radio Network Temporary Identifier (RNTI) may be configured to UE to monitor the new group common DCI format. Further, the aforementioned embodiments for triggering SRS transmission using SRS request via UE specific DCI format can be applied for group common DCI.

In another embodiment, for SRS transmission for positioning with frequency hopping, the starting PRB of the different hops may be configured by higher layers via RRC signalling. In addition, the reference point of the starting PRB may be defined as Point A that corresponds to the lowest subcarrier of the common resource block (CRB) 0, or as starting PRB of SRS transmission in accordance with configuration of SRS resource set or SRS resource.

In another option, the reference point of the starting PRB may be defined as starting PRB of the configured UL BWP or subband for RedCap UEs or the starting PRB of the aforementioned subband.

Note that the concepts in the above embodiments and examples have been described for the case involving two SRS resource sets or SRS resources or UL BWPs or subbands (as applicable) within which frequency hopping is applied to simplify the exposition. It will be apparent that the disclosed techniques may be applied to cases involving more than two SRS resource sets or SRS resources or UL BWPs or subbands (as applicable) in accordance with various embodiments herein.

SYSTEMS AND IMPLEMENTATIONS

Figures 9-11 illustrate various systems, devices, and components that may implement aspects of disclosed embodiments.

Figure 9 illustrates a network 900 in accordance with various embodiments. The network 900 may operate in a manner consistent with 3GPP technical specifications for LTE or 5G/NR systems. However, the example embodiments are not limited in this regard and the described embodiments may apply to other networks that benefit from the principles described herein, such as future 3GPP systems, or the like.

The network 900 may include a UE 902, which may include any mobile or non-mobile computing device designed to communicate with a RAN 904 via an over-the-air connection. The UE 902 may be communicatively coupled with the RAN 904 by a Uu interface. The UE 902 may be, but is not limited to, a smartphone, tablet computer, wearable computer device, desktop computer, laptop computer, in-vehicle infotainment, in-car entertainment device, instrument cluster, head-up display device, onboard diagnostic device, dashtop mobile equipment, mobile data terminal, electronic engine management system, electronic/engine control unit, electronic/engine control module, embedded system, sensor, microcontroller, control module, engine management system, networked appliance, machine-type communication device, M2M or D2D device, IoT device, etc.

In some embodiments, the network 900 may include a plurality of UEs coupled directly with one another via a sidelink interface. The UEs may be M2M/D2D devices that communicate using physical sidelink channels such as, but not limited to, PSBCH, PSDCH, PSSCH, PSCCH, PSFCH, etc.

In some embodiments, the UE 902 may additionally communicate with an AP 906 via an over-the-air connection. The AP 906 may manage a WLAN connection, which may serve to offload some/all network traffic from the RAN 904. The connection between the UE 902 and the AP 906 may be consistent with any IEEE 802.11 protocol, wherein the AP 906 could be a wireless fidelity (Wi-Fi®) router. In some embodiments, the UE 902, RAN 904, and AP 906 may utilize cellular-WLAN aggregation (for example, LWA/LWIP). Cellular-WLAN aggregation may involve the UE 902 being configured by the RAN 904 to utilize both cellular radio resources and WLAN resources.

The RAN 904 may include one or more access nodes, for example, AN 908. AN 908 may terminate air-interface protocols for the UE 902 by providing access stratum protocols including RRC, PDCP, RLC, MAC, and L1 protocols. In this manner, the AN 908 may enable data/voice connectivity between CN 920 and the UE 902. In some embodiments, the AN 908 may be implemented in a discrete device or as one or more software entities running on server computers as part of, for example, a virtual network, which may be referred to as a CRAN or virtual baseband unit pool. The AN 908 be referred to as a BS, gNB, RAN node, eNB, ng-eNB, NodeB, RSU, TRxP, TRP, etc. The AN 908 may be a macrocell base station or a low power base station for providing femtocells, picocells or other like cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells.

In embodiments in which the RAN 904 includes a plurality of ANs, they may be coupled with one another via an X2 interface (if the RAN 904 is an LTE RAN) or an Xn interface (if the RAN 904 is a 5G RAN). The X2/Xn interfaces, which may be separated into control/user plane interfaces in some embodiments, may allow the ANs to communicate information related to handovers, data/context transfers, mobility, load management, interference coordination, etc.

The ANs of the RAN 904 may each manage one or more cells, cell groups, component carriers, etc. to provide the UE 902 with an air interface for network access. The UE 902 may be simultaneously connected with a plurality of cells provided by the same or different ANs of the RAN 904. For example, the UE 902 and RAN 904 may use carrier aggregation to allow the UE 902 to connect with a plurality of component carriers, each corresponding to a Pcell or Scell. In dual connectivity scenarios, a first AN may be a master node that provides an MCG and a second AN may be secondary node that provides an SCG. The first/second ANs may be any combination of eNB, gNB, ng-eNB, etc.

The RAN 904 may provide the air interface over a licensed spectrum or an unlicensed spectrum. To operate in the unlicensed spectrum, the nodes may use LAA, eLAA, and/or feLAA mechanisms based on CA technology with PCells/Scells. Prior to accessing the unlicensed spectrum, the nodes may perform medium/carrier-sensing operations based on, for example, a listen-before-talk (LBT) protocol.

In V2X scenarios the UE 902 or AN 908 may be or act as a RSU, which may refer to any transportation infrastructure entity used for V2X communications. An RSU may be implemented in or by a suitable AN or a stationary (or relatively stationary) UE. An RSU implemented in or by: a UE may be referred to as a "UE-type RSU"; an eNB may be referred to as an "eNB-type RSU"; a gNB may be referred to as a "gNB-type RSU"; and the like. In one example, an RSU is a computing device coupled with radio frequency circuitry located on a roadside that provides connectivity support to passing vehicle UEs. The RSU may also include internal data storage circuitry to store intersection map geometry, traffic statistics, media, as well as applications/software to sense and control ongoing vehicular and pedestrian traffic. The RSU may provide very low latency communications required for high speed events, such as crash avoidance, traffic warnings, and the like. Additionally or alternatively, the RSU may provide other cellular/WLAN communications services. The components of the RSU may be packaged in a weatherproof enclosure suitable for outdoor installation, and may include a network interface controller to provide a wired connection (e.g., Ethernet) to a traffic signal controller or a backhaul network.

In some embodiments, the RAN 904 may be an LTE RAN 910 with eNBs, for example, eNB 912. The LTE RAN 910 may provide an LTE air interface with the following characteristics:

SCS of 15 kHz; CP-OFDM waveform for DL and SC-FDMA waveform for UL; turbo codes for data and TBCC for control; etc. The LTE air interface may rely on CSI-RS for CSI acquisition and beam management; PDSCH/PDCCH DMRS for PDSCH/PDCCH demodulation; and CRS for cell search and initial acquisition, channel quality measurements, and channel estimation for coherent demodulation/detection at the UE. The LTE air interface may operating on sub-6 GHz bands.

In some embodiments, the RAN 904 may be an NG-RAN 914 with gNBs, for example, gNB 916, or ng-eNBs, for example, ng-eNB 918. The gNB 916 may connect with 5G-enabled UEs using a 5G NR interface. The gNB 916 may connect with a 5G core through an NG interface, which may include an N2 interface or an N3 interface. The ng-eNB 918 may also connect with the 5G core through an NG interface, but may connect with a UE via an LTE air interface. The gNB 916 and the ng-eNB 918 may connect with each other over an Xn interface.

In some embodiments, the NG interface may be split into two parts, an NG user plane (NG-U) interface, which carries traffic data between the nodes of the NG-RAN 914 and a UPF 948 (e.g., N3 interface), and an NG control plane (NG-C) interface, which is a signaling interface between the nodes of the NG-RAN914 and an AMF 944 (e.g., N2 interface).

The NG-RAN 914 may provide a 5G-NR air interface with the following characteristics: variable SCS; CP-OFDM for DL, CP-OFDM and DFT-s-OFDM for UL; polar, repetition, simplex, and Reed-Muller codes for control and LDPC for data. The 5G-NR air interface may rely on CSI-RS, PDSCH/PDCCH DMRS similar to the LTE air interface. The 5G-NR air interface may not use a CRS, but may use PBCH DMRS for PBCH demodulation; PTRS for phase tracking for PDSCH; and tracking reference signal for time tracking. The 5G-NR air interface may operating on FR1 bands that include sub-6 GHz bands or FR2 bands that include bands from 24.25 GHz to 52.6 GHz. The 5G-NR air interface may include an SSB that is an area of a downlink resource grid that includes PSS/SSS/PBCH.

In some embodiments, the 5G-NR air interface may utilize BWPs for various purposes. For example, BWP can be used for dynamic adaptation of the SCS. For example, the UE 902 can be configured with multiple BWPs where each BWP configuration has a different SCS. When a BWP change is indicated to the UE 902, the SCS of the transmission is changed as well. Another use case example of BWP is related to power saving. In particular, multiple BWPs can be configured for the UE 902 with different amount of frequency resources (for example, PRBs) to support data transmission under different traffic loading scenarios. A BWP containing a smaller number of PRBs can be used for data transmission with small traffic load while allowing power saving at the UE 902 and in some cases at the gNB 916. A BWP containing a larger number of PRBs can be used for scenarios with higher traffic load.

The RAN 904 is communicatively coupled to CN 920 that includes network elements to provide various functions to support data and telecommunications services to customers/subscribers (for example, users of UE 902). The components of the CN 920 may be implemented in one physical node or separate physical nodes. In some embodiments, NFV may be utilized to virtualize any or all of the functions provided by the network elements of the CN 920 onto physical compute/storage resources in servers, switches, etc. A logical instantiation of the CN 920 may be referred to as a network slice, and a logical instantiation of a portion of the CN 920 may be referred to as a network sub-slice.

In some embodiments, the CN 920 may be an LTE CN 922, which may also be referred to as an EPC. The LTE CN 922 may include MME 924, SGW 926, SGSN 928, HSS 930, PGW 932, and PCRF 934 coupled with one another over interfaces (or "reference points") as shown. Functions of the elements of the LTE CN 922 may be briefly introduced as follows.

The MME 924 may implement mobility management functions to track a current location of the UE 902 to facilitate paging, bearer activation/deactivation, handovers, gateway selection, authentication, etc.

The SGW 926 may terminate an S1 interface toward the RAN and route data packets between the RAN and the LTE CN 922. The SGW 926 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

The SGSN 928 may track a location of the UE 902 and perform security functions and access control. In addition, the SGSN 928 may perform inter-EPC node signaling for mobility between different RAT networks; PDN and S-GW selection as specified by MME 924; MME selection for handovers; etc. The S3 reference point between the MME 924 and the SGSN 928 may enable user and bearer information exchange for inter-3GPP access network mobility in idle/active states.

The HSS 930 may include a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The HSS 930 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 930 and the MME 924 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the LTE CN 920.

The PGW 932 may terminate an SGi interface toward a data network (DN) 936 that may include an application/content server 938. The PGW 932 may route data packets between the LTE CN 922 and the data network 936. The PGW 932 may be coupled with the SGW 926 by an S5 reference point to facilitate user plane tunneling and tunnel management. The PGW 932 may further include a node for policy enforcement and charging data collection (for example, PCEF). Additionally, the SGi reference point between the PGW 932 and the data network 9 36 may be an operator external public, a private PDN, or an intra-operator packet data network, for example, for provision of IMS services. The PGW 932 may be coupled with a PCRF 934 via a Gx reference point.

The PCRF 934 is the policy and charging control element of the LTE CN 922. The PCRF 934 may be communicatively coupled to the app/content server 938 to determine appropriate QoS and charging parameters for service flows. The PCRF 932 may provision associated rules into a PCEF (via Gx reference point) with appropriate TFT and QCI.

In some embodiments, the CN 920 may be a 5GC 940. The 5GC 940 may include an AUSF 942, AMF 944, SMF 946, UPF 948, NSSF 950, NEF 952, NRF 954, PCF 956, UDM 958, and AF 960 coupled with one another over interfaces (or “reference points”) as shown. Functions of the elements of the 5GC 940 may be briefly introduced as follows.

The AUSF 942 may store data for authentication of UE 902 and handle authentication-related functionality. The AUSF 942 may facilitate a common authentication framework for various access types. In addition to communicating with other elements of the 5GC 940 over reference points as shown, the AUSF 942 may exhibit an Nausf service-based interface.

The AMF 944 may allow other functions of the 5GC 940 to communicate with the UE 902 and the RAN 904 and to subscribe to notifications about mobility events with respect to the UE 902. The AMF 944 may be responsible for registration management (for example, for registering UE 902), connection management, reachability management, mobility management, lawful interception of AMF-related events, and access authentication and authorization. The AMF 944 may provide transport for SM messages between the UE 902 and the SMF 946, and act as a transparent proxy for routing SM messages. AMF 944 may also provide transport for SMS messages between UE 902 and an SMSF. AMF 944 may interact with the AUSF 942 and the UE 902 to perform various security anchor and context management functions. Furthermore, AMF 944 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the RAN 904 and the AMF 944; and the AMF 944 may be a termination point of NAS (N1) signaling, and perform NAS ciphering and integrity protection. AMF 944 may also support NAS signaling with the UE 902 over an N3 IWF interface.

The SMF 946 may be responsible for SM (for example, session establishment, tunnel management between UPF 948 and AN 908); UE IP address allocation and management (including optional authorization); selection and control of UP function; configuring traffic steering at UPF 948 to route traffic to proper destination; termination of interfaces toward policy control functions; controlling part of policy enforcement, charging, and QoS; lawful intercept (for

SM events and interface to LI system); termination of SM parts of NAS messages; downlink data notification; initiating AN specific SM information, sent via AMF 944 over N2 to AN 908; and determining SSC mode of a session. SM may refer to management of a PDU session, and a PDU session or "session" may refer to a PDU connectivity service that provides or enables the exchange of PDUs between the UE 902 and the data network 936.

The UPF 948 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to data network 936, and a branching point to support multi-homed PDU session. The UPF 948 may also perform packet routing and forwarding, perform packet inspection, enforce the user plane part of policy rules, lawfully intercept packets (UP collection), perform traffic usage reporting, perform QoS handling for a user plane (e.g., packet filtering, gating, UL/DL rate enforcement), perform uplink traffic verification (e.g., SDF-to-QoS flow mapping), transport level packet marking in the uplink and downlink, and perform downlink packet buffering and downlink data notification triggering. UPF 948 may include an uplink classifier to support routing traffic flows to a data network.

The NSSF 950 may select a set of network slice instances serving the UE 902. The NSSF 950 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 950 may also determine the AMF set to be used to serve the UE 902, or a list of candidate AMFs based on a suitable configuration and possibly by querying the NRF 954. The selection of a set of network slice instances for the UE 902 may be triggered by the AMF 944 with which the UE 902 is registered by interacting with the NSSF 950, which may lead to a change of AMF. The NSSF 950 may interact with the AMF 944 via an N22 reference point; and may communicate with another NSSF in a visited network via an N31 reference point (not shown). Additionally, the NSSF 950 may exhibit an Nnssf service-based interface.

The NEF 952 may securely expose services and capabilities provided by 3GPP network functions for third party, internal exposure/re-exposure, AFs (e.g., AF 960), edge computing or fog computing systems, etc. In such embodiments, the NEF 952 may authenticate, authorize, or throttle the AFs. NEF 952 may also translate information exchanged with the AF 960 and information exchanged with internal network functions. For example, the NEF 952 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 952 may also receive information from other NFs based on exposed capabilities of other NFs. This information may be stored at the NEF 952 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 952 to other NFs and AFs, or used for other purposes such as analytics. Additionally, the NEF 952 may exhibit an Nnef service-based interface.

The NRF 954 may support service discovery functions, receive NF discovery requests from NF instances, and provide the information of the discovered NF instances to the NF instances. NRF 954 also maintains information of available NF instances and their supported services. As used herein, the terms "instantiate," "instantiation," and the like may refer to the creation of an instance, and an "instance" may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. Additionally, the NRF 954 may exhibit the Nnrf service-based interface.

The PCF 956 may provide policy rules to control plane functions to enforce them, and may also support unified policy framework to govern network behavior. The PCF 956 may also implement a front end to access subscription information relevant for policy decisions in a UDR of the UDM 958. In addition to communicating with functions over reference points as shown, the PCF 956 exhibit an Npcf service-based interface.

The UDM 958 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 902. For example, subscription data may be communicated via an N8 reference point between the UDM 958 and the AMF 944. The UDM 958 may include two parts, an application front end and a UDR. The UDR may store subscription data and policy data for the UDM 958 and the PCF 956, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 902) for the NEF 952. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 958, PCF 956, and NEF 952 to access a particular set of the stored data, as well as to read, update (e.g., add, modify), delete, and subscribe to notification of relevant data changes in the UDR. The UDM may include a UDM-FE, which is in charge of processing credentials, location management, subscription management and so on. Several different front ends may serve the same user in different transactions. The UDM-FE accesses subscription information stored in the UDR and performs authentication credential processing, user identification handling, access authorization, registration/mobility management, and subscription management. In addition to communicating with other NFs over reference points as shown, the UDM 958 may exhibit the Nudm service-based interface.

The AF 960 may provide application influence on traffic routing, provide access to NEF, and interact with the policy framework for policy control.

In some embodiments, the 5GC 940 may enable edge computing by selecting operator/3rd party services to be geographically close to a point that the UE 902 is attached to the network. This may reduce latency and load on the network. To provide edge-computing implementations, the 5GC 940 may select a UPF 948 close to the UE 902 and execute traffic steering from the UPF 948 to data network 936 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 960. In this way, the AF 960 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 960 is considered to be a trusted entity, the network operator may permit AF 960 to interact directly with relevant NFs. Additionally, the AF 960 may exhibit an Naf service-based interface.

The data network 936 may represent various network operator services, Internet access, or third party services that may be provided by one or more servers including, for example, application/content server 938.

Figure 10 schematically illustrates a wireless network 1000 in accordance with various embodiments. The wireless network 1000 may include a UE 1002 in wireless communication with an AN 1004. The UE 1002 and AN 1004 may be similar to, and substantially interchangeable with, like-named components described elsewhere herein.

The UE 1002 may be communicatively coupled with the AN 1004 via connection 1006. The connection 1006 is illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols such as an LTE protocol or a 5G NR protocol operating at mmWave or sub-6GHz frequencies.

The UE 1002 may include a host platform 1008 coupled with a modem platform 1010. The host platform 1008 may include application processing circuitry 1012, which may be coupled with protocol processing circuitry 1014 of the modem platform 1010. The application processing circuitry 1012 may run various applications for the UE 1002 that source/sink application data. The application processing circuitry 1012 may further implement one or more layer operations to transmit/receive application data to/from a data network. These layer operations may include transport (for example UDP) and Internet (for example, IP) operations

The protocol processing circuitry 1014 may implement one or more of layer operations to facilitate transmission or reception of data over the connection 1006. The layer operations implemented by the protocol processing circuitry 1014 may include, for example, MAC, RLC, PDCP, RRC and NAS operations.

The modem platform 1010 may further include digital baseband circuitry 1016 that may implement one or more layer operations that are "below" layer operations performed by the protocol processing circuitry 1014 in a network protocol stack. These operations may include, for example, PHY operations including one or more of HARQ-ACK functions, scrambling/descrambling, encoding/decoding, layer mapping/de-mapping, modulation symbol mapping, received symbol/bit metric determination, multi-antenna port precoding/decoding, which may include one or more of space-time, space-frequency or spatial coding, reference signal generation/detection, preamble sequence generation and/or decoding, synchronization sequence generation/detection, control channel signal blind decoding, and other related functions.

The modem platform 1010 may further include transmit circuitry 1018, receive circuitry 1020, RF circuitry 1022, and RF front end (RFFE) 1024, which may include or connect to one or more antenna panels 1026. Briefly, the transmit circuitry 1018 may include a digital-to-analog converter, mixer, intermediate frequency (IF) components, etc.; the receive circuitry 1020 may include an analog-to-digital converter, mixer, IF components, etc.; the RF circuitry 1022 may include a low-noise amplifier, a power amplifier, power tracking components, etc.; RFFE 1024 may include filters (for example, surface/bulk acoustic wave filters), switches, antenna tuners, beamforming components (for example, phase-array antenna components), etc. The selection and arrangement of the components of the transmit circuitry 1018, receive circuitry 1020, RF circuitry 1022, RFFE 1024, and antenna panels 1026 (referred generically as "transmit/receive components") may be specific to details of a specific implementation such as, for example, whether communication is TDM or FDM, in mmWave or sub-6 gHz frequencies, etc. In some embodiments, the transmit/receive components may be arranged in multiple parallel transmit/receive chains, may be disposed in the same or different chips/modules, etc.

In some embodiments, the protocol processing circuitry 1014 may include one or more instances of control circuitry (not shown) to provide control functions for the transmit/receive components.

A UE reception may be established by and via the antenna panels 1026, RFFE 1024, RF circuitry 1022, receive circuitry 1020, digital baseband circuitry 1016, and protocol processing circuitry 1014. In some embodiments, the antenna panels 1026 may receive a transmission from the AN 1004 by receive-beamforming signals received by a plurality of antennas/antenna elements of the one or more antenna panels 1026.

A UE transmission may be established by and via the protocol processing circuitry 1014, digital baseband circuitry 1016, transmit circuitry 1018, RF circuitry 1022, RFFE 1024, and antenna panels 1026. In some embodiments, the transmit components of the UE 1004 may apply a spatial filter to the data to be transmitted to form a transmit beam emitted by the antenna elements of the antenna panels 1026.

Similar to the UE 1002, the AN 1004 may include a host platform 1028 coupled with a modem platform 1030. The host platform 1028 may include application processing circuitry 1032 coupled with protocol processing circuitry 1034 of the modem platform 1030. The modem platform may further include digital baseband circuitry 1036, transmit circuitry 1038, receive circuitry 1040, RF circuitry 1042, RFFE circuitry 1044, and antenna panels 1046. The components of the AN 1004 may be similar to and substantially interchangeable with like-named components of the UE 1002. In addition to performing data transmission/reception as described above, the components of the AN 1008 may perform various logical functions that include, for example, RNC functions such as radio bearer management, uplink and downlink dynamic radio resource management, and data packet scheduling.

Figure 11 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 11 shows a diagrammatic representation of hardware resources 1100 including one or more processors (or processor cores) 1110, one or more memory/storage devices 1120, and one or more communication resources 1130, each of which may be communicatively coupled via a bus 1140 or other interface circuitry. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 1102 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 1100.

The processors 1110 may include, for example, a processor 1112 and a processor 1114. The processors 1110 may be, for example, a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.

The memory/storage devices 1120 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1120 may include, but are not limited to, any type of volatile, non-volatile, or semi-volatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

The communication resources 1130 may include interconnection or network interface controllers, components, or other suitable devices to communicate with one or more peripheral devices 1104 or one or more databases 1106 or other network elements via a network 1108. For example, the communication resources 1130 may include wired communication components (e.g., for coupling via USB, Ethernet, etc.), cellular communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components.

Instructions 1150 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1110 to perform any one or more of the methodologies discussed herein. The instructions 1150 may reside, completely or partially, within at least one of the processors 1110 (e.g., within the processor's cache memory), the memory/storage devices 1120, or any suitable combination thereof. Furthermore, any portion of the instructions 1150 may be transferred to the hardware resources 1100 from any combination of the peripheral devices 1104 or the databases 1106. Accordingly, the memory of processors 1110, the memory/storage devices 1120, the peripheral devices 1104, and the databases 1106 are examples of computer-readable and machine-readable media.

EXAMPLE PROCEDURES

In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 9-11, or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process 1200 is depicted in Figure 12. In some embodiments, the process 1200 may be performed by a UE, e.g., a RedCap UE, or a portion thereof. At 1202, the process 1200 may include receiving configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE. At 1204, the process 1200 may further include performing DL-PRS measurements on respective subbands of the DL-PRS resource using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE. At 1206, the process 1200 may further include generating a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

Figure 13 illustrates another example process 1300 in accordance with various embodiments. In some embodiments, the process 1300 may be performed by a gNB or a portion thereof. At 1302, the process 1300 may include transmitting, to a reduced capability (RedCap) user equipment (UE), configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE, wherein the configuration information indicates subbands of the DL-PRS resource on which the RedCap UE is to perform DL-PRS measurements using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE. At 1304, the process 1300 may further include transmitting a DL-PRS on the respective subbands. At 1306, the process may further include receiving, from the RedCap UE, a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

Figure 14 illustrates another example process 1400 in accordance with various embodiments. The process 1400 may be performed by a UE (e.g., a RedCap UE) or a portion thereon. At 1402, the process 1400 may include receiving configuration information for a plurality of bandwidth parts (BWPs) or subbands to be used for transmission of an uplink sounding reference signal (UL-SRS) with frequency hopping. At 1404, the process 1400 may further include encoding the UL-SRS for transmission with frequency hopping in the plurality of BWPs or subbands based on the configuration information.

For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section.

EXAMPLES

Example A1 may include an apparatus to be implemented in a reduced capability (RedCap) user equipment (UE), the apparatus comprising: a memory to store configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE; and processor circuitry to: perform DL-PRS measurements on respective subbands of the DL-PRS resource using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE; and generate a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

Example A2 may include the apparatus of example A1 or some other example herein, wherein the measurements on the respective subbands are separated in a time domain by respective gaps.

Example A3 may include the apparatus of example A1-A2 or some other example herein, wherein two or more of the subbands partially overlap in a frequency domain.

Example A4 may include the apparatus of example A1-A3 or some other example herein, wherein the processor circuitry is to receive the configuration information via radio resource control (RRC) signaling.

Example A5 may include the apparatus of example A1-A4 or some other example herein, wherein the configuration information indicates a frequency hopping pattern for the DL-PRS measurements.

Example A6 may include the apparatus of example A5 or some other example herein, wherein the configuration information further indicates a starting physical resource block (PRB) of the different frequency hops.

Example A7 may include the apparatus of example A6 or some other example herein, wherein the processor circuitry is further to identify a reference point to indicate the starting PRB, wherein the reference point corresponds to: a lowest subcarrier of a common resource block (CRB) 0; a starting PRB of a DL-PRS transmission in accordance with a configuration of DL-PRS positioning frequency layers, a DL-PRS resource set, or a DL-PRS resource; or a starting PRB of a configured bandwidth part (BWP) or a subband of the RedCap UE.

Example A8 may include the apparatus of any one of examples A1-A7 or some other example herein, wherein the processor circuitry is to report the wideband positioning measurement to a next generation Node B (gNB).

Example A9 may include an apparatus to be implemented in a reduced capability (RedCap) user equipment (UE), the apparatus comprising: a memory to store configuration information for a plurality of bandwidth parts (BWPs) or subbands to be used for transmission of an uplink sounding reference signal (UL-SRS) with frequency hopping; and processor circuitry to encode the UL-SRS for transmission with frequency hopping in the plurality of BWPs or subbands based on the configuration information.

Example A10 may include the apparatus of example A9 or some other example herein, wherein the UL-SRS is transmitted with a gap between respective frequency hops.

Example A11 may include the apparatus of example A10 or some other example herein, wherein the gap is defined as a number of symbols or slots.

Example A12 may include the apparatus of example A11 or some other example herein, wherein the number of symbols or slots is based on a numerology of the UL-SRS.

Example A13 may include the apparatus of example A9-A12 or some other example herein, wherein individual BWPs or subbands have a bandwidth that is less than or equal to a maximum bandwidth for the RedCap UE, and wherein the plurality of BWPs or subbands together have a bandwidth that is greater than the maximum bandwidth.

Example A14 may include the apparatus of example A9-A13 or some other example herein, wherein the configuration information indicates an association between a first SRS resource or resource set in a first BWP or subband of the BWPs or subbands and a second SRS resource or resource set in a second BWP or subband of the BWPs or subbands.

Example A15 may include the apparatus of example A14 or some other example herein, wherein the processor circuitry is further to: receive an indication that the first SRS resource or resource set is activated or deactivated; and determine that the second SRS resource set or resource is activated or deactivated based on the association.

Example A16 may include the apparatus of any one of examples A9-A15 or some other example herein, wherein the SRS is a semi-persistent SRS.

Example A17 may include one or more non-transitory computer-readable media (NTCRM) having instructions, stored thereon, that when executed by one or more processors of a next generation Node B (gNB), configure the gNB to: transmit, to a reduced capability (RedCap) user equipment (UE), configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE, wherein the configuration information indicates subbands of the DL-PRS resource on which the RedCap UE is to perform DL-PRS measurements using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE; transmit a DL-PRS on the respective subbands; and receive, from the RedCap UE, a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

Example A18 may include the one or more NTCRM of example A17 or some other example herein, wherein the DL-PRS transmissions on the respective subbands are separated in a time domain by respective gaps.

Example A19 may include the one or more NTCRM of example A17-A18 or some other example herein, wherein two or more of the subbands partially overlap in a frequency domain.

Example A20 may include the one or more NTCRM of any one of examples A17-A19 or some other example herein, wherein the configuration information indicates a frequency hopping pattern for the DL-PRS measurements.

Example B1 may include a method of wireless communication in a wireless cellular network, the method comprising:

Configuring, by a gNB, one or more downlink (DL) bandwidth part (BWP) or subbands for a DL positioning reference signal (DL-PRS) or sounding reference signal (SRS) for positioning with frequency hopping; and

Configuring, by the gNB, one or more gaps between DL-PRS and SRS for positioning with frequency hopping.

Example B2 may include the method of example B1 or some other example herein, wherein DL PRS sequence is generated in accordance with the DL PRS positioning frequency layer configuration that may exceed the maximum supported bandwidth by a RedCap UE; wherein DL PRS sequence may be mapped to the time-frequency resources allocated for DL PRS transmission in accordance with DL PRS positioning frequency layer configuration.

Example B3 may include the method of example B1 or some other example herein, wherein a RedCap UE may assume that a DL PRS sequence is transmitted in the time-frequency resources confined to a frequency subband in accordance with a frequency hopping pattern provided to a RedCap UE.

Example B4 may include the method of example B1 or some other example herein, wherein the starting PRB of the different hops may be configured by higher layers via RRC signalling.

Example B5 may include the method of example B1 or some other example herein, wherein the reference point to indicate the starting PRB may be defined as Point A that corresponds to the lowest subcarrier of the common resource block (CRB) 0, or as starting PRB of DL PRS transmission in accordance with configuration of DL PRS positioning frequency layers, DL PRS resource set or DL PRS resource.

Example B6 may include the method of example B1 or some other example herein, wherein the reference point of the starting PRB may be defined as starting PRB of the configured BWP for RedCap UEs or the starting PRB of a subband.

Example B7 may include the method of example B1 or some other example herein, wherein an association between SRS resource set in a first UL BWP and SRS resource set in a second UL BWP may be configured by higher layers via RRC signalling.

Example B8 may include the method of example B1 or some other example herein, wherein for semi-persistent SRS transmission with frequency hopping, when the SRS resource set in the first UL BWP is activated or deactivated, SRS resource set in the second UL BWP is also activated or deactivated in accordance with the association.

Example B9 may include the method of example B1 or some other example herein, wherein for aperiodic SRS transmission with frequency hopping, when the SRS resource set in the first UL BWP is triggered, SRS resource set in the second UL BWP is also triggered in accordance with the association.

Example B10 may include the method of example B1 or some other example herein, wherein an association between SRS resource in a first UL BWP and SRS resource in a second UL BWP may be configured by higher layers via RRC signalling.

Example B11 may include the method of example B1 or some other example herein, wherein for semi-persistent SRS for positioning with frequency hopping for RedCap UEs, more than one SRS resource sets in different UL BWPs in a carrier may be activated or deactivated via Medium Access Control - Control Element (MAC-CE).

Example B12 may include the method of example B1 or some other example herein, wherein for aperiodic SRS for positioning with frequency hopping for RedCap UEs, more than one SRS resource sets in different BWPs in a carrier may be triggered via DCI format 0_1, 0_2, 1_1, 1_2 and/or DCI format for multi-cell scheduling.

Example B13 may include the method of example B1 or some other example herein, wherein a group common DCI may be defined to trigger SRS transmission for positioning with frequency hopping in different BWPs for RedCap UEs.

Example B14 may include the method of example B1 or some other example herein, wherein for SRS transmission for positioning with frequency hopping, the starting PRB of the different hops may be configured by higher layers via RRC signalling.

Example B15 may include the method of example B1 or some other example herein, wherein the reference point of the starting PRB may be defined as Point A that corresponds to the lowest subcarrier of the common resource block (CRB) 0, or as starting PRB of SRS transmission in accordance with configuration of SRS resource set or SRS resource.

Example B16 may include the method of example B1 or some other example herein, wherein the reference point of the starting PRB may be defined as starting PRB of the configured UL BWP for RedCap UEs or the starting PRB of the aforementioned subband.

Example B17 may include a method of a reduced capability (RedCap) user equipment (UE), the method comprising:

receiving configuration information to indicate one or more downlink (DL) bandwidth parts (BWPs) or subbands for a DL positioning reference signal (DL PRS) or a sounding reference signal (SRS) for positioning with frequency hopping, wherein the configuration information further includes one or more gaps between frequency hops of the DL PRS or SRS; and

receiving the DL-PRS or transmitting the SRS based on the configuration information.

Example B18 may include the method of example B17 or some other example herein, wherein a DL PRS sequence for the DL PRS is generated in accordance with a DL PRS positioning frequency layer configuration, and wherein the DL PRS sequence is mapped to time-frequency resources allocated for DL PRS transmission in accordance with a DL PRS positioning frequency layer configuration.

Example B19 may include the method of example B18 or some other example herein, wherein the DL PRS positioning frequency layer configuration exceeds a maximum supported bandwidth by a RedCap UE.

Example B20 may include the method of example B17-19 or some other example herein, wherein the configuration information indicates a frequency hopping pattern for the DL PRS, and wherein the DL PRS is received based on an assumption that a DL PRS sequence is transmitted in time-frequency resources confined to a frequency subband in accordance with the frequency hopping pattern.

Example B21 may include the method of example B17-20 or some other example herein, wherein the configuration information further indicates a starting PRB of the different frequency hops.

Example B22 may include the method of example B17-21 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the DL PRS, wherein the reference point corresponds to a lowest subcarrier of a common resource block (CRB) 0, or as a starting PRB of the DL PRS transmission in accordance with a configuration of DL PRS positioning frequency layers, a DL PRS resource set, or a DL PRS resource.

Example B23 may include the method of example B17-22 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the DL PRS, wherein the reference point is defined as a starting PRB of a configured BWP for RedCap UEs or a starting PRB of a subband

Example B24 may include the method of example B17-23 or some other example herein, wherein the configuration information for the SRS indicates an association between a first SRS resource set in a first UL BWP and a second SRS resource set in a second UL BWP.

Example B25 may include the method of example B24 or some other example herein, further comprising receiving an indication that the first SRS resource set is activated or deactivated, and determining that the second SRS resource set is activated or deactivated based on the association.

Example B26 may include the method of example B17-26 or some other example herein, wherein the SRS is a semi-persistent SRS.

Example B27 may include the method of example B17-26 or some other example herein, further comprising receiving a medium access control – control element (MAC-CE) to activate multiple SRS resource sets in different UL BWPs in a carrier for the SRS.

Example B28 may include the method of example B24 or some other example herein, wherein the SRS is an aperiodic SRS, and wherein the method further comprises receiving an indication that the first SRS resource set is triggered, and determining that the second SRS resource set is also triggered based on the association.

Example B29 may include the method of example B17-23, 28, or some other example herein, further comprising receiving a downlink control information (DCI) to trigger multiple SRS resource sets in different UL BWPs in a carrier.

Example B30 may include the method of example B29 or some other example herein, wherein the DCI has a DCI format 0_1, 0_2, 1_1, 1_2 and/or DCI format for multi-cell scheduling.

Example B31 may include the method of example B17-30 or some other example herein, further comprising receiving a group common DCI to trigger the SRS transmission in different BWPs.

Example B32 may include the method of example B17-32 or some other example herein, wherein the configuration information indicates a starting PRB of the different frequency hops of the SRS.

Example B33 may include the method of example B17-32 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the SRS, wherein the reference point corresponds to a lowest subcarrier of a common resource block (CRB) 0, or as a starting PRB of SRS transmission in accordance with a configuration of a SRS resource set or a SRS resource.

Example B34 may include the method of example B17-32 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the SRS, wherein the reference point is defined as a starting PRB of a configured UL BWP for RedCap UEs or a starting PRB of the respective subband.

Example B35 may include a method of a next generation Node B (gNB), the method comprising:

encoding, for transmission to a reduced capability (RedCap) user equipment (UE), configuration information to indicate one or more downlink (DL) bandwidth parts (BWPs) or subbands for a DL positioning reference signal (DL PRS) or a sounding reference signal (SRS) for positioning with frequency hopping, wherein the configuration information further includes one or more gaps between frequency hops of the DL PRS or SRS; and

transmitting the DL-PRS or receiving the SRS based on the configuration information.

Example B36 may include the method of example B35 or some other example herein, further comprising generating a DL PRS sequence in accordance with a DL PRS positioning frequency layer configuration, and wherein the DL PRS sequence is mapped to time-frequency resources allocated for DL PRS transmission in accordance with a DL PRS positioning frequency layer configuration.

Example B37 may include the method of example B36 or some other example herein, wherein the DL PRS positioning frequency layer configuration exceeds a maximum supported bandwidth by the RedCap UE.

Example B38 may include the method of example B35-37 or some other example herein, wherein the configuration information indicates a frequency hopping pattern for the DL PRS, and wherein the UE is to receive the DL PRS based on an assumption that a DL PRS sequence is transmitted in time-frequency resources confined to a frequency subband in accordance with the frequency hopping pattern.

Example B39 may include the method of example B35-38 or some other example herein, wherein the configuration information further indicates a starting PRB of the different frequency hops.

Example B40 may include the method of example B35-39 or some other example herein, wherein a reference point to indicate a starting PRB of the DL PRS corresponds to a lowest subcarrier of a common resource block (CRB) 0, or as a starting PRB of the DL PRS transmission in accordance with a configuration of DL PRS positioning frequency layers, a DL PRS resource set, or a DL PRS resource.

Example B41 may include the method of example B35-40 or some other example herein, wherein a reference point to indicate a starting PRB of the DL PRS is defined as a starting PRB of a configured BWP for RedCap UEs or a starting PRB of a subband

Example B42 may include the method of example B35-41 or some other example herein, wherein the configuration information for the SRS indicates an association between a first SRS resource set in a first UL BWP and a second SRS resource set in a second UL BWP.

Example B43 may include the method of example B42 or some other example herein, further comprising transmitting an indication that the first SRS resource set is activated or deactivated, wherein the indication also activates or deactivates the second SRS resource set based on the association.

Example B44 may include the method of example B35-43 or some other example herein, wherein the SRS is a semi-persistent SRS.

Example B45 may include the method of example B35-44 or some other example herein, further comprising transmitting, to the UE, a medium access control – control element (MAC-CE) to activate multiple SRS resource sets in different UL BWPs in a carrier for the SRS.

Example B46 may include the method of example B42 or some other example herein, wherein the SRS is an aperiodic SRS, and wherein the method further comprises transmitting, to the UE, an indication that the first SRS resource set is triggered, wherein the indication also triggers the second SRS resource set based on the association.

Example B47 may include the method of example B35-46 or some other example herein, further comprising transmitting, to the UE, a downlink control information (DCI) to trigger multiple SRS resource sets in different UL BWPs in a carrier.

Example B48 may include the method of example B47 or some other example herein, wherein the DCI has a DCI format 0_1, 0_2, 1_1, 1_2 and/or DCI format for multi-cell scheduling.

Example B49 may include the method of example B35-48 or some other example herein, further comprising transmitting, to a plurality of UEs including the UE, a group common DCI to trigger the SRS transmission in different BWPs.

Example B50 may include the method of example B35-49 or some other example herein, wherein the configuration information indicates a starting PRB of the different frequency hops of the SRS.

Example B51 may include the method of example B35-50 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the SRS, wherein the reference point corresponds to a lowest subcarrier of a common resource block (CRB) 0, or as a starting PRB of SRS transmission in accordance with a configuration of a SRS resource set or a SRS resource.

Example B52 may include the method of example B35-51 or some other example herein, further comprising identifying a reference point to indicate a starting PRB of the SRS, wherein the reference point is defined as a starting PRB of a configured UL BWP for RedCap UEs or a starting PRB of the respective subband.

Example C1 may include a method of wireless communication for a fifth generation (5G) or new radio (NR) system, the method comprising:

Configuring, by a gNB, one or more downlink (DL) bandwidth part (BWP) for a DL positioning reference signal (DL-PRS) repetitions; and

Configuring, by the gNB, one or more gaps between DL-PRS repetitions.

Example C2 may include the method of example C1 or some other example herein, wherein wideband DL-PRS transmission may be configured to a RedCap UE for a DL-PRS resource such that the wideband DL-PRS transmission BW may exceed the maximum RedCap UE BW for the corresponding Frequency Range (FR).

Example C3 may include the method of example C1 or some other example herein, wherein multiple subbands for DL-PRS transmission in frequency can be configured by higher layers via radio resource control (RRC) signalling.

Example C4 may include the method of example C1 or some other example herein, wherein subband size and subband distance between two adjacent subbands in each DL-PRS repetition can be configured by higher layers via RRC signalling.

Example C5 may include the method of example C1 or some other example herein, wherein the subband size and number of overlapping PRBs between two subbands can be configured by higher layers via RRC signalling.

Example C6 may include the method of example C1 or some other example herein, wherein the starting subband index for the frequency hopping can be configured by higher layers via RRC signalling; wherein the subband index can be increased by 1 and modulo on total number of subbands for the subsequent DL-PRS repetition in a DL-PRS resource.

Example C7 may include the method of example C1 or some other example herein, wherein a DL-PRS frequency hopping pattern may be defined in accordance with one or more following parameters: starting PRB for the first repetition, the subband index and DL-PRS repetition index.

Example C8 may include the method of example C1 or some other example herein, wherein UE performs subband frequency hopping for positioning measurement on a group of every K DL-PRS repetitions; wherein within the group of every K DL-PRS repetitions, same set of PRBs are used for DL-PRS measurement.

Example C9 may include the method of example C8 or some other example herein, wherein two gaps between DL-PRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K DL-PRS repetitions; and the second gap may be configured between two groups of every K DL-PRS repetitions.

Example C10 may include the method of example C1 or some other example herein, wherein DL-PRS repetitions for a DL-PRS resource may be transmitted in different DL bandwidth parts (BWPs) that may be configured to a RedCap UE for frequency hopping.

Example C11 may include the method of example C1 or some other example herein, wherein a gap may be configured between two DL-PRS repetitions for BWP switching; wherein the gaps may be defined in accordance with a number of symbols or slots or absolute time.

Example C12 may include the method of example C1 or some other example herein, wherein a group of every K DL-PRS repetitions for a DL-PRS resource may be transmitted in different DL BWPs configured to a RedCap UE for frequency hopping.

Example C13 may include the method of example C12 or some other example herein, wherein two gaps between DL-PRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K DL-PRS repetitions; and the second gap may be configured between two groups of every K DL-PRS repetitions.

Example C14 may include the method of example C1 or some other example herein, wherein a RedCap UE may be configured with a DL-PRS configuration such that the DL-PRS are mapped to one of N subbands or N DL BWPs across r*N consecutive DL-PRS transmission occasions such that a pair of consecutive DL-PRS occasions may be separated by a time gap of a number of symbols or slots of absolute time, wherein r is an integer greater than or equal to one.

Example C15 may include the method of example C1 or some other example herein, wherein UL SRS repetitions for positioning for a UL SRS resource are transmitted in different UL BWPs configured to a RedCap UE for frequency hopping.

Example C16 may include the method of example C15 or some other example herein, wherein a gap may be configured between two UL SRS repetitions for BWP switching; wherein the gaps may be defined in accordance with a number of symbols or slots or absolute time.

Example C17 may include the method of example C1 or some other example herein, wherein a group of every K SRS repetitions for positioning for a SRS resource are transmitted in different UL BWP for frequency hopping; wherein same set of frequency resources are used for SRS repetitions within the group of every K SRS repetitions.

Example C18 may include the method of example C17 or some other example herein, wherein two gaps between SRS repetitions may be configured by higher layers, where the first gap may be configured between two repetitions within a group of every K SRS repetitions; and the second gap may be configured between two groups of every K SRS repetitions.

Example C19 may include the method of example C1 or some other example herein, wherein a RedCap UE may be configured with a SRS configuration such that the SRS are mapped to one of N UL BWPs across r*N consecutive SRS transmission occasions such that a pair of consecutive SRS occasions may be separated by a time gap of a number of symbols or slots of absolute time, wherein r is an integer greater than or equal to one.

Example C20 may include a method of a reduced capability (RedCap) user equipment (UE), the method comprising:

receiving configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE; and

performing one or more DL-PRS measurements on respective subbands of the DL-PRS resource using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE.

Example C21 may include the method of example C20 or some other example herein, wherein the configuration information is to configure the subbands.

Example C22 may include the method of example C20-21 or some other example herein, wherein the measurements on the individual subbands are separated in the time domain by one or more respective gaps.

Example C23 may include the method of example C20-22 or some other example herein, wherein the configuration information is further to configure the one or more gaps.

Example C24 may include the method of example C20-23 or some other example herein, further comprising stitching the measurements for the multiple subbands together to generate a wideband measurement.

Example C25 may include the method of example C24 or some other example herein, further comprising reporting the wideband measurement to a gNB.

Example Z01 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples A1-A20, B1-B52, C1-C25, or any other method or process described herein.

Example Z02 may include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of a method described in or related to any of examples A1-A20, B1-B52, C1-C25, or any other method or process described herein.

Example Z03 may include an apparatus comprising logic, modules, or circuitry to perform one or more elements of a method described in or related to any of examples A1-A20, B1-B52, C1-C25, or any other method or process described herein.

Example Z04 may include a method, technique, or process as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions or parts thereof.

Example Z05 may include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions thereof.

Example Z06 may include a signal as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions or parts thereof.

Example Z07 may include a datagram, packet, frame, segment, protocol data unit (PDU), or message as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions or parts thereof, or otherwise described in the present disclosure.

Example Z08 may include a signal encoded with data as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions or parts thereof, or otherwise described in the present disclosure.

Example Z09 may include a signal encoded with a datagram, packet, frame, segment, protocol data unit (PDU), or message as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions or parts thereof, or otherwise described in the present disclosure.

Example Z10 may include an electromagnetic signal carrying computer-readable instructions, wherein execution of the computer-readable instructions by one or more processors is to cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions thereof.

Example Z11 may include a computer program comprising instructions, wherein execution of the program by a processing element is to cause the processing element to carry out the method, techniques, or process as described in or related to any of examples A1-A20, B1-B52, C1-C25, or portions thereof.

Example Z12 may include a signal in a wireless network as shown and described herein.

Example Z13 may include a method of communicating in a wireless network as shown and described herein.

Example Z14 may include a system for providing wireless communication as shown and described herein.

Example Z15 may include a device for providing wireless communication as shown and described herein.

Any of the above-described examples may be combined with any other example (or combination of examples), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

Abbreviations

Unless used differently herein, terms, definitions, and abbreviations may be consistent with terms, definitions, and abbreviations defined in 3GPP TR 21.905 v16.0.0 (2019-06). For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein.

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5GC	5G Core network
AC	Application Client
ACR	Application Context Relocation
ACK	Acknowledgement
ACID	Application Client Identification
ADRF	Analytics Data Repository Function
AF	Application Function
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AN	Access Network
AnLF	Analytics Logical Function
ANR	Automatic Neighbour Relation
AOA	Angle of Arrival
AP	Application Protocol, Antenna Port, Access Point
API	Application Programming Interface
APN	Access Point Name
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat Request
AS	Access Stratum
ASP	Application Service Provider
ASN.1	Abstract Syntax Notation One
AUSF	Authentication Server Function
AWGN	Additive White Gaussian Noise
BAP	Backhaul Adaptation Protocol
BCH	Broadcast Channel
BER	Bit Error Ratio
BFD	Beam Failure Detection
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BRAS	Broadband Remote Access Server
BSS	Business Support System
BS	Base Station
BSR	Buffer Status Report
BW	Bandwidth
BWP	Bandwidth Part
C-RNTI	Cell Radio Network Temporary Identity
CA	Carrier Aggregation, Certification Authority
CAPEX	CAPital Expenditure
CBD	Candidate Beam Detection
CBRA	Contention Based Random Access
CC	Component Carrier, Country Code, Cryptographic Checksum

CCA	Clear Channel Assessment
CCE	Control Channel Element
CCCH	Common Control Channel
CE	Coverage Enhancement
CDM	Content Delivery Network
CDMA	Code-Division Multiple Access
CDR	Charging Data Request
CDR	Charging Data Response
CFRA	Contention Free Random Access
CG	Cell Group
CGF	Charging Gateway Function
CHF	Charging Function
CI	Cell Identity
CID	Cell-ID (e.g., positioning method)
CIM	Common Information Model
CIR	Carrier to Interference Ratio
CK	Cipher Key
CM	Connection Management, Conditional Mandatory
CMAS	Commercial Mobile Alert Service
CMD	Command
CMS	Cloud Management System
CO	Conditional Optional
CoMP	Coordinated Multi-Point
CORESET	Control Resource Set
COTS	Commercial Off-The-Shelf
CP	Control Plane, Cyclic Prefix, Connection Point
CPD	Connection Point Descriptor
CPE	Customer Premise Equipment
CPICH	Common Pilot Channel
CQI	Channel Quality Indicator
CPU	CSI processing unit, Central Processing Unit
C/R	Command/Response field bit
CRAN	Cloud Radio Access Network, Cloud RAN
CRB	Common Resource Block
CRC	Cyclic Redundancy Check
CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
C-RNTI	Cell RNTI
CS	Circuit Switched
CSCF	call session control function
CSAR	Cloud Service Archive
CSI	Channel-State Information
CSI-IM	CSI Interference Measurement
CSI-RS	CSI Reference Signal
CSI-RSRP	CSI reference signal received power
CSI-RSRQ	CSI reference signal received quality
CSI-SINR	CSI signal-to-noise and

	interference ratio
CSMA	Carrier Sense Multiple Access
CSMA/CA	CSMA with collision avoidance
CSS	Common Search Space, Cell-specific Search Space
CTF	Charging Trigger Function
CTS	Clear-to-Send
CW	Codeword
CWS	Contention Window Size
D2D	Device-to-Device
DC	Dual Connectivity, Direct Current
DCI	Downlink Control Information
DF	Deployment Flavour
DL	Downlink
DMTF	Distributed Management Task Force
DPDK	Data Plane Development Kit
DM-RS, DMRS	Demodulation Reference Signal
DN	Data network
DNN	Data Network Name
DNAI	Data Network Access Identifier
DRB	Data Radio Bearer
DRS	Discovery Reference Signal
DRX	Discontinuous Reception
DSL	Domain Specific Language. Digital Subscriber Line
DSLAM	DSL Access Multiplexer
DwPTS	Downlink Pilot Time Slot
E-LAN	Ethernet Local Area Network
E2E	End-to-End
EAS	Edge Application Server
ECCA	extended clear channel assessment, extended CCA
ECCE	Enhanced Control Channel Element, Enhanced CCE
ED	Energy Detection
EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
EAS	Edge Application Server
EASID	Edge Application Server Identification
ECS	Edge Configuration Server
ECSP	Edge Computing Service Provider
EDN	Edge Data Network
EEC	Edge Enabler Client
EECID	Edge Enabler Client Identification
EES	Edge Enabler Server
EESID	Edge Enabler Server Identification
EHE	Edge Hosting Environment
EGMF	Exposure Governance Management Function
EGPRS	

	Enhanced GPRS
EIR	Equipment Identity Register
eLAA	enhanced Licensed Assisted Access, enhanced LAA
EM	Element Manager
eMBB	Enhanced Mobile Broadband
EMS	Element Management System
eNB	evolved NodeB, E-UTRAN Node B
EN-DC	E-UTRA-NR Dual Connectivity
EPC	Evolved Packet Core
EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Cannel
EPRE	Energy per resource element
EPS	Evolved Packet System
EREG	enhanced REG, enhanced resource element groups
ETSI	European Telecommunications Standards Institute
ETWS	Earthquake and Tsunami Warning System
eUICC	embedded UICC, embedded Universal Integrated Circuit Card
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
EV2X	Enhanced V2X
F1AP	F1 Application Protocol
F1-C	F1 Control plane interface
F1-U	F1 User plane interface
FACCH	Fast Associated Control CHannel
FACCH/F	Fast Associated Control Channel/Full rate
FACCH/H	Fast Associated Control Channel/Half rate
FACH	Forward Access Channel
FAUSCH	Fast Uplink Signalling Channel
FB	Functional Block
FBI	Feedback Information
FCC	Federal Communications Commission
FCCH	Frequency Correction CHannel
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FE	Front End
FEC	Forward Error Correction
FFS	For Further Study
FFT	Fast Fourier Transformation
feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
FN	Frame Number
FPGA	Field-

	Programmable Gate Array
FR	Frequency Range
FQDN	Fully Qualified Domain Name
G-RNTI	GERAN Radio Network Temporary Identity
GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
gNB	Next Generation NodeB
gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPSI	Generic Public Subscription Identifier
GSM	Global System for Mobile Communications, Groupe Spécial Mobile
GTP	GPRS Tunneling Protocol
GTP-U	GPRS Tunnelling Protocol for User Plane
GTS	Go To Sleep Signal (related to WUS)
GUMMEI	Globally Unique MME Identifier
GUTI	Globally Unique Temporary UE Identity
HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
HANDO	Handover
HFN	HyperFrame Number
HHO	Hard Handover
HLR	Home Location Register
HN	Home Network
HO	Handover
HPLMN	Home Public Land Mobile Network
HSDPA	High Speed Downlink Packet Access
HSN	Hopping Sequence Number
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
I-Block	Information Block
ICCID	Integrated Circuit Card Identification

IAB	Integrated Access and Backhaul
ICIC	Inter-Cell Interference Coordination
ID	Identity, identifier
IDFT	Inverse Discrete Fourier Transform
IE	Information element
IBE	In-Band Emission
IEEE	Institute of Electrical and Electronics Engineers
IEI	Information Element Identifier
IEIDL	Information Element Identifier Data Length
IETF	Internet Engineering Task Force
IF	Infrastructure
IIOT	Industrial Internet of Things
IM	Interference Measurement, Intermodulation, IP Multimedia
IMC	IMS Credentials
IMEI	International Mobile Equipment Identity
IMGI	International mobile group identity
IMPI	IP Multimedia Private Identity
IMPU	IP Multimedia PUblic identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
Ipsec	IP Security, Internet Protocol Security
IP-CAN	IP-Connectivity Access Network
IP-M	IP Multicast
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
IR	Infrared
IS	In Sync
IRP	Integration Reference Point
ISDN	Integrated Services Digital Network
ISIM	IM Services Identity Module
ISO	International Organisation for Standardisation
ISP	Internet Service Provider
IWF	Interworking-Function
I-WLAN	Interworking WLAN
	Constraint length of the convolutional code, USIM Individual key
kB	Kilobyte (1000 bytes)
kbps	kilo-bits per second
Kc	Ciphering key
Ki	Individual subscriber authentication key
KPI	Key Performance Indicator
KQI	Key Quality

	Indicator
KSI	Key Set Identifier
ksps	kilo-symbols per second
KVM	Kernel Virtual Machine
L1	Layer 1 (physical layer)
L1-RSRP	Layer 1 reference signal received power
L2	Layer 2 (data link layer)
L3	Layer 3 (network layer)
LAA	Licensed Assisted Access
LAN	Local Area Network
LADN	Local Area Data Network
LBT	Listen Before Talk
LCM	LifeCycle Management
LCR	Low Chip Rate
LCS	Location Services
LCID	Logical Channel ID
LI	Layer Indicator
LLC	Logical Link Control, Low Layer Compatibility
LMF	Location Management Function
LOS	Line of Sight
LPLMN	Local PLMN
LPP	LTE Positioning Protocol
LSB	Least Significant Bit
LTE	Long Term Evolution
LWA	LTE-WLAN aggregation
LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
LTE	Long Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control (protocol layering context)
MAC	Message authentication code (security/encryption context)
MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
MANO	Management and Orchestration
MBMS	Multimedia Broadcast and Multicast Service
MBSFN	Multimedia Broadcast multicast service Single Frequency Network
MCC	Mobile Country Code
MCG	Master Cell Group
MCOT	Maximum Channel Occupancy Time
MCS	Modulation and coding scheme
MDAF	Management Data Analytics Function
MDAS	Management Data Analytics

	Service
MDT	Minimization of Drive Tests
ME	Mobile Equipment
MeNB	master eNB
MER	Message Error Ratio
MGL	Measurement Gap Length
MGRP	Measurement Gap Repetition Period
MIB	Master Information Block, Management Information Base
MIMO	Multiple Input Multiple Output
MLC	Mobile Location Centre
MM	Mobility Management
MME	Mobility Management Entity
MN	Master Node
MNO	Mobile Network Operator
MO	Measurement Object, Mobile Originated
MPBCH	MTC Physical Broadcast CHannel
MPDCCH	MTC Physical Downlink Control CHannel
MPDSCH	MTC Physical Downlink Shared CHannel
MPRACH	MTC Physical Random Access CHannel
MPUSCH	MTC Physical Uplink Shared Channel
MPLS	MultiProtocol Label Switching
MS	Mobile Station
MSB	Most Significant Bit
MSC	Mobile Switching Centre
MSI	Minimum System Information, MCH Scheduling Information
MSID	Mobile Station Identifier
MSIN	Mobile Station Identification Number
MSISDN	Mobile Subscriber ISDN Number
MT	Mobile Terminated, Mobile Termination
MTC	Machine-Type Communications
MTLF	Model Training Logical Functions
mMTC	massive MTC, massive Machine-Type Communications
MU-MIMO	Multi User MIMO
MWUS	MTC wake-up signal, MTC WUS
NACK	Negative Acknowledgement
NAI	Network Access Identifier
NAS	Non-Access Stratum, Non- Access Stratum layer
NCT	Network Connectivity Topology
NC-JT	Non-Coherent Joint Transmission
NEC	Network Capability Exposure
NE-DC	NR-E-

	UTRA Dual Connectivity
NEF	Network Exposure Function
NF	Network Function
NFP	Network Forwarding Path
NFPD	Network Forwarding Path Descriptor
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NG	Next Generation, Next Gen
NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
NM	Network Manager
NMS	Network Management System
N-PoP	Network Point of Presence
NMIB, N-MIB	Narrowband MIB
NPBCH	Narrowband Physical Broadcast CHannel
NPDCCH	Narrowband Physical Downlink Control CHannel
NPDSCH	Narrowband Physical Downlink Shared CHannel
NPRACH	Narrowband Physical Random Access CHannel
NPUSCH	Narrowband Physical Uplink Shared CHannel
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
NR	New Radio, Neighbour Relation
NRF	NF Repository Function
NRS	Narrowband Reference Signal
NS	Network Service
NSA	Non-Standalone operation mode
NSD	Network Service Descriptor
NSR	Network Service Record
NSSAI	Network Slice Selection Assistance Information
S-NNSAI	Single-NSSAI
NSSF	Network Slice Selection Function
NW	Network
NWDAF	Network Data Analytics Function
NWUS	Narrowband wake-up signal, Narrowband WUS
NZP	Non-Zero Power
O&M	Operation and Maintenance
ODU2	Optical channel Data Unit - type 2
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-of-band

OOS	Out of Sync
OPEX	OPerating EXpense
OSI	Other System Information
OSS	Operations Support System
OTA	over-the-air
PAPR	Peak-to-Average Power Ratio
PAR	Peak to Average Ratio
PBCH	Physical Broadcast Channel
PC	Power Control, Personal Computer
PCC	Primary Component Carrier, Primary CC
P-CSCF	Proxy CSCF
PCell	Primary Cell
PCI	Physical Cell ID, Physical Cell Identity
PCEF	Policy and Charging Enforcement Function
PCF	Policy Control Function
PCRF	Policy Control and Charging Rules Function
PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network, Public Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PEI	Permanent Equipment Identifiers
PFD	Packet Flow Description
P-GW	PDN Gateway
PHICH	Physical hybrid-ARQ indicator channel
PHY	Physical layer
PLMN	Public Land Mobile Network
PIN	Personal Identification Number
PM	Performance Measurement
PMI	Precoding Matrix Indicator
PNF	Physical Network Function
PNFD	Physical Network Function Descriptor
PNFR	Physical Network Function Record
POC	PTT over Cellular
PP, PTP	Point-to-Point
PPP	Point-to-Point Protocol
PRACH	Physical RACH
PRB	Physical resource block
PRG	Physical resource block group
ProSe	Proximity Services, Proximity-Based Service
PRS	Positioning Reference Signal
PRR	Packet Reception Radio
PS	Packet Services
PSBCH	Physical Sidelink Broadcast

	Channel
PSDCH	Physical Sidelink Downlink Channel
PSCCH	Physical Sidelink Control Channel
PSSCH	Physical Sidelink Shared Channel
PSFCH	physical sidelink feedback channel
PSCell	Primary SCell
PSS	Primary Synchronization Signal
PSTN	Public Switched Telephone Network
PT-RS	Phase-tracking reference signal
PTT	Push-to-Talk
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS class of identifier
QCL	Quasi co-location
QFI	QoS Flow ID, QoS Flow Identifier
QoS	Quality of Service
QPSK	Quadrature (Quaternary) Phase Shift Keying
QZSS	Quasi-Zenith Satellite System
RA-RNTI	Random Access RNTI
RAB	Radio Access Bearer, Random Access Burst
RACH	Random Access Channel
RADIUS	Remote Authentication Dial In User Service
RAN	Radio Access Network
RAND	RANDom number (used for authentication)
RAR	Random Access Response
RAT	Radio Access Technology
RAU	Routing Area Update
RB	Resource block, Radio Bearer
RBG	Resource block group
REG	Resource Element Group
Rel	Release
REQ	REQuest
RF	Radio Frequency
RI	Rank Indicator
RIV	Resource indicator value
RL	Radio Link
RLC	Radio Link Control, Radio Link Control layer
RLC AM	RLC Acknowledged Mode
RLC UM	RLC Unacknowledged Mode
RLF	Radio Link Failure
RLM	Radio Link Monitoring
RLM-RS	Reference Signal for RLM
RM	Registration Management
RMC	Reference Measurement Channel
RMSI	Remaining MSI, Remaining Minimum System Information

RN	Relay Node
RNC	Radio Network Controller
RNL	Radio Network Layer
RNTI	Radio Network Temporary Identifier
ROHC	RObust Header Compression
RRC	Radio Resource Control, Radio Resource Control layer
RRM	Radio Resource Management
RS	Reference Signal
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
RSTD	Reference Signal Time difference
RTP	Real Time Protocol
RTS	Ready-To-Send
RTT	Round Trip Time
Rx	Reception, Receiving, Receiver
S1AP	S1 Application Protocol
S1-MME	S1 for the control plane
S1-U	S1 for the user plane
S-CSCF	serving CSCF
S-GW	Serving Gateway
S-RNTI	SRNC Radio Network Temporary Identity
S-TMSI	SAE Temporary Mobile Station Identifier
SA	Standalone operation mode
SAE	System Architecture Evolution
SAP	Service Access Point
SAPD	Service Access Point Descriptor
SAPI	Service Access Point Identifier
SCC	Secondary Component Carrier, Secondary CC
SCell	Secondary Cell
SCEF	Service Capability Exposure Function
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCG	Secondary Cell Group
SCM	Security Context Management
SCS	Subcarrier Spacing
SCTP	Stream Control Transmission Protocol
SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
SDL	Supplementary Downlink
SDNF	Structured Data Storage Network Function
SDP	Session Description Protocol
SDSF	Structured Data Storage Function
SDT	Small Data Transmission

SDU	Service Data Unit
SEAF	Security Anchor Function
SeNB	secondary eNB
SEPP	Security Edge Protection Proxy
SFI	Slot format indication
SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
SFN	System Frame Number
SgNB	Secondary gNB
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SI	System Information
SI-RNTI	System Information RNTI
SIB	System Information Block
SIM	Subscriber Identity Module
SIP	Session Initiated Protocol
SiP	System in Package
SL	Sidelink
SLA	Service Level Agreement
SM	Session Management
SMF	Session Management Function
SMS	Short Message Service
SMSF	SMS Function
SMTC	SSB-based Measurement Timing Configuration
SN	Secondary Node, Sequence Number
SoC	System on Chip
SON	Self-Organizing Network
SpCell	Special Cell
SP-CSI-RNTI	Semi-Persistent CSI RNTI
SPS	Semi-Persistent Scheduling
SQN	Sequence number
SR	Scheduling Request
SRB	Signalling Radio Bearer
SRS	Sounding Reference Signal
SS	Synchronization Signal
SSB	Synchronization Signal Block
SSID	Service Set Identifier
SS/PBCH	Block
SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
SSC	Session and Service Continuity
SS-RSRP	Synchronization Signal based Reference Signal Received Power
SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
SSS	Secondary Synchronization Signal
SSSG	Search Space Set Group
SSSIF	Search Space

	Set Indicator
SST	Slice/Service Types
SU-MIMO	Single User MIMO
SUL	Supplementary Uplink
TA	Timing Advance, Tracking Area
TAC	Tracking Area Code
TAG	Timing Advance Group
TAI	Tracking Area Identity
TAU	Tracking Area Update
TB	Transport Block
TBS	Transport Block Size
TBD	To Be Defined
TCI	Transmission Configuration Indicator
TCP	Transmission Communication Protocol
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TEID	Tunnel End Point Identifier
TFT	Traffic Flow Template
TMSI	Temporary Mobile Subscriber Identity
TNL	Transport Network Layer
TPC	Transmit Power Control
TPMI	Transmitted Precoding Matrix Indicator
TR	Technical Report
TRP, TRxP	Transmission Reception Point
TRS	Tracking Reference Signal
TRx	Transceiver
TS	Technical Specifications, Technical Standard
TTI	Transmission Time Interval
Tx	Transmission, Transmitting, Transmitter
U-RNTI	UTRAN Radio Network Temporary Identity
UART	Universal Asynchronous Receiver and Transmitter
UCI	Uplink Control Information
UE	User Equipment
UDM	Unified Data Management
UDP	User Datagram Protocol
UDSF	Unstructured Data Storage Network Function
UICC	Universal Integrated Circuit Card
UL	Uplink
UM	Unacknowledged Mode
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
URI	Uniform Resource Identifier

URL	Uniform Resource Locator
URLLC	Ultra-Reliable and Low Latency
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
USS	UE-specific search space
UTRA	UMTS Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
UwPTS	Uplink Pilot Time Slot
V2I	Vehicle-to-Infrastruction
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VIM	Virtualized Infrastructure Manager
VL	Virtual Link,
VLAN	Virtual LAN, Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualized Network Function
VNFFG	VNF Forwarding Graph
VNFFGD	VNF Forwarding Graph Descriptor
VNFM	VNF Manager
VoIP	Voice-over-IP, Voice-over-Internet Protocol
VPLMN	Visited Public Land Mobile Network
VPN	Virtual Private Network
VRB	Virtual Resource Block
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
X2-C	X2-Control plane
X2-U	X2-User plane
XML	eXtensible Markup Language
XRES	EXpected user RESponse
XOR	eXclusive OR
ZC	Zadoff-Chu
ZP	Zero Power

Terminology

For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein.

The term “application” may refer to a complete and deployable package, environment to achieve a certain function in an operational environment. The term “AI/ML application” or the like may be an application that contains some AI/ML models and application-level descriptions.

The term “circuitry” as used herein refers to, is part of, or includes hardware components such as an electronic circuit, a logic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group), an Application Specific Integrated Circuit (ASIC), a field-programmable device (FPD) (e.g., a field-programmable gate array (FPGA), a programmable logic device (PLD), a complex PLD (CPLD), a high-capacity PLD (HCPLD), a structured ASIC, or a programmable SoC), digital signal processors (DSPs), etc., that are configured to provide the described functionality. In some embodiments, the circuitry may execute one or more software or firmware programs to provide at least some of the described functionality. The term “circuitry” may also refer to a combination of one or more hardware elements (or a combination of circuits used in an electrical or electronic system) with the program code used to carry out the functionality of that program code. In these embodiments, the combination of hardware elements and program code may be referred to as a particular type of circuitry.

The term “processor circuitry” as used herein refers to, is part of, or includes circuitry capable of sequentially and automatically carrying out a sequence of arithmetic or logical operations, or recording, storing, and/or transferring digital data. Processing circuitry may include one or more processing cores to execute instructions and one or more memory structures to store program and data information. The term “processor circuitry” may refer to one or more application processors, one or more baseband processors, a physical central processing unit (CPU), a single-core processor, a dual-core processor, a triple-core processor, a quad-core processor, and/or any other device capable of executing or otherwise operating computer-executable instructions, such as program code, software modules, and/or functional processes. Processing circuitry may include more hardware accelerators, which may be microprocessors, programmable processing devices, or the like. The one or more hardware accelerators may include, for example, computer vision (CV) and/or deep learning (DL) accelerators. The terms “application circuitry” and/or “baseband circuitry” may be considered synonymous to, and may be referred to as, “processor circuitry.”

The term “interface circuitry” as used herein refers to, is part of, or includes circuitry that enables the exchange of information between two or more components or devices. The term "interface circuitry" may refer to one or more hardware interfaces, for example, buses, I/O interfaces, peripheral component interfaces, network interface cards, and/or the like.

The term "user equipment" or "UE" as used herein refers to a device with radio communication capabilities and may describe a remote user of network resources in a communications network. The term "user equipment" or "UE" may be considered synonymous to, and may be referred to as, client, mobile, mobile device, mobile terminal, user terminal, mobile unit, mobile station, mobile user, subscriber, user, remote station, access agent, user agent, receiver, radio equipment, reconfigurable radio equipment, reconfigurable mobile device, etc. Furthermore, the term "user equipment" or "UE" may include any type of wireless/wired device or any computing device including a wireless communications interface.

The term "network element" as used herein refers to physical or virtualized equipment and/or infrastructure used to provide wired or wireless communication network services. The term "network element" may be considered synonymous to and/or referred to as a networked computer, networking hardware, network equipment, network node, router, switch, hub, bridge, radio network controller, RAN device, RAN node, gateway, server, virtualized VNF, NFVI, and/or the like.

The term "computer system" as used herein refers to any type interconnected electronic devices, computer devices, or components thereof. Additionally, the term "computer system" and/or "system" may refer to various components of a computer that are communicatively coupled with one another. Furthermore, the term "computer system" and/or "system" may refer to multiple computer devices and/or multiple computing systems that are communicatively coupled with one another and configured to share computing and/or networking resources.

The term "appliance," "computer appliance," or the like, as used herein refers to a computer device or computer system with program code (e.g., software or firmware) that is specifically designed to provide a specific computing resource. A "virtual appliance" is a virtual machine image to be implemented by a hypervisor-equipped device that virtualizes or emulates a computer appliance or otherwise is dedicated to provide a specific computing resource.

The term "resource" as used herein refers to a physical or virtual device, a physical or virtual component within a computing environment, and/or a physical or virtual component within a particular device, such as computer devices, mechanical devices, memory space, processor/CPU time, processor/CPU usage, processor and accelerator loads, hardware time or usage, electrical power, input/output operations, ports or network sockets, channel/link allocation, throughput, memory usage, storage, network, database and applications, workload units, and/or the like. A "hardware resource" may refer to compute, storage, and/or network resources provided by physical hardware element(s). A "virtualized resource" may refer to compute, storage, and/or network resources provided by virtualization infrastructure to an application, device, system, etc. The term "network resource" or "communication resource" may refer to resources that are accessible by computer devices/systems via a communications network. The term "system resources" may refer to any kind of shared entities to provide services, and may include computing and/or network resources. System resources may be considered as a set of coherent functions, network data objects or services, accessible through a server where such system resources reside on a single host or multiple hosts and are clearly identifiable.

The term "channel" as used herein refers to any transmission medium, either tangible or intangible, which is used to communicate data or a data stream. The term "channel" may be synonymous with and/or equivalent to "communications channel," "data communications channel," "transmission channel," "data transmission channel," "access channel," "data access channel," "link," "data link," "carrier," "radiofrequency carrier," and/or any other like term denoting a pathway or medium through which data is communicated. Additionally, the term "link" as used herein refers to a connection between two devices through a RAT for the purpose of transmitting and receiving information.

The terms "instantiate," "instantiation," and the like as used herein refers to the creation of an instance. An "instance" also refers to a concrete occurrence of an object, which may occur, for example, during execution of program code.

The terms "coupled," "communicatively coupled," along with derivatives thereof are used herein. The term "coupled" may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term "directly coupled" may mean that two or more elements are in direct contact with one another. The term "communicatively coupled" may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or link, and/or the like.

The term "information element" refers to a structural element containing one or more fields. The term "field" refers to individual contents of an information element, or a data element that contains content.

The term "SMTC" refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.

The term “SSB” refers to an SS/PBCH block.

The term “a “Primary Cell” refers to the MCG cell, operating on the primary frequency, in which the UE either performs the initial connection establishment procedure or initiates the connection re-establishment procedure.

The term “Primary SCG Cell” refers to the SCG cell in which the UE performs random access when performing the Reconfiguration with Sync procedure for DC operation.

The term “Secondary Cell” refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.

The term “Secondary Cell Group” refers to the subset of serving cells comprising the PSCell and zero or more secondary cells for a UE configured with DC.

The term “Serving Cell” refers to the primary cell for a UE in RRC_CONNECTED not configured with CA/DC there is only one serving cell comprising of the primary cell.

The term “serving cell” or “serving cells” refers to the set of cells comprising the Special Cell(s) and all secondary cells for a UE in RRC_CONNECTED configured with CA/.

The term “Special Cell” refers to the PCell of the MCG or the PSCell of the SCG for DC operation; otherwise, the term “Special Cell” refers to the Pcell.

The term “machine learning” or “ML” refers to the use of computer systems implementing algorithms and/or statistical models to perform specific task(s) without using explicit instructions, but instead relying on patterns and inferences. ML algorithms build or estimate mathematical model(s) (referred to as “ML models” or the like) based on sample data (referred to as “training data,” “model training information,” or the like) in order to make predictions or decisions without being explicitly programmed to perform such tasks. Generally, an ML algorithm is a computer program that learns from experience with respect to some task and some performance measure, and an ML model may be any object or data structure created after an ML algorithm is trained with one or more training datasets. After training, an ML model may be used to make predictions on new datasets. Although the term “ML algorithm” refers to different concepts than the term “ML model,” these terms as discussed herein may be used interchangeably for the purposes of the present disclosure.

The term “machine learning model,” “ML model,” or the like may also refer to ML methods and concepts used by an ML-assisted solution. An “ML-assisted solution” is a solution that addresses a specific use case using ML algorithms during operation. ML models include supervised learning (e.g., linear regression, k-nearest neighbor (KNN), descision tree algorithms, support machine vectors, Bayesian algorithm, ensemble algorithms, etc.) unsupervised learning (e.g., K-means clustering, principle component analysis (PCA), etc.), reinforcement learning (e.g., Q-learning, multi-armed bandit learning, deep RL, etc.), neural networks, and the like.

Depending on the implementation a specific ML model could have many sub-models as components and the ML model may train all sub-models together. Separately trained ML models can also be chained together in an ML pipeline during inference. An “ML pipeline” is a set of functionalities, functions, or functional entities specific for an ML-assisted solution; an ML pipeline may include one or several data sources in a data pipeline, a model training pipeline, a model evaluation pipeline, and an actor. The “actor” is an entity that hosts an ML assisted solution using the output of the ML model inference). The term “ML training host” refers to an entity, such as a network function, that hosts the training of the model. The term “ML inference host” refers to an entity, such as a network function, that hosts model during inference mode (which includes both the model execution as well as any online learning if applicable). The ML-host informs the actor about the output of the ML algorithm, and the actor takes a decision for an action (an “action” is performed by an actor as a result of the output of an ML assisted solution). The term “model inference information” refers to information used as an input to the ML model for determining inference(s); the data used to train an ML model and the data used to determine inferences may overlap, however, “training data” and “inference data” refer to different concepts.

CLAIMS

1. An apparatus to be implemented in a reduced capability (RedCap) user equipment (UE), the apparatus comprising:

a memory to store configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE; and

processor circuitry to:

perform DL-PRS measurements on respective subbands of the DL-PRS resource using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE; and

generate a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

2. The apparatus of claim 1, wherein the measurements on the respective subbands are separated in a time domain by respective gaps.

3. The apparatus of claim 1, wherein two or more of the subbands partially overlap in a frequency domain.

4. The apparatus of claim 1, wherein the processor circuitry is to receive the configuration information via radio resource control (RRC) signaling.

5. The apparatus of claim 1, wherein the configuration information indicates a frequency hopping pattern for the DL-PRS measurements.

6. The apparatus of claim 5, wherein the configuration information further indicates a starting physical resource block (PRB) of the different frequency hops.

7. The apparatus of claim 6, wherein the processor circuitry is further to identify a reference point to indicate the starting PRB, wherein the reference point corresponds to:

a lowest subcarrier of a common resource block (CRB) 0;

a starting PRB of a DL-PRS transmission in accordance with a configuration of DL-PRS positioning frequency layers, a DL-PRS resource set, or a DL-PRS resource; or

a starting PRB of a configured bandwidth part (BWP) or a subband of the RedCap UE.

8. The apparatus of any one of claims 1-7, wherein the processor circuitry is to report the wideband positioning measurement to a next generation Node B (gNB).

9. An apparatus to be implemented in a reduced capability (RedCap) user equipment (UE), the apparatus comprising:

a memory to store configuration information for a plurality of bandwidth parts (BWPs) or subbands to be used for transmission of an uplink sounding reference signal (UL-SRS) with frequency hopping; and

processor circuitry to encode the UL-SRS for transmission with frequency hopping in the plurality of BWPs or subbands based on the configuration information.

10. The apparatus of claim 9, wherein the UL-SRS is transmitted with a gap between respective frequency hops.

11. The apparatus of claim 10, wherein the gap is defined as a number of symbols or slots.

12. The apparatus of claim 11, wherein the number of symbols or slots is based on a numerology of the UL-SRS.

13. The apparatus of claim 9, wherein individual BWPs or subbands have a bandwidth that is less than or equal to a maximum bandwidth for the RedCap UE, and wherein the plurality of BWPs or subbands together have a bandwidth that is greater than the maximum bandwidth.

14. The apparatus of claim 9, wherein the configuration information indicates an association between a first SRS resource or resource set in a first BWP or subband of the BWPs or subbands and a second SRS resource or resource set in a second BWP or subband of the BWPs or subbands.

15. The apparatus of claim 14, wherein the processor circuitry is further to:

receive an indication that the first SRS resource or resource set is activated or deactivated; and

determine that the second SRS resource set or resource is activated or deactivated based on the association.

16. The apparatus of any one of claims 9-15, wherein the SRS is a semi-persistent SRS.

17. One or more non-transitory computer-readable media (NTCRM) having instructions, stored thereon, that when executed by one or more processors of a next generation Node B (gNB), configure the gNB to:

transmit, to a reduced capability (RedCap) user equipment (UE), configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE, wherein the configuration information indicates subbands of the DL-PRS resource on which the RedCap UE is to perform DL-PRS measurements using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE;

transmit a DL-PRS on the respective subbands; and

receive, from the RedCap UE, a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands.

18. The one or more NTCRM of claim 17, wherein the DL-PRS transmissions on the respective subbands are separated in a time domain by respective gaps.

19. The one or more NTCRM of claim 17, wherein two or more of the subbands partially overlap in a frequency domain.

20. The one or more NTCRM of any one of claims 17-19, wherein the configuration information indicates a frequency hopping pattern for the DL-PRS measurements.

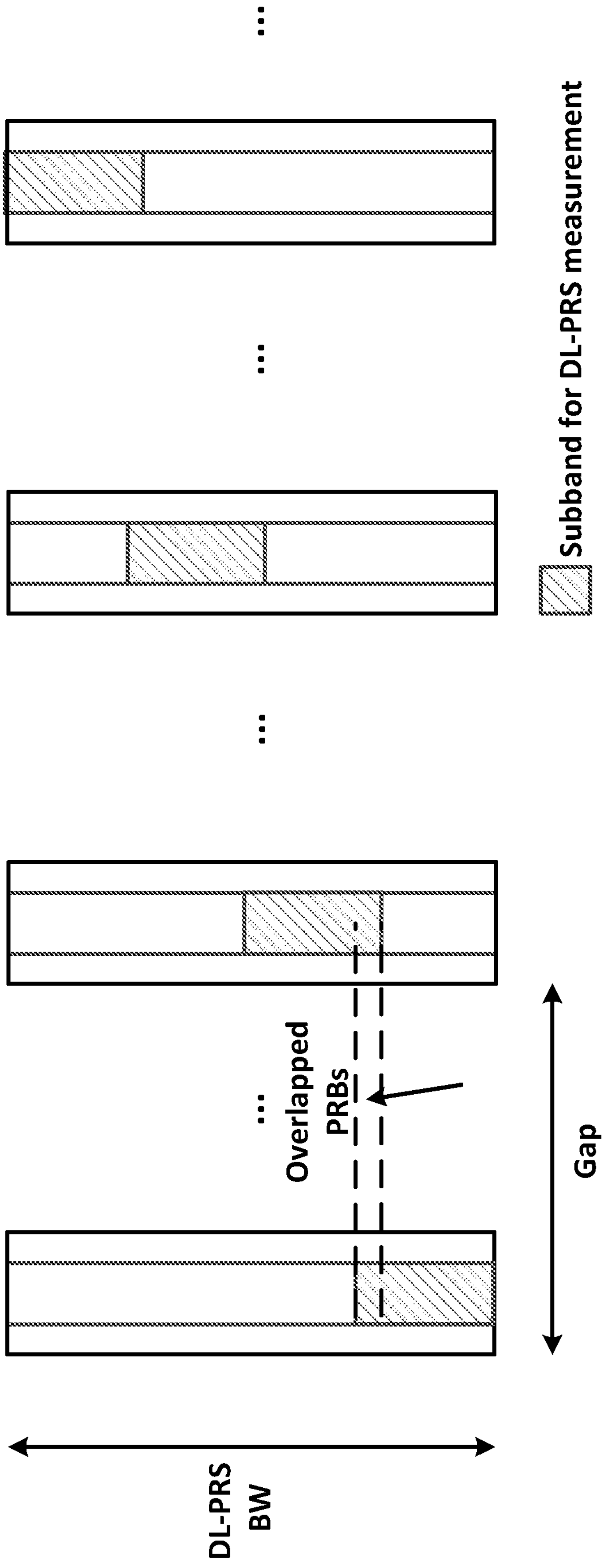
▨ Subband for DL-PRS measurement
Overlapped PRBs
Gap
DL-PRS BW

Figure 1

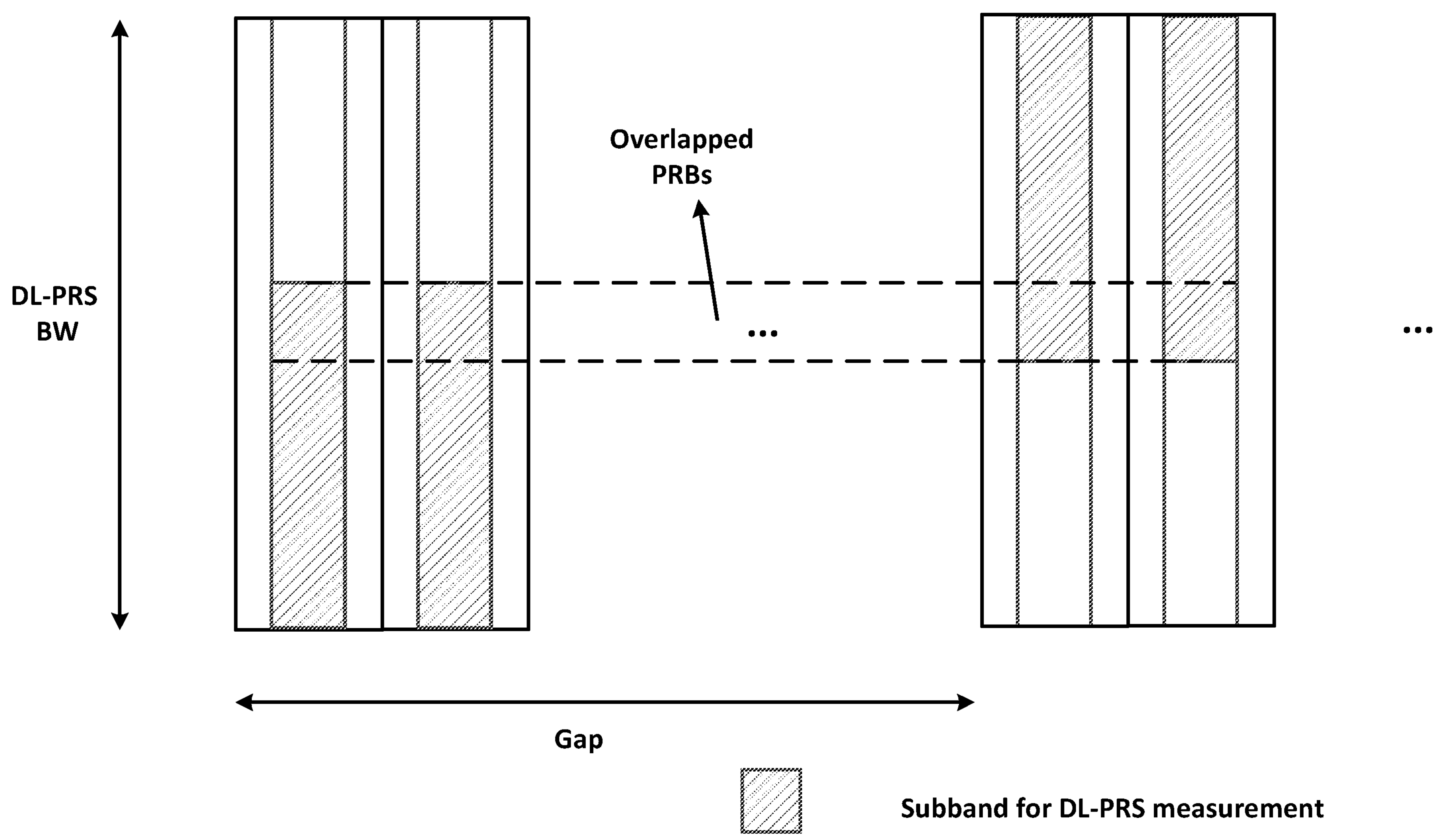
Overlapped
PRBs
DL-PRS
BW
...
...
Gap
▨ Subband for DL-PRS measurement

Figure 2

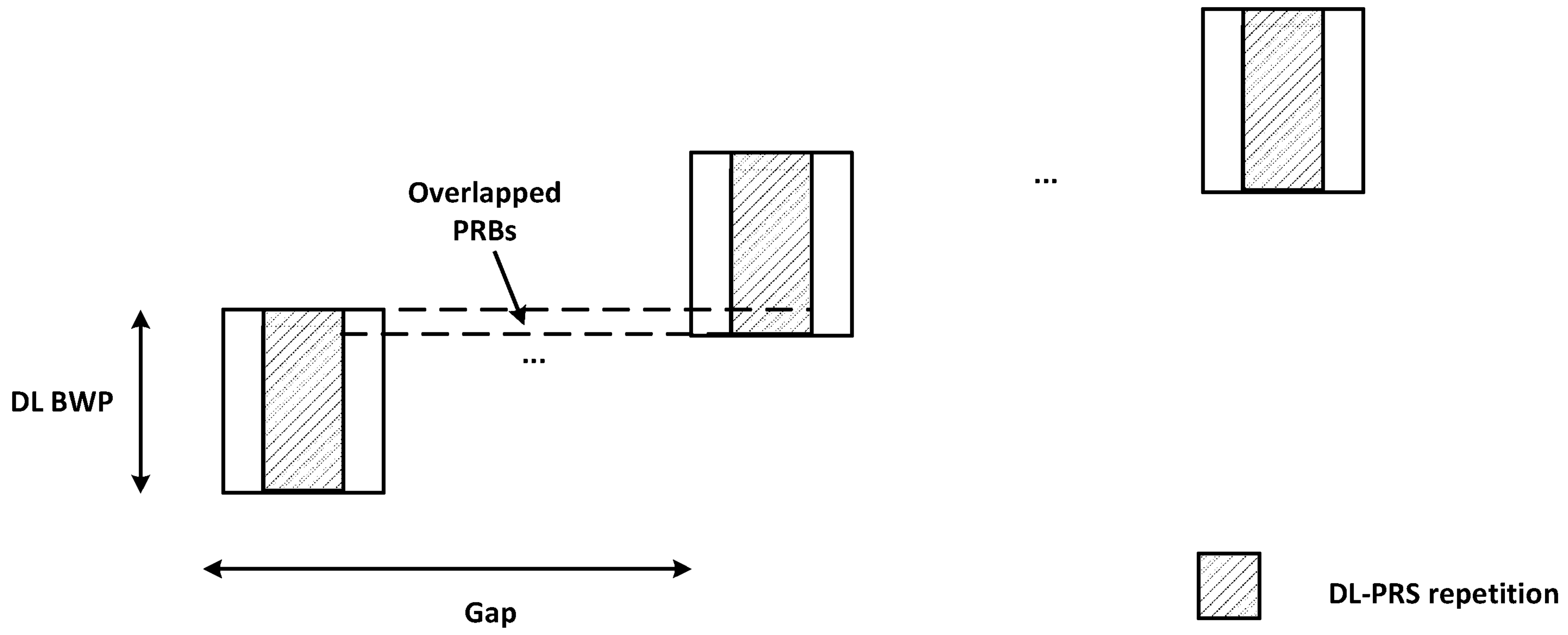

Figure 3

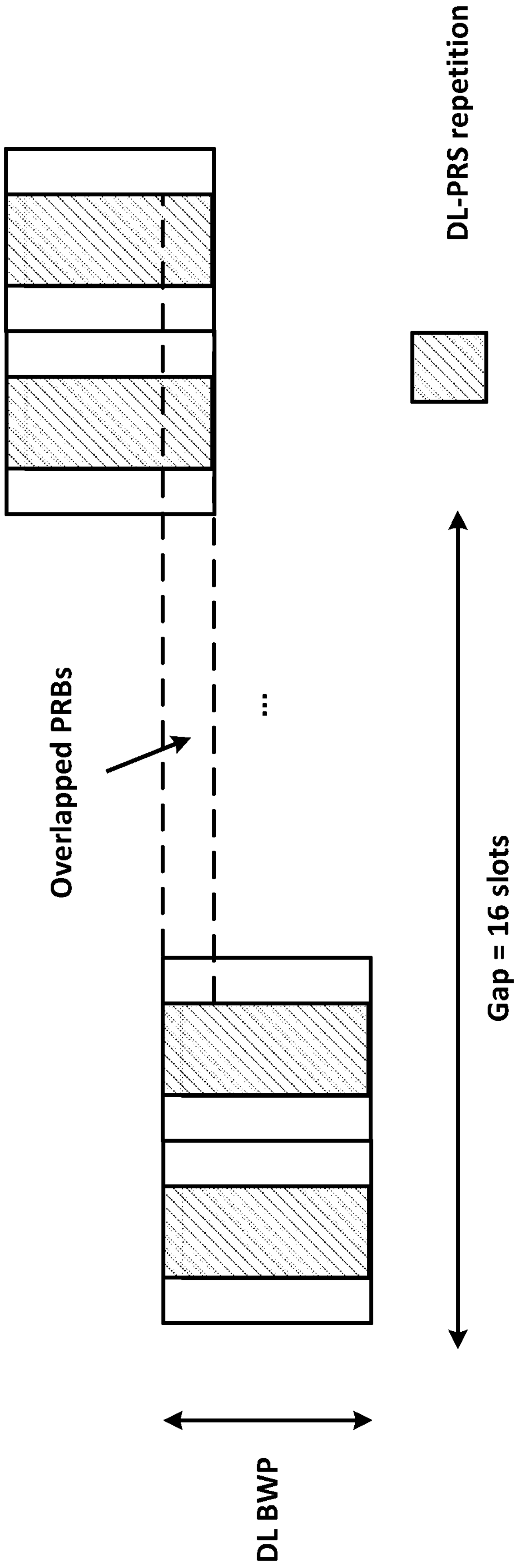

Figure 4

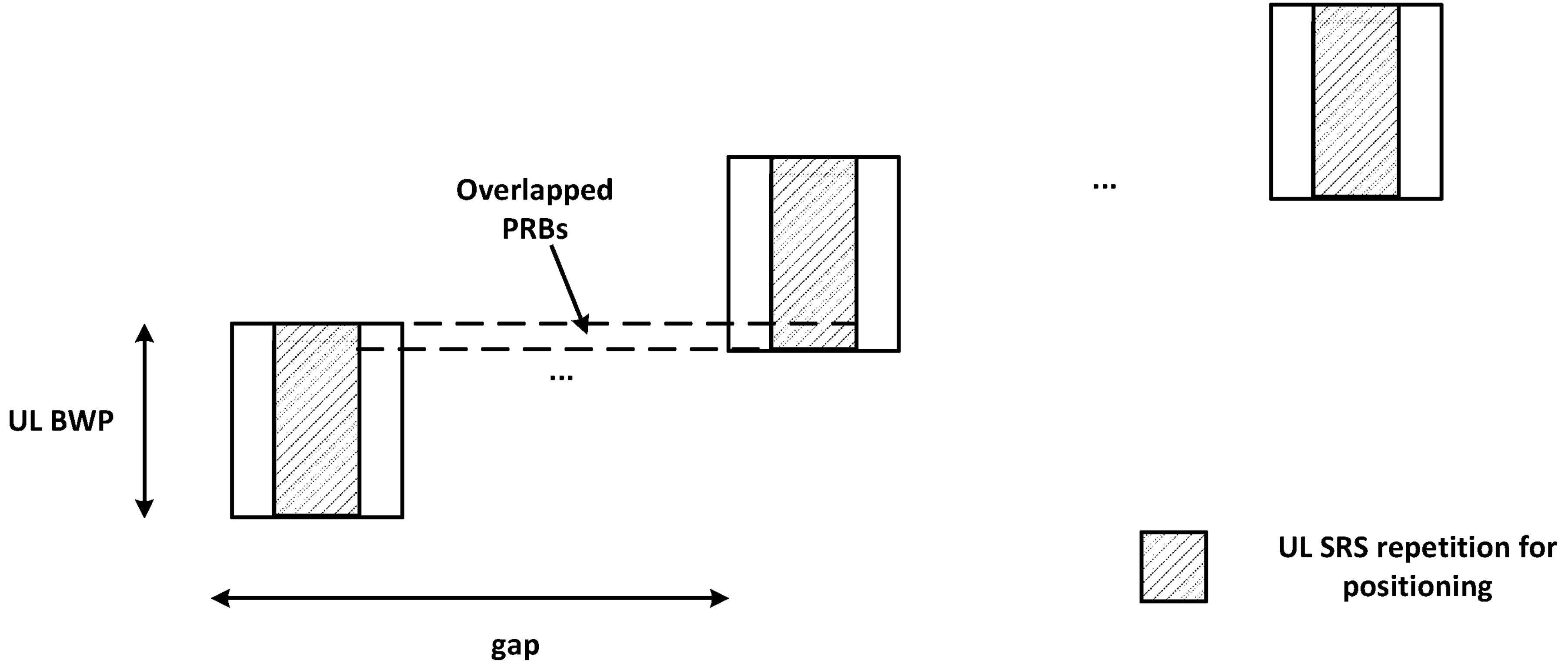
Overlapped PRBs
...
UL BWP
gap
...
UL SRS repetition for positioning

Figure 5

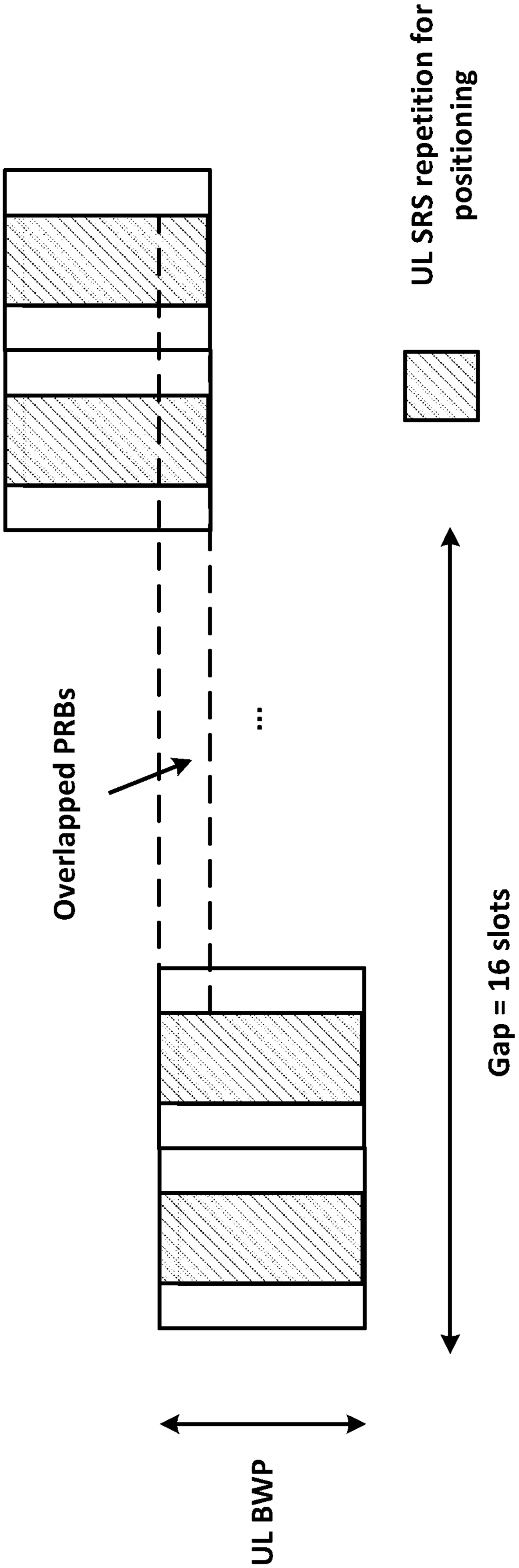
UL SRS repetition for positioning
Overlapped PRBs
...
Gap = 16 slots
UL BWP

Figure 6

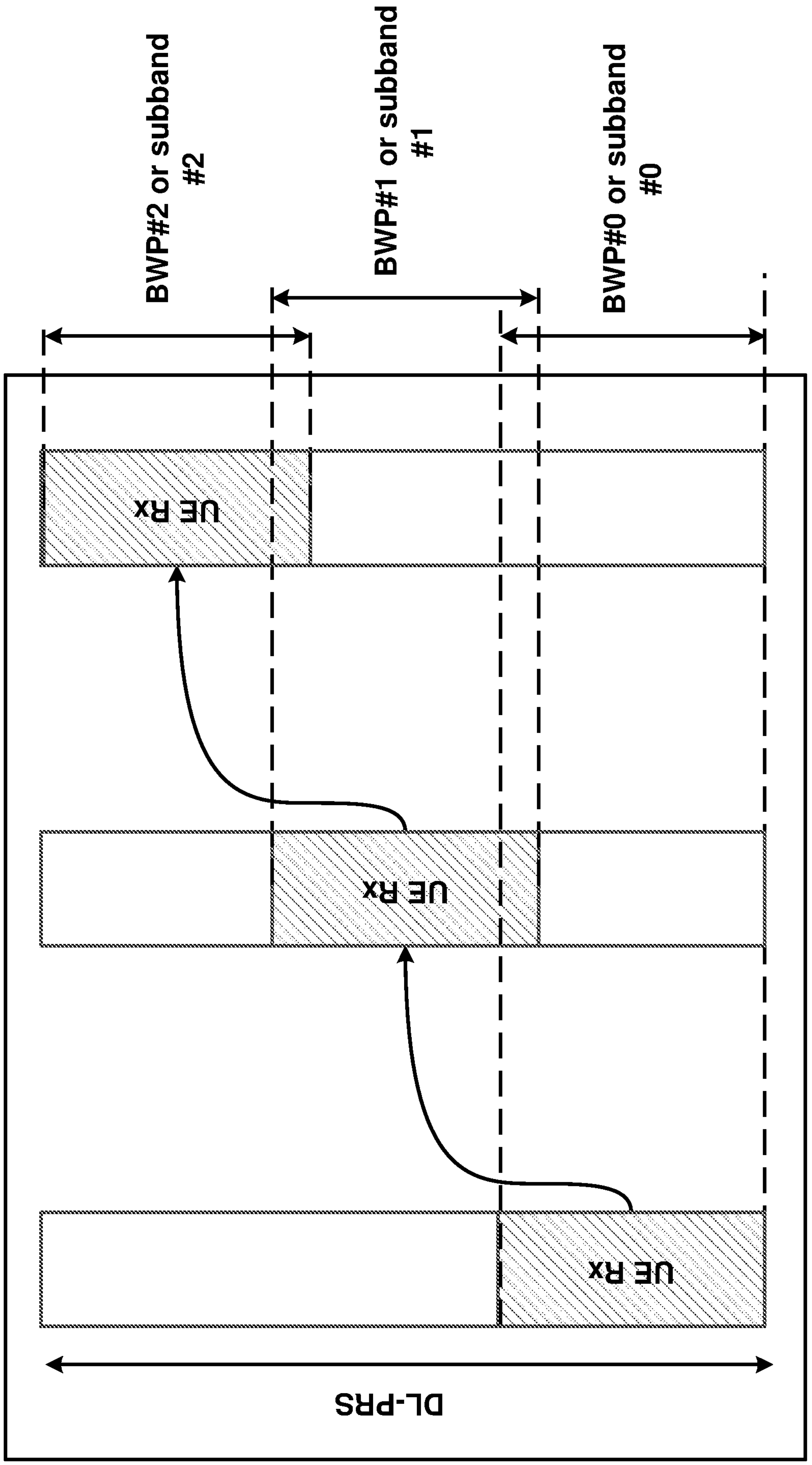
BWP#2 or subband #2
BWP#1 or subband #1
BWP#0 or subband #0
UE Rx
UE Rx
UE Rx
DL-PRS

Figure 7

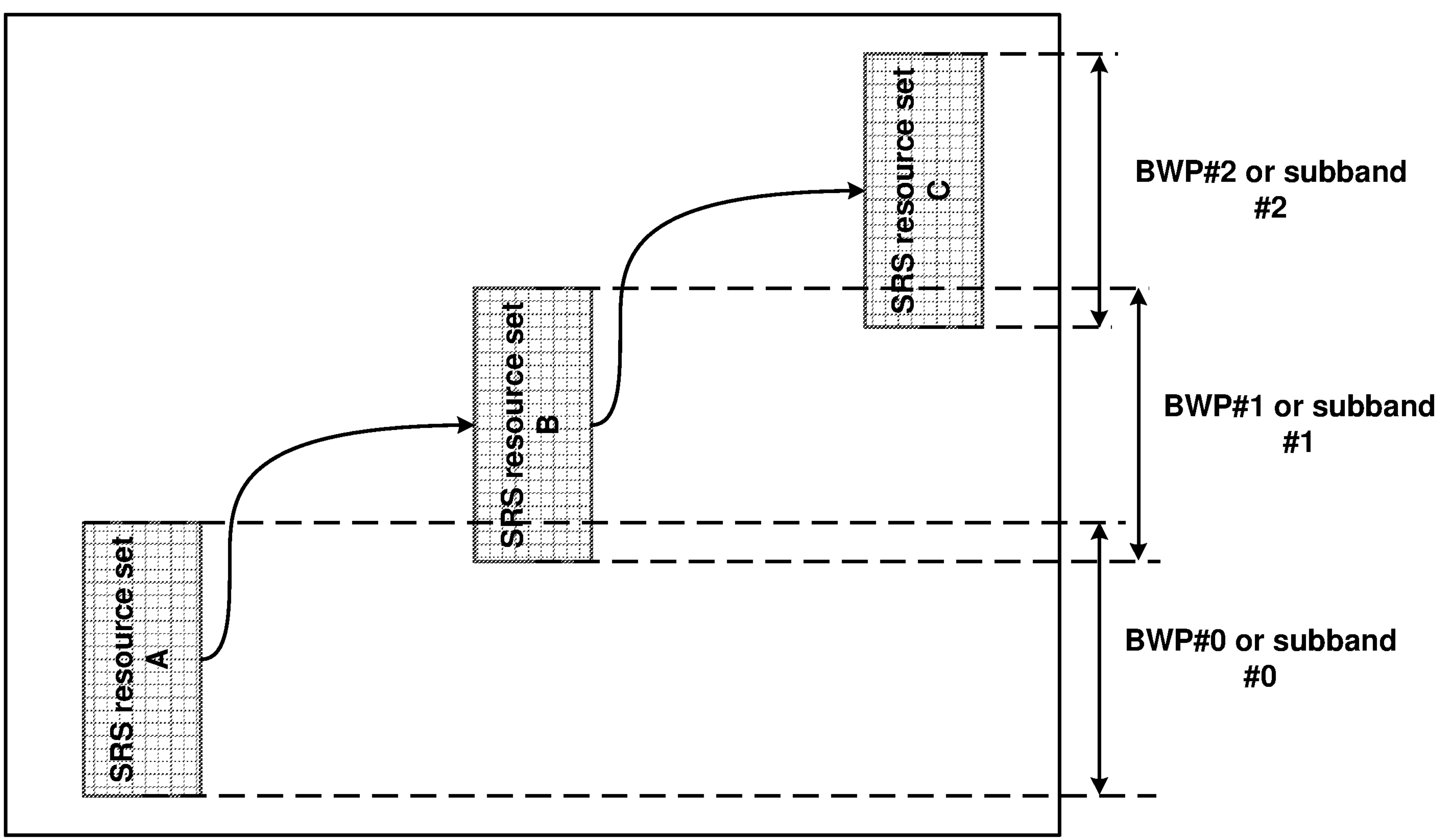
SRS resource set A
SRS resource set B
SRS resource set C
BWP#2 or subband #2
BWP#1 or subband #1
BWP#0 or subband #0

Figure 8

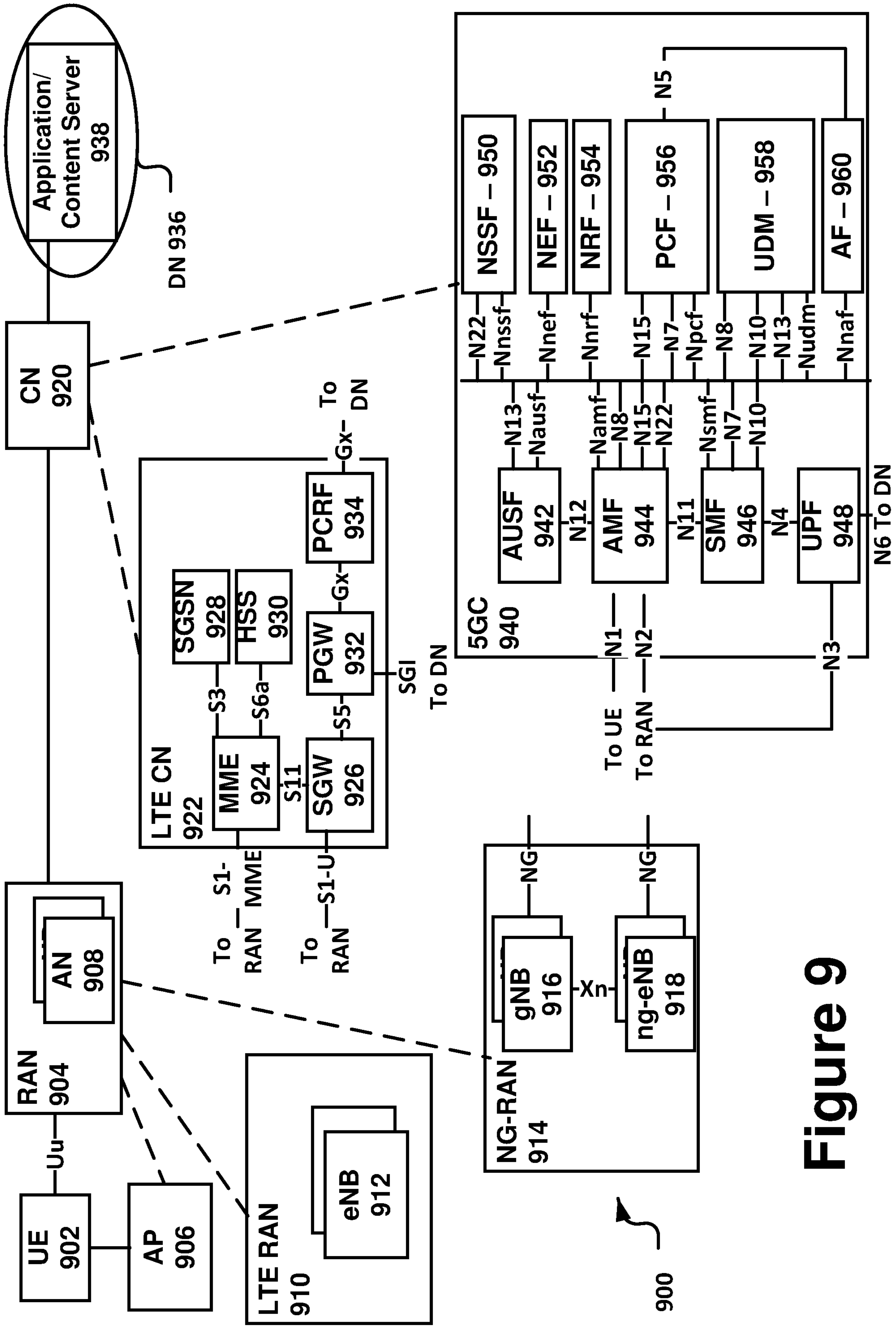
UE 902
AP 906
Uu
RAN 904
AN 908
CN 920
Application/ Content Server 938
DN 936
LTE RAN 910
eNB 912
NG-RAN 914
gNB 916
Xn
ng-eNB 918
NG
NG
LTE CN 922
MME 924
SGW 926
S11
SGSN 928
HSS 930
PGW 932
PCRF 934
S3
S6a
S5
Gx
Gx
SGI
To DN
To DN
To RAN S1-MME
To RAN S1-U
5GC 940
AUSF 942
AMF 944
SMF 946
UPF 948
N12
N11
N4
N6 To DN
N1
N2
N3
To UE
To RAN
N13
Nausf
Namf
N8
N15
N22
Nsmf
N7
N10
NSSF – 950
NEF – 952
NRF – 954
PCF – 956
UDM – 958
AF – 960
N22
Nnssf
Nnef
Nnrf
N15
N7
Npcf
N8
N10
N13
Nudm
Nnaf
N5
900

Figure 9

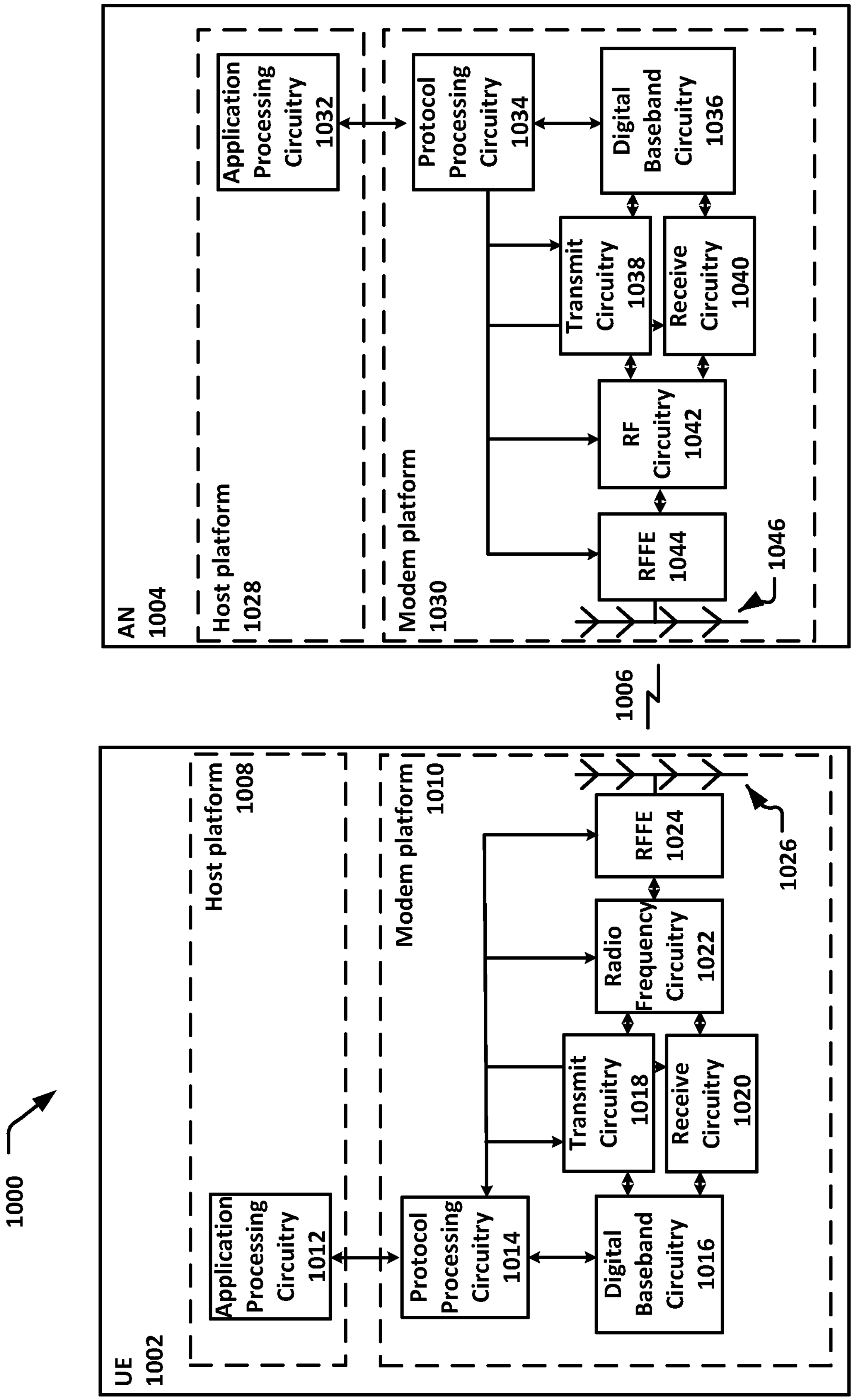
1000
UE
1002
Host platform
1008
Application Processing Circuitry
1012
Modem platform
1010
Protocol Processing Circuitry
1014
Digital Baseband Circuitry
1016
Transmit Circuitry
1018
Receive Circuitry
1020
Radio Frequency Circuitry
1022
RFFE
1024
1026
1006
AN
1004
Host platform
1028
Application Processing Circuitry
1032
Modem platform
1030
Protocol Processing Circuitry
1034
Digital Baseband Circuitry
1036
Transmit Circuitry
1038
Receive Circuitry
1040
RF Circuitry
1042
RFFE
1044
1046

Figure 10

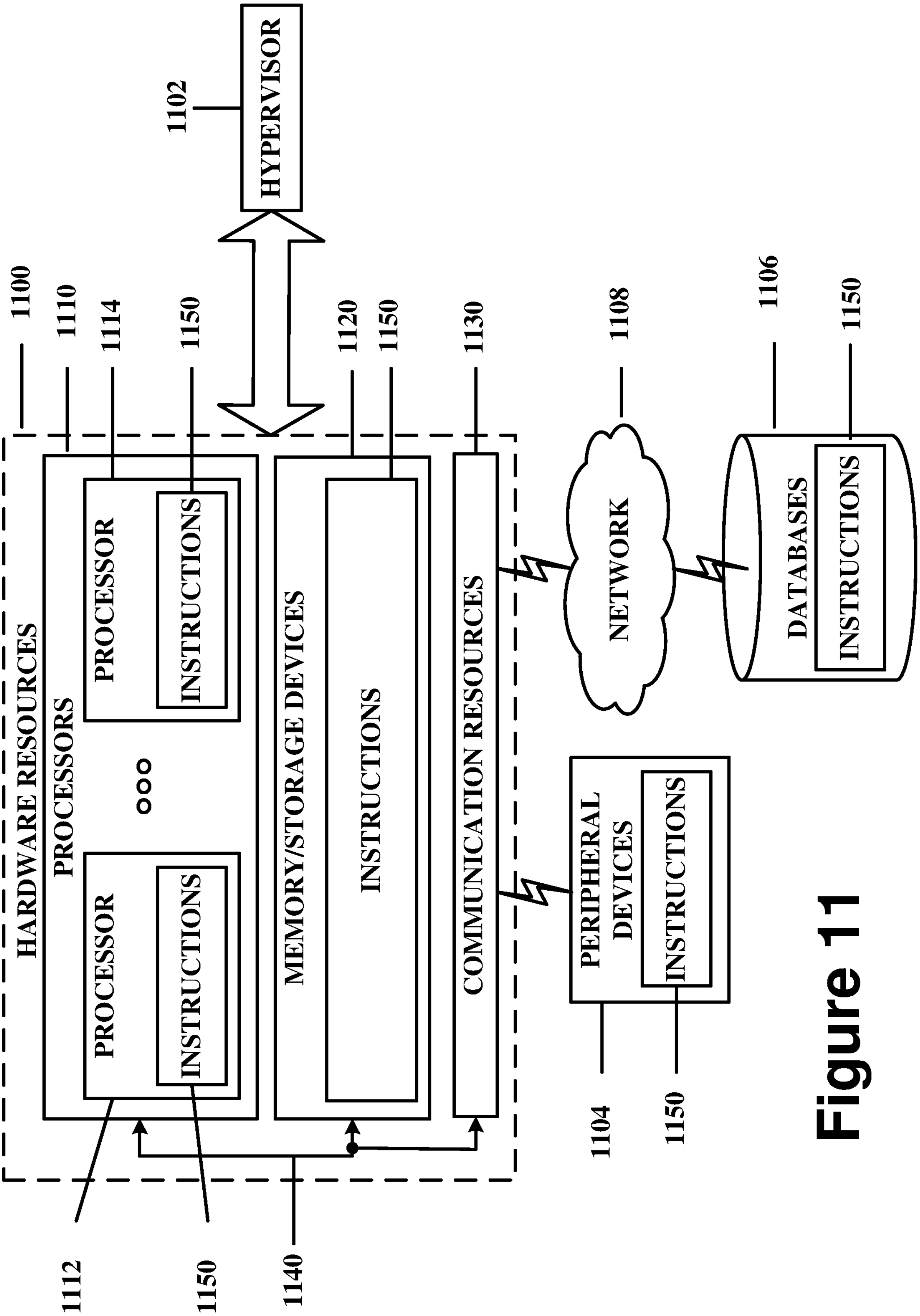
HARDWARE RESOURCES
PROCESSORS
PROCESSOR
INSTRUCTIONS
PROCESSOR
INSTRUCTIONS
MEMORY/STORAGE DEVICES
INSTRUCTIONS
COMMUNICATION RESOURCES
HYPERVISOR
NETWORK
DATABASES
INSTRUCTIONS
PERIPHERAL DEVICES
INSTRUCTIONS
1100
1110
1114
1150
1120
1150
1130
1102
1108
1106
1150
1112
1150
1140
1104
1150

Figure 11

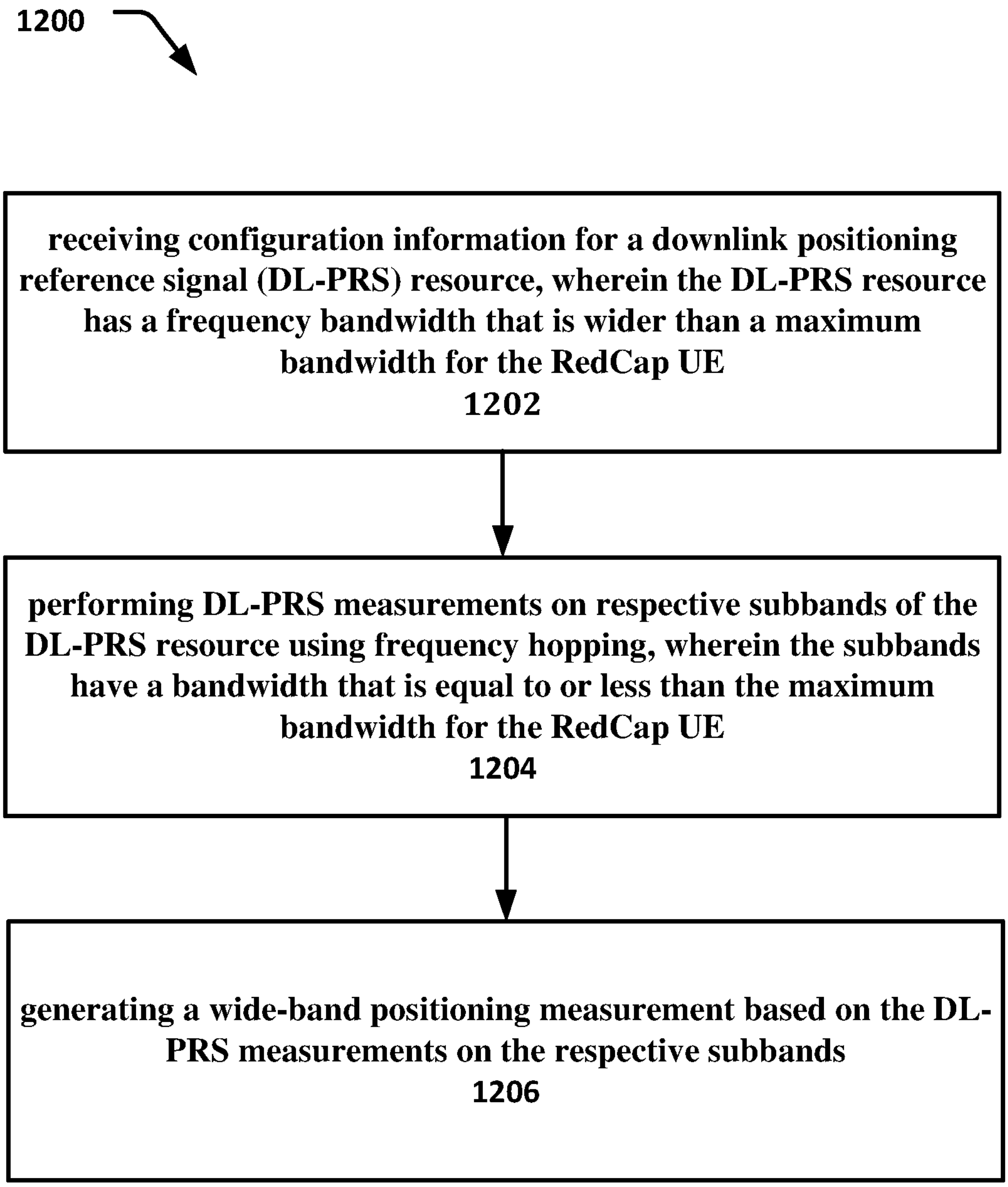
1200
receiving configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE
1202
performing DL-PRS measurements on respective subbands of the DL-PRS resource using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE
1204
generating a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands
1206

Figure 12

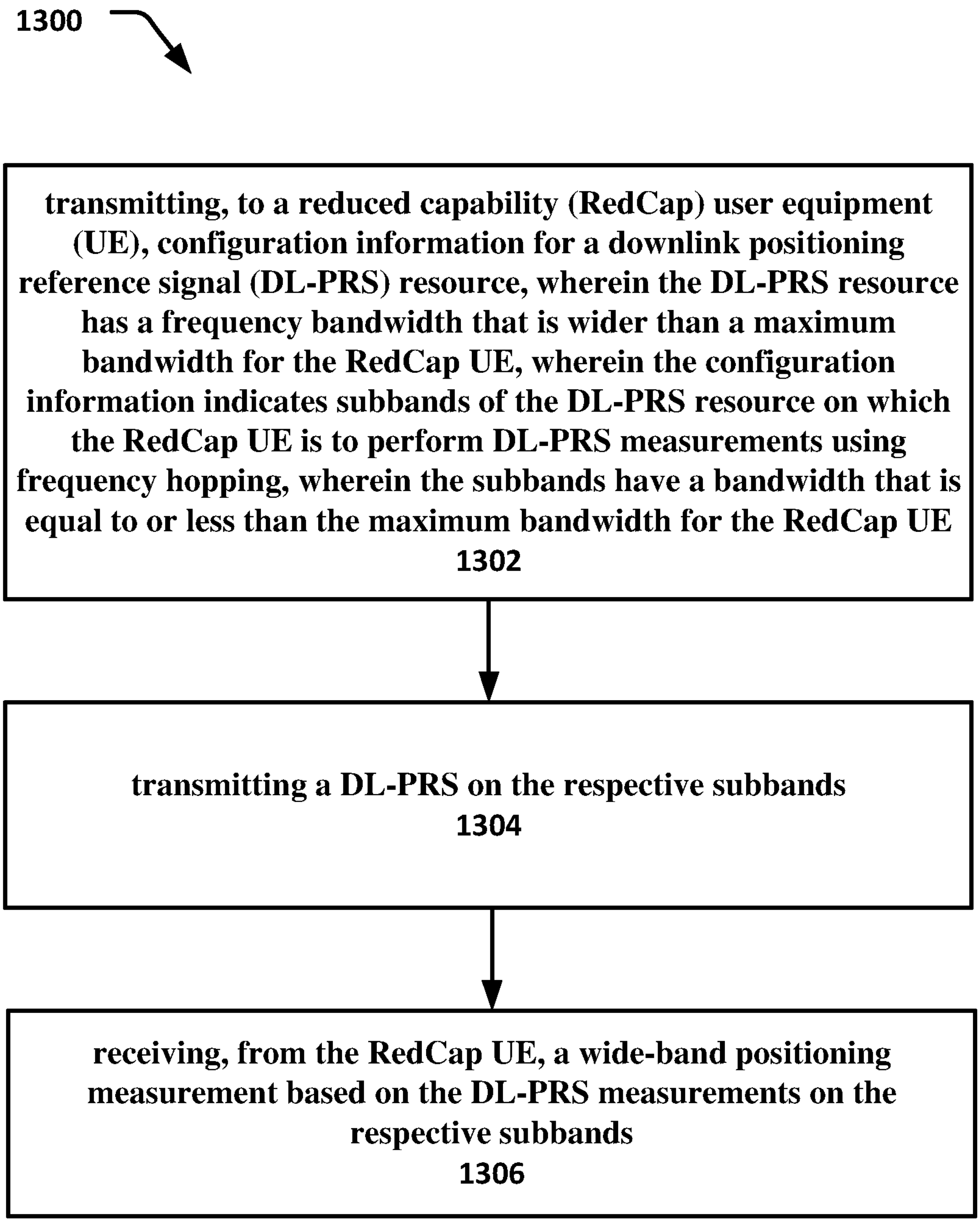
1300
transmitting, to a reduced capability (RedCap) user equipment (UE), configuration information for a downlink positioning reference signal (DL-PRS) resource, wherein the DL-PRS resource has a frequency bandwidth that is wider than a maximum bandwidth for the RedCap UE, wherein the configuration information indicates subbands of the DL-PRS resource on which the RedCap UE is to perform DL-PRS measurements using frequency hopping, wherein the subbands have a bandwidth that is equal to or less than the maximum bandwidth for the RedCap UE
1302
transmitting a DL-PRS on the respective subbands
1304
receiving, from the RedCap UE, a wide-band positioning measurement based on the DL-PRS measurements on the respective subbands
1306

Figure 13

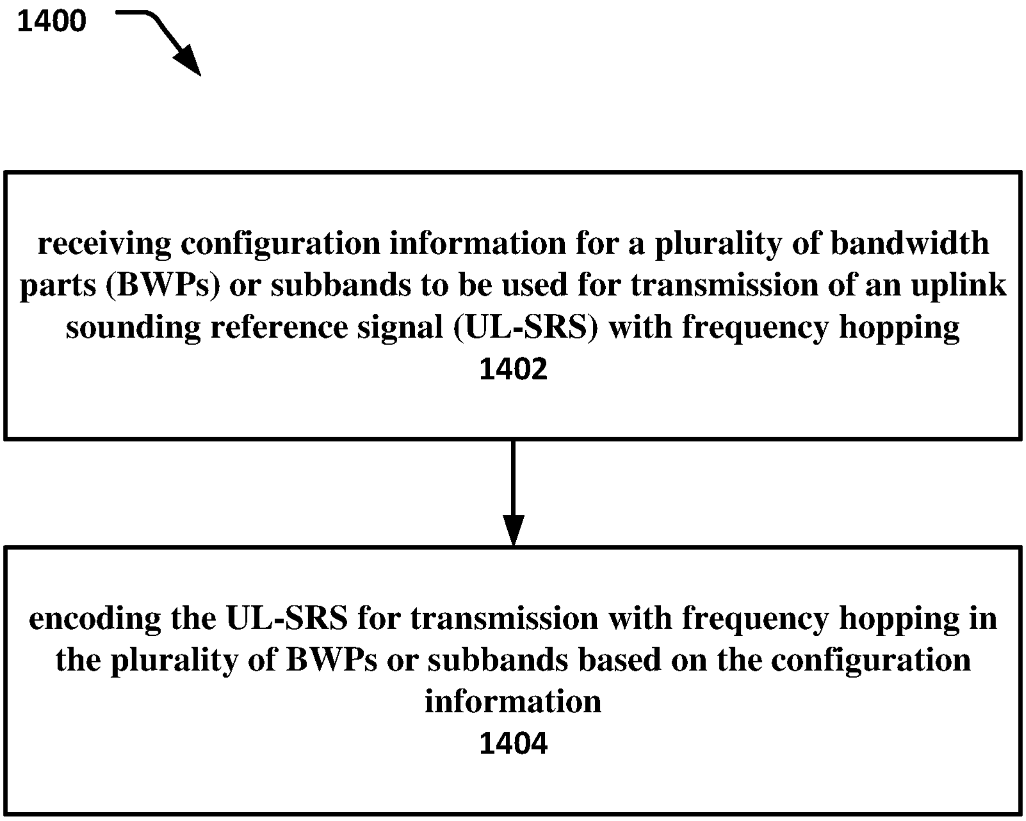
1400
receiving configuration information for a plurality of bandwidth parts (BWPs) or subbands to be used for transmission of an uplink sounding reference signal (UL-SRS) with frequency hopping
1402
encoding the UL-SRS for transmission with frequency hopping in the plurality of BWPs or subbands based on the configuration information
1404

Figure 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/072011

A. CLASSIFICATION OF SUBJECT MATTER

H04W 64/00(2009.01)i; **H04W 24/08**(2009.01)i; **H04L 5/00**(2006.01)i; **H04W 72/04**(2009.01)i; **H04W 88/02**(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 64/00(2009.01); H04B 1/7143(2011.01); H04L 25/02(2006.01); H04L 5/00(2006.01); H04W 72/04(2009.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: downlink positioning reference signal (DL-PRS), frequency hopping, subband, bandwidth, reduced capability (RedCap), uplink sounding reference signal (UL-SRS), bandwidth parts (BWPs), maximum bandwidth

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NEC, `Discussion on positioning support for RedCap UEs', R1-2203696, 3GPP TSG RAN WG1 #109-e, e-Meeting, 29 April 2022 sections 1, 2.2	1-20
Y	SONY, `Discussion on positioning for RedCap UEs', R1-2203740, 3GPP TSG RAN WG1 #109-e, e-Meeting, 29 April 2022 section 2	1-8,13,17-20
Y	WO 2022-153284 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 21 July 2022 (2022-07-21) page 9, lines 16-20; page 11, lines 5-23; page 33, lines 3-13; and claims 7-8	9-16
A	US 2022-0109466 A1 (QUALCOMM INCORPORATED) 07 April 2022 (2022-04-07) paragraphs [0272]-[0277]	1-20

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search **27 November 2023**	Date of mailing of the international search report **28 November 2023**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea** Facsimile No. **+82-42-481-8578**	Authorized officer **BYUN, Sung Cheal** Telephone No. **+82-42-481-8262**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2019-0253282 A1 (FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.) 15 August 2019 (2019-08-15) claims 1-2	1-20

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2023/072011

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2022-153284 A1	21 July 2022	KR 10-2023-0121911 A	21 August 2023
US 2022-0109466 A1	07 April 2022	BR 112023005555 A2	09 May 2023
		CN 116210208 A	02 June 2023
		EP 4226548 A1	16 August 2023
		KR 10-2023-0074741 A	31 May 2023
		WO 2022-076086 A1	14 April 2022
US 2019-0253282 A1	15 August 2019	CN 110089080 A	02 August 2019
		CN 110089080 B	28 October 2022
		EP 3316534 A1	02 May 2018
		EP 3533190 A1	04 September 2019
		EP 3533190 B1	18 November 2020
		EP 3800847 A1	07 April 2021
		JP 2020-500467 A	09 January 2020
		JP 6959333 B2	02 November 2021
		US 11108596 B2	31 August 2021
		WO 2018-078119 A1	03 May 2018