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(54) Title: METHOD OF HETEROGENEOUS BRS TRANSMISSION IN NR

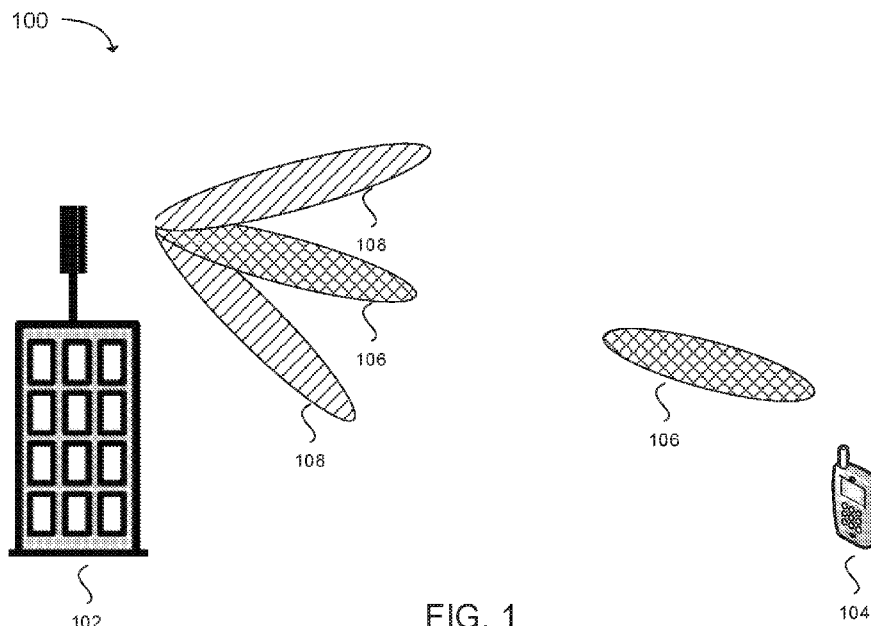


FIG. 1

(57) Abstract: Technology for an apparatus of a base station configured for beam forming new radio wireless system is disclosed. The base station can encode a first reference signal (BRS) for transmission at a selected angle, on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam. The base station can encode a set of second RSs for transmission after the first RS beam. Each second RS can be configured to be transmitted on a second RS beam having a narrow beam width relative to the first RS beam. The base station can also comprise of a memory interface configured to send to a memory the selected angle.



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METHOD OF HETEROGENEOUS BRS TRANSMISSION IN NR

BACKGROUND

[0001] Wireless systems typically include multiple User Equipment (UE) devices communicatively coupled to one or more Base Stations (BS). The one or more BSs may be Long Term Evolved (LTE) evolved NodeBs (eNB) or New Radio (NR) next generation NodeBs (gNB) that can be communicatively coupled to one or more UEs by a Third-Generation Partnership Project (3GPP) network. The UE can be one or more of a smart phone, a tablet computing device, a laptop computer, an internet of things (IOT) device, and/or another type of computing devices that is configured to provide digital communications. As used herein, digital communications can include data and/or voice communications, as well as control information.

[0002] In a fifth generation (5G) wireless communication system, both control and data channels at millimeter- or centimeter-wave frequency band are characterized by a beamformed transmission. With beamforming, the antenna gain pattern is shaped like a cone pointing to a spatial area so that a high antenna gain can be achieved. At the transmitter, beamforming is achieved by applying a phase shift to an antenna array. Dependent on the phase shift, multiple beams can be formed at a transmission point (TP) at a time and beams from different TPs can point to the same location. Similarly, the receiver can apply a phase shift to its antenna array to achieve large receive gain for a signal arriving from a specific spatial angle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Features and advantages of the disclosure will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the disclosure; and, wherein:

[0004] FIG. 1 illustrates signaling between an eNodeB and a user equipment (UE) to indicate a beamformed transmission and reception in new radio wireless system, in accordance with an example;

[0005] FIG. 2 illustrates an example of a beam reference signal (BRS) structure, in accordance with an example;

[0006] FIG. 3 illustrates an example of a heterogeneous BRS transmission, in accordance with an example;

[0007] FIG. 4 illustrates multiplexing different numerologies in-band, in accordance with an example;

[0008] FIG. 5 depicts a C-RAN deployment showing three transmission points (TP) transmitting MRS signal in a cell area, in accordance with an example;

[0009] FIG. 6 illustrates a diagram of an MMRC configuration , and an embodiment wherein multiple MMRC configurations may be transmitted in two subframes in a cell, in accordance with an example;

[0010] Figure 7A shows a block interleaved pattern where each MRS occupies eight consecutive REs in accordance with an example;

[0011] Figure 7B shows a scheme where up to eight MRS can be code division multiplied in accordance with an example;

[0012] FIG. 8 illustrates a diagram of idle mode measurements that can take place with multiple UEs in accordance with an example;

[0013] FIG. 9 depicts a flowchart of a base station configured for beam forming in a new radio wireless system in accordance with an example;

[0014] FIG. 10 depicts a flowchart of a user equipment (UE) configured for beam forming in a new radio wireless system in accordance with an example;

[0015] FIG. 11 depicts a flowchart of configured to decode reference signals in a new radio system in accordance with an example;

[0016] FIG. 12 depicts a flowchart of a base station, configured for beam forming in a new radio wireless system in accordance with an example;

[0017] FIG. 13 illustrates a diagram of a wireless device (e.g., UE) and a base station (e.g., eNodeB) in accordance with an example; and

[0018] FIG. 14 illustrates a diagram of a wireless device (e.g., UE) in accordance with an example.

[0019] Reference will now be made to the exemplary embodiments illustrated, and

specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the technology is thereby intended.

DETAILED DESCRIPTION

[0020] Before the present technology is disclosed and described, it is to be understood that this technology is not limited to the particular structures, process actions, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular examples only and is not intended to be limiting. The same reference numerals in different drawings represent the same element. Numbers provided in flow charts and processes are provided for clarity in illustrating actions and operations and do not necessarily indicate a particular order or sequence.

EXAMPLE EMBODIMENTS

[0021] An initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail later. This initial summary is intended to aid readers in understanding the technology more quickly but is not intended to identify key features or essential features of the technology nor is it intended to limit the scope of the claimed subject matter.

[0022] Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. 4G LTE networks are deployed in more than 100 countries to provide service in various spectrum band allocations depending on spectrum regime. Recently, significant momentum has started to build around the idea of a next generation, i.e. fifth generation (5G), wireless communications technology.

[0023] As previously discussed, in a 5G system both control and data channels at a millimeter- or centimeter-wave frequency band are characterized by a beamformed transmission. With beamforming, the antenna gain pattern is shaped like a cone pointing to a spatial area so that a high antenna gain can be achieved. At the transmitter, beamforming is achieved by applying a phase shift to an antenna array that is either one-

dimension or two-dimension periodically placed. Dependent on the phase shift, multiple beams can be formed at a transmission point (TP) at a time and beams from different TPs can point to the same location. Similarly, the receiver can apply a phase shift to its antenna array to achieve large receive gain for a signal arriving from a specific spatial angle. As shown in FIG. 1, the best receive signal quality can be achieved when transmit and receive beams are aligned.

[0024] As used herein, the term “Base Station (BS)” includes “Base Transceiver Stations (BTS),” “NodeBs,” “evolved NodeBs (eNodeB or eNB),” and/or “next generation NodeBs (gNodeB or gNB),” and refers to a device or configured node of a mobile phone network that communicates wirelessly with UEs.

[0025] FIG. 1 illustrates signaling between a base station 102, such as an eNodeB or gNodeB and a user equipment (UE) 104 to indicate a beamformed transmission and reception in new radio wireless system, such as a LTE, 5G, or other enhanced wireless communication system 100. In one example, in order to benefit from such beamformed transmissions, a UE 104 can be configured to perform measurements on the available beams 106, 108 and inform the base station 102 to use a beam 106 that points to the base station's location. In this way, the signal to interference and noise ratio (SINR) of reception signal can be improved.

[0026] In one example, due to factors like initial access, mobility of UE 104, change of propagation environment, and rotation of UE 104 antenna, the beam direction that is best for the UE 104 may not be known or can be subject to change. As a result, UE 104 can monitor the receive signal quality from all possible beams 108 and notify the base station that a single beam 106 or a set of beams is considered acceptable for reception.

[0027] In one example, due to the existence of a large number of beams and possibly high mobility speed, a low complexity measurement process that allows efficient implementation can provide significant advantages. The process can allow for detection of beams at a low signal to noise ratio (SNR) so that the beam can be monitored and switched to when beam quality is improved.

[0028] In one example, In order to facilitate such measurement, a reference signal such as a beam reference signal (BRS) can be employed at the base station 102. The BRS may be CSI-RS or PBCH/SS block. The noise ratio (NR) can be configured to support CSI-RS

and PBCH/SS blocks for beam management. The BRS can be a predefined sequence that is associated with a beam for its transmission. With orthogonal frequency-division multiplexing (OFDM) communication systems, a large number of closely spaced orthogonal subcarrier signals are used to carry information symbols.

[0029] FIG. 2 illustrates an example of a beam reference signal (BRS) structure 200. In one example, in order to facilitate such measurement, a beam reference signal (BRS) 202 is usually employed at the base station. The BRS 202 is a predefined sequence that is associated with a beam for its transmission. With orthogonal frequency-division multiplexing (OFDM) communication systems, a large number of closely spaced orthogonal subcarrier signals are used to carry information symbols.

[0030] In one example, the BRS 202 is typically transmitted in a burst manner, where each burst comprises a set of OFDM symbols containing BRS 202 resource elements. For BRS 202 in each OFDM symbol different beamforming can be applied. BRS can be applied to different beams, as a plurality of beams are swept around a predetermined segment of a radius, as illustrated in FIG 2.

[0031] In one example, the UE can perform BRS-received power (BRS-RP) measurements on different BRS resources and report the best beam indexes along with the measurements to the serving eNB. The eNB can also be a next generation base station, or gNodeB (gNB). It should be noted that, in one embodiment, BRS transmission with the homogenous beams of the same gain (beam-width) is supported. Alternatively, in some scenarios, support of heterogeneous beams with different beamforming gain (beam width) is desirable.

[0032] In one example, to support outdoor high mobility UEs, the BRS can transmit using beams with relatively wide beam-width, which can be more preferable to facilitate more accurate tracking and measurements of beams in a fast varying propagation environment. At the same time, support of BRS transmission with narrow beams and high beamforming gains can be beneficial to address coverage issues for indoor UEs.

[0033] In one embodiment, heterogeneous beams for BRS transmission are disclosed, where different beams have different beamforming gain for the same beam direction 206 and a sync region 204 which can allow for matching of BRS 202 of the beam training regions. In addition, at least two BRS subsets, where a BRS of each BRS subset is

associated with beams with the same beamforming gain is disclosed. Further disclosed is signaling of the BRS subsets for the UE to facilitate independent tracking, measurements and reporting of the measurements corresponding to different BRS subsets, and an optional association of BRS resources from different BRS subsets.

[0034] FIG. 3 discloses an example of a heterogeneous BRS transmission 300. It can be seen that the BRS 302 can be transmitted using either a low gain pattern (with a wide beam width) or a high gain pattern (with a narrow beam width).

[0035] In one embodiment, the BRS subset 302 can be signaled to the UE using higher-layer signaling. The higher layer signaling may correspond to radio resource control (RRC) signaling, extended system information block (xSIB) signaling, extended master information block (xMIB) signaling, or other unicast/broadcast/multicast signaling defined in a 5G network.

[0036] In one embodiment, in the time-domain, the BRS subset 302 can be provided in the form of a bitmap, where each bit can be associated with a time-domain BRS resource 302. In one embodiment, the BRS resource 302 can be associated with one bit indicating association of the BRS resource 302 with the BRS subset.

[0037] In the frequency domain, the BRS resource 302 can be transmitted on a frequency resource that may comprise a set of resource elements (REs) and physical resource blocks (PRBs) that can be contiguous and/or non-contiguous in the frequency domain. In the frequency-domain, the BRS subset can be provided in the form of a bitmap where each bit can be associated with frequency-domain BRS resource 302. In one embodiment the BRS resource can be associated with one bit indicating association of the BRS resource with the BRS subset.

[0038] In one embodiment there can be a wide beam BRS, where the wide beam BRS and sync can belong to the first BRS set and narrow beam BRS and sync may belong to the second BRS set. Additionally, the wide beam can be used for a high mobility UE as the beams are more robust to possible UE position change. Narrow beam can be used for improved coverage transmission due to increased beamforming gains. In one example, a first reference signal or set of reference signals can have a relatively wide beam, such as 30, 45, 60, 75, 90, 120, 150, or 180 degrees. A second set of reference signals can have a beam with a beam with that is narrower than the first reference signal. For example, the

second reference signal beam can have a beam width of 10, 15, 20, or 30 degrees. The examples are not intended to be limiting. The first and second reference signals can beams can have narrower or broader beam widths than provided in this example.

[0039] In one embodiment, the beam width of each second reference signal beam can be a selected portion of the beam width of the first reference signal beam. For example, the first reference signal beam may have a beam width of 90 degrees. A set of second beam reference signals can have a beam width of 10, 15, 30, or 45 degrees, allowing for 9, 6, 3, or 2 second reference signals within the beam width of the first beam reference signal, respectively, as shown in FIG. 3. The first beam width can have a beam width that is wider than the sum of the beam widths of each second reference signal.

[0040] In one embodiment the bitmap may correspond to time, frequency and possibly a code resource BRS resources 302.

[0041] In one embodiment the BRS resource 302 may correspond only to one BRS subset.

[0042] In one embodiment the BRS subset can be predefined in the specification or derived from a configuration of another BRS subset.

[0043] In other embodiments, the BRS resource of one BRS subset can be associated with one or more BRS resources of another BRS subset. The association can be based on the angular coverage area 306 of the corresponding beams of BRS resources and the sync region 304 to allow for BRS resource 302 correspondence.

[0044] In other embodiment, BRS subset may correspond to different reference signals, for example, the first BRS subset may correspond to physical broadcast channel / synchronization signal block (PBCH/SS block) and the second BRS subset to the channel state information reference signal (CSI-RS)

[0045] After receiving BRS resource 302 configurations indicating the association of a BRS to a different BRS subset, the UE can perform BRS measurements on BRS resources 302. The BRS reporting, including a determination of BRS reporting criteria for each BRS subset, can be carried out independently. For example, if the best beam RSRP reporting is configured, the UE can report a BRS-RP for the best BRS resources within each BRS subset.

[0046] FIG. 4 illustrates multiplexing different numerologies in-band 400. In one embodiment it can be assumed that a wireless network is deployed in a carrier without legacy third generation partnership project (3GPP) long term evolution (LTE) Advanced deployment.

[0047] In one embodiment, in such a system, the design constraint is on co-existence with multiple 5G numerologies in the same carrier due to the coexistence of different network services, such as eMBB (enhanced Mobile Broadband) 404, mMTC (massive Machine Type Communications or massive IoT) 402 and URLLC (Ultra Reliable Low Latency Communications or Critical Communications) 406. The carrier in a 5G system can be above or below 6GHz. Multiple carriers can be aggregated for expanding the resources at the physical (PHY) layer.

[0048] In one embodiment, multiplexing different numerologies in-band is illustrated as indicated in FIG.4. FIG. 4 illustrates a time-frequency resource, such as an orthogonal frequency division multiplexing (OFDM) symbol, wherein network services such as mMTC 402, eMBB 404, and URLLC 406 can be multiplexed together within the same symbol, or within another selected time-frequency constraint. In one embodiment, each network service can have a different numerology defining the transmission time interval (TTI), subcarrier spacing, and so forth.

[0049] In one embodiment, due to requirement on multiplexing of different network services, a Common Reference Signal (CRS), as used in 3GPP LTE Rel-8, is not preferable. Discovery Reference Signals (DRS), used in LTE Rel-12, were introduced as an option for UEs in an RRC connected state. However, the use of DRS is not applicable in a 5G multiplexed system, as illustrated in FIG. 4, due to the inability of supporting Idle Mode operation.

[0050] In one embodiment, there is a need to define a reference signal (RS) for providing the following functionalities: radio resource monitoring (RRM) measurements for both RRC connected mode and RRC idle mode UEs; fine timing and carrier frequency offset (CFO) estimation and tracking; and, providing a quasi-co-location (QCL) assumption for demodulation reference symbols (DMRS) and physical downlink shared channel (PDSCH).

[0051] In one embodiment CRS, as described in 3GPP LTE Release 8, does not conform

to the lean 5G design since it has a fixed footprint in time and frequency. In addition, discovery RS, as described in 3GPP LTE Release 12, does not enable an idle mode operation for UEs.

[0052] FIG. 5 depicts a centralized-radio access network (C-RAN) deployment 500 showing three transmission points (TP) transmitting a mobility reference signal (MRS) signal in a cell area. In accordance with an embodiment, a mobility reference signal (MRS) provides one or more of several functionalities. One functionality can be RRM measurements for both RRC connected mode and idle mode UEs (both intra and inter cell). Another functionality can be a fine timing and carrier frequency offset (CFO) estimation and tracking. Another functionality can be allowing a Quasi Co-location (QCL) assumption for a DMRS/PDSCH.

[0053] In one embodiment, an MRS is defined per carrier frequency. It is defined as a collection of one or more reference signals {MRS-1 502, MRS-2 514, MRS-3 512, MRS-4 506}. In FIG. 5, a C-RAN architecture with 3 Transmission Points (TPs), TP1 504 transmitting MRS-1 502, TP-2 508 transmitting MRS-4 506, and TP3 510 transmitting MRS-2 514 and MRS-3 512 is illustrated. In this example, the same primary synchronization signal / secondary synchronization signal/ physical broadcast channel (PSS/SSS/PBCH) signal is transmitted in the coverage area encompassing TP1 504, TP2 508 and TP3 510. In addition, the PSS and SSS can be used as a part of the physical random access channel (PRACH) to sync a cellphone that is not connected to an eNB.

[0054] In one embodiment, it can be shown that the MRS plays a critical role in associating a PDSCH transmission to a QCL assumption that cannot be provided by a PSS/SSS. It is assumed that the TPs are closely synchronized in time and frequency (e.g. using GPS). GPS satellites each contain an atomic clock with a very high level of accuracy (better than 1 in 1 billion). So the signals from GPS satellites can be used to synchronize different TPs with fairly accurate clocks.

[0055] One purpose of MRS is to facilitate RRM measurements for intra-cell mobility, as illustrated in FIG. 5. In FIG. 5, there can be a C-RAN deployment showing 3 TPs transmitting a total of 4 MRS signals in the cell area 500. The same Sync/PBCH 516 signal can be transmitted in the cell area covered by the 3 TPs.

[0056] In one embodiment a UE can determine a mobility measurement occasion,

resource element (RE) mapping for MRS and mobility measurement parameters from information that is broadcasted in a cell which can be carried by, e.g. master information block or system information block (SIB). This information does not change quickly and any change can be notified using paging and/or a system information value tag present in the system information.

[0057] In one embodiment the MRS can facilitate RRM measurements for intra-cell mobility. Additionally, the MRS can be configured to correspond to one or more CSI-RS used for mobility measurements.

[0058] In one embodiment, a UE can determine a mobility measurement occasion (MMO) in terms of a frame number and a subframe number using the following calculation. Mobility Measurement Timing Configuration (MMTC) refers to a set of parameters MMTC-offset, MMTC-periodicity and MMTC-duration that determines a MMO and the duration of measurements. The measurements can comprise the following: single frequency network (SFN) mod $T = \text{floor}(\text{MMTC-offset}/N_s)$; $T = T\text{-sib}$. Where, N_s is a number of subframes per frame that depends on numerology and is specified; $T\text{-sib}$ is the MMTC – periodicity obtained from broadcast information (e.g. SIB); and MMTC-offset is the MMTC – offset in terms of the number of subframes, obtained from broadcast information (e.g. SIB).

[0059] In one embodiment, a processor at a UE can be used to determine the RE mapping for MRS for a MMO (within the measurement duration) from a list of Mobility Measurement Resource Configuration (MMRC) values indicated in the broadcast information (e.g. SIB).

[0060] In one embodiment, MMRC-m, MMRC-n, MMRC-p, MMRC-q values corresponding to MRS-1 502, MRS-2 514, MRS-3 512 and MRS-4 506 can be indicated in the SIB. Note that the RE mapping for MRS is used by connected mode UEs for purposes of PDSCH rate matching. The PDSCH allocated in the same subframe as MRS can be mapped around the REs dedicated for MRS.

[0061] In FIG. 5 it is shown how a value of MMRC defines RE mapping of a MRS to 2 consecutive OFDM symbols (each MRS signal is defined here as a single port though multiple ports can also be envisioned for a MRS) and a total of 8 MMRCs can be defined using 2 OFDM symbols. The wideband nature of the RE mapping allows fine timing

tracking and a pair of OFDM symbols allow an easy estimate of CFO. A total of 80 MMRC values (indicated by 7 bits) can be defined using 2 subframes as shown in the following figure.

[0062] In one embodiment, the MRS bandwidth is obtained from the broadcast information (e.g. MIB) and the scrambling sequence is obtained from the cell-id detected from a PSS/SSS and/or symbol/subframe index. A UE may use coarse timing and frequency synchronization obtained from PSS/SSS for first limiting the timing offset and frequency offset within a certain limit before performing measurement of MRS. Typical reported measurement quantities are reference signal received power (RSRP) and reference signal received quality (RSRQ).

[0063] FIG. 6 illustrates a diagram of an MMRC configuration 600, and how multiple MMRC configurations may be transmitted in two subframes in a cell. An example of an MMRC configuration 602 is shown in the figure on the left. The figure on the right shows how multiple MMRC configurations may be transmitted in two subframes 604/606 in a cell. If MRS is transmitted in the same subframe as PSS/SSS/PBCH 608 then the MRS can be configured to have orthogonal allocations. The two subframes 604/606 can comprise 14 symbols

[0064] In one embodiment, for a particular MMRC the REs can be mapped in several different ways providing various tradeoff of functionalities and overhead. In general, overhead can be reduced by reducing the density of REs in the frequency domain. If the MRS REs are distributed in 2 OFDM symbols, as shown in FIG. 6, the density of REs can be different in the first symbol and the second symbol.

[0065] Further, two alternative examples of RE mapping for a MMRC is shown in FIG. 7. FIG. 7 illustrates a diagram of resource element (RE) mapping for a MMRC. Figure 7A shows a block interleaved pattern where each MRS 702 occupies eight consecutive REs in the frequency domain. Figure 7B shows a scheme where up to eight MRS 702 can be code division multiplied or multiplexed using length-8 orthogonal cover codes (OCCs) and transmitted in a block of 8 REs. Each length 8 OCC can be chosen from a row of a Hadamard matrix of order 8.

[0066] In one embodiment, a UE determines the mobility measurement parameters for cell selection such as the minimum required receive power (dBm) at the cell from the

broadcast information (e.g. SIB).

[0067] In one embodiment, a UE is able to perform initial cell selection after determining a MMO, RE mapping for MRS 702/704, and mobility measurement parameters from broadcast information.

[0068] In one embodiment, a UE operating in an RRC CONNECTED mode, can obtain information via higher layer signaling that changes the determination of a MMO. A UE specific MMTC-periodicity may be signaled to the UE in a manner similar to the UE specific discontinuous reception (DRX) cycle that can increase the MMTC-periodicity for more power savings at the UE, where $T = \min(T\text{-sib}, T\text{-ue})$.

[0069] FIG. 8 illustrates a diagram of idle mode measurements 800 that can take place with multiple UEs. In one embodiment, if a UE specific MMTC is used, different UEs in a cell may perform mobility measurements at different periodicities as illustrated in the proceeding paragraphs. In addition, higher layer signaling can be used to modify the set of MRS for performing measurements from neighbor cells.

[0070] In one embodiment, as in FIG. 8, UE-1 can be requested to monitor MRS 1-4 from cell A and MRS 5 from cell B while UE-2 can be requested to monitor MRS 1-6 from cell A, cell B and cell C. Note that the UE may report only a subset of the measurements performed on the monitored MRS.

[0071] In one embodiment, higher layer signaling can be used to associate a MRS signal explicitly to a physical cell-id and for explicitly indicating a scrambling-id for a MRS signal (this could be a virtual cell ID or an identification (ID) specific to a TP). This is useful in case the PSS/SSS is not transmitted on the particular carrier frequency or if the scrambling ID for the MRS is not the same as the cell-ID.

[0072] In one embodiment, the disclosed is also applicable to UEs operating in a stored information cell selection state and for cell reselection.

[0073] FIG. 9 provides functionality 900 of a base station configured for beam forming in a new radio wireless system. The base station can comprise of one or more processors configured to: encode a first reference signal (RS) for transmission at a selected angle, on a first RS beam having a relatively wide beam width 910. The base station can comprise of one or more processors configured to: encode a set of second RSs for transmission

after the first RS beam, wherein each second RS is configured to be transmitted on a second RS beam having a narrower beam width than a beam width of the first RS beam 920. In addition, the base station can also comprise of a memory interface configured to send to a memory the selected angle.

[0074] In one embodiment the one or more processors can be configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle associated with the selected angle of the first RS beam.

[0075] In one embodiment the one or more processors can be configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle within the beam width of the selected angle of the first RS beam.

[0076] In one embodiment the one or more processors can be configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a different angle associated with the selected angle of the first RS beam.

[0077] In one embodiment the first RS beam can have a first beam forming gain, and the second RS beam can have a second beam forming gain that is greater than the first beam forming gain.

[0078] In one embodiment, each of the second RS beams have a different beamforming gain.

[0079] In one embodiment, the one or more processors can be configured to encode the first RS in a first beam training region of a time-frequency resource and a second beam training region of the time-frequency resource.

[0080] In one embodiment, the one or more processors can be configured to encode the second set of RSs in the first beam training region and the second beam training region at a location after the first RS.

[0081] In one embodiment, the one or more processors can be configured to encode the first RS in the first beam training region and the second beam training region, wherein a sync region is located in a frequency resource of the time-frequency resource located between the first beam training region and the second beam training region.

[0082] In one embodiment, the one or more processors can be configured to associate each RS in the set of second RSs with a selected second RS beam having one or more of a selected angle and a beam forming gain.

[0083] In one embodiment, the one or more processors can be configured to encode each RS in the first RS and the set of second RSs in a frequency resource comprising one or more resource elements that are contiguous or non-contiguous in the frequency domain. In addition, the one or more processors can be configured to associate each RS in the first RS and the set of second RSs in a bitmap with a first RS beam or a selected second RS beam having one or more of a selected angle and a beam forming gain. Wherein, each bit in the bitmap corresponds to one or more of a time, a frequency, or a code resource of the time-frequency resources.

[0084] FIG. 10 provides functionality 1000 of a user equipment (UE) configured for beam forming in a new radio wireless system. The UE can comprise of one or more processors configured to: decode a first reference signal (RS) configured to be received at a selected angle on a first RS beam having a relatively wide beam width 1010. The UE can comprise of one or more processors configured to: decode a set of second RSs received after the first RS beam wherein the each second RS is configured to be received on a second RS beam having a narrower beam width than a beam width of the first RS beam 1020. The UE can comprise of a memory interface configured to send to a memory channel quality information (CQI) associated with the first RS and the set of second RSs.

[0085] In one embodiment, the one or more processors can be configured to perform RS measurements on the first RS and the set of second RSs; and, encode the RS measurements for transmission to a base station in the new radio wireless system.

[0086] In one embodiment, the one or more processors can be configured to determine a RS measurement of a RS having a maximum received power or received quality. The one or more processors can be configured to associate the RS having the maximum received power or received quality with the first RS beam or one of the second RS beams. The one or more processors can be configured to encode the RS measurement of the RS having the maximum received power or the received quality and the associated first RS beam or second RS beam for transmission to the base station.

[0087] FIG. 11 provides functionality 1100 of a user equipment configured to decode

reference signals in a new radio system. The UE can comprise of one or more processors configured to: decode a plurality of mobility measurement resource configuration (MMRC) values from broadcast information received in a broadcast from a base station 1110. The UE can comprise of one or more processors configured to: determine a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO) from the MMRC values 1120.

[0088] In one embodiment the one or more processors can be further configured to determine the MMO in terms of a frame number and a subframe number using: $\text{SFN mod } T = \text{floor}(\text{MMTC-offset}/N_s)$. In this embodiment, $T=T\text{-sib}$, and $T\text{-sib}$ is a mobility measurement timing configuration periodicity (MMTC-periodicity) obtained from the broadcast information. In addition, N_s is a number of subframes per frame that depends on a numerology of the 5G system and measurement timing configuration offset (MMTC-offset) is an offset of the MMTC in terms of a number of subframes obtained from the broadcast information.

[0089] In one embodiment, the one or more processors can be configured to perform physical downlink shared channel (PDSCH) rate matching while the UE is in a connected mode.

[0090] In one embodiment, the one or more processors can be configured to perform radio resource monitoring (RRM) of the MRS while the UE is in a connected mode and in an idle mode.

[0091] In one embodiment, the one or more processors can be configured to determine a minimum receive power for a cell associated with the 5G system from the broadcast information.

[0092] In one embodiment, the one or more processors can be configured to perform initial cell selection in the 5G system based on the RE mapping for the MRS and mobility measurement parameters decoded from the broadcast information.

[0093] In one embodiment, the one or more processors can be configured to decode a UE specific mobility measurement timing configuration (MMTC) periodicity received from the base station via higher layer signaling.

[0094] In one embodiment, the one or more processors can be configured to decode a

modified set of one or more MRSs for selected cells associated with the 5G system.

[0095] In one embodiment, the one or more processors can be configured to monitor selected MRSs based on higher layer signaling to perform measurements on the selected MRSs; and encode at least a subset of the measurements performed on the monitored MRSs for transmission to a base station associated with the MRSs.

[0096] In one embodiment, the one or more processors can be configured to associate an MRS with a physical cell identification (ID); and decode the MRS using the physical cell ID.

[0097] FIG. 12 provides functionality 1200 of a base station configured for beam forming in a new radio wireless system. The base station can comprise of one or more processors configured to: perform a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO) 1210. The base station can comprise of one or more processors configured to: encode a plurality of mobility measurement resource configuration (MMRC) values, based on the RE mapping, in broadcast information to be broadcast from the base station, to one or more user equipment (UEs).

[0098] In one embodiment, the one or more processors can be configured to allocate resource elements for physical downlink shared channel (PDSCH) data transmission, wherein the PDSCH REs are mapped around REs that are dedicated for the MRS.

[0099] In one embodiment, the one or more processors can be configured to map the REs to selected MMRCs, wherein each MMRC is comprised of: two REs in two adjacent symbols; eight consecutive REs interleaved in a frequency domain; and eight REs code division multiplexed using a length-8 orthogonal cover code (OCC).

[00100] FIG. 13 illustrates example components of a device in accordance with some embodiments. In some embodiments, the device 1300 may include application circuitry 1302, baseband circuitry 1304, Radio Frequency (RF) circuitry 1306, front-end module (FEM) circuitry 1308, and one or more antennas 1310, coupled together at least as shown. The components of the illustrated device 1300 may be included a UE or a RAN node. In some embodiments, the device 1300 may include less elements (e.g., a RAN node may not utilize application circuitry 1302, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 1300 may include

additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

[00101] The application circuitry 1302 may include one or more application processors. For example, the application circuitry 1302 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system. In some embodiments, processors of application circuitry 1302 may process IP data packets received from an EPC.

[00102] The baseband circuitry 1304 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1304 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1306 and to generate baseband signals for a transmit signal path of the RF circuitry 1306. Baseband processing circuitry 1304 may interface with the application circuitry 1302 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1306. For example, in some embodiments, the baseband circuitry 1304 may include a second generation (2G) baseband processor 1304a, third generation (3G) baseband processor 1304b, fourth generation (4G) baseband processor 1304c, and/or other baseband processor(s) 1304d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1304 (e.g., one or more of baseband processors 1304a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1306. In other embodiments, some or all of the functionality of baseband processors 1304a-d may be included in modules stored in the memory 1304g and executed via a Central Processing Unit (CPU) 1304e. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio

frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1304 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1304 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[00103] In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1304f. The audio DSP(s) 1304f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1304 and the application circuitry 1302 may be implemented together such as, for example, on a system on a chip (SOC).

[00104] In some embodiments, the baseband circuitry 1304 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1304 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1304 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00105] RF circuitry 1306 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1306 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1306 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1308 and provide baseband signals to the baseband circuitry 1304. RF circuitry 1306 may also include a transmit signal path which may include

circuitry to up-convert baseband signals provided by the baseband circuitry 1304 and provide RF output signals to the FEM circuitry 1308 for transmission.

[00106] In some embodiments, the RF circuitry 1306 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1306 may include mixer circuitry 1306a, amplifier circuitry 1306b and filter circuitry 1306c. The transmit signal path of the RF circuitry 1306 may include filter circuitry 1306c and mixer circuitry 1306a. RF circuitry 1306 may also include synthesizer circuitry 1306d for synthesizing a frequency for use by the mixer circuitry 1306a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1306a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1308 based on the synthesized frequency provided by synthesizer circuitry 1306d. The amplifier circuitry 1306b may be configured to amplify the down-converted signals and the filter circuitry 1306c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1304 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 1306a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00107] In some embodiments, the mixer circuitry 1306a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1306d to generate RF output signals for the FEM circuitry 1308. The baseband signals may be provided by the baseband circuitry 1304 and may be filtered by filter circuitry 1306c. The filter circuitry 1306c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[00108] In some embodiments, the mixer circuitry 1306a of the receive signal path and the mixer circuitry 1306a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 1306a of the receive signal path and the mixer circuitry 1306a of the transmit signal path may include two or more mixers and may be

arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1306a of the receive signal path and the mixer circuitry 1306a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 1306a of the receive signal path and the mixer circuitry 1306a of the transmit signal path may be configured for super-heterodyne operation.

[00109] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1306 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1304 may include a digital baseband interface to communicate with the RF circuitry 1306.

[00110] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[00111] In some embodiments, the synthesizer circuitry 1306d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1306d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00112] The synthesizer circuitry 1306d may be configured to synthesize an output frequency for use by the mixer circuitry 1306a of the RF circuitry 1306 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1306d may be a fractional N/N+1 synthesizer.

[00113] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 1304 or the applications processor 1302 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1302.

[00114] Synthesizer circuitry 1306d of the RF circuitry 1306 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00115] In some embodiments, synthesizer circuitry 1306d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 1306 may include an IQ/polar converter.

[00116] FEM circuitry 1308 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1310, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1306 for further processing. FEM circuitry 1308 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1306 for transmission by one or more of the one or more antennas 1310.

[00117] In some embodiments, the FEM circuitry 1308 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry

1306). The transmit signal path of the FEM circuitry 1308 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1306), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1310).

[00118] In some embodiments, the device 1300 comprises a plurality of power saving mechanisms. If the device 1300 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device may power down for brief intervals of time and thus save power.

[00119] If there is no data traffic activity for an extended period of time, then the device 1300 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device 1300 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device cannot receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00120] An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[00121] Processors of the application circuitry 1302 and processors of the baseband circuitry 1304 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1304, alone or in combination, may be used execute Layer 3, Layer 2, and/or Layer 1 functionality, while processors of the application circuitry 1304 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY)

layer of a UE/RAN node, described in further detail below.

[00122] FIG. 14 provides an example illustration of the wireless device, such as a user equipment (UE), a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The wireless device can include one or more antennas configured to communicate with a node, macro node, low power node (LPN), or, transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband processing unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), or other type of wireless wide area network (WWAN) access point. The wireless device can be configured to communicate using at least one wireless communication standard such as, but not limited to, 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The wireless device can communicate using separate antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The wireless device can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN. The wireless device can also comprise a wireless modem. The wireless modem can comprise, for example, a wireless radio transceiver and baseband circuitry (e.g., a baseband processor). The wireless modem can, in one example, modulate signals that the wireless device transmits via the one or more antennas and demodulate signals that the wireless device receives via the one or more antennas.

[00123] FIG. 14 also provides an illustration of a microphone and one or more speakers that can be used for audio input and output from the wireless device. The display screen can be a liquid crystal display (LCD) screen, or other type of display screen such as an organic light emitting diode (OLED) display. The display screen can be configured as a touch screen. The touch screen can use capacitive, resistive, or another type of touch screen technology. An application processor and a graphics processor can be coupled to internal memory to provide processing and display capabilities. A non-volatile memory port can also be used to provide data input/output options to a user. The non-volatile memory port can also be used to expand the memory capabilities of the wireless device. A keyboard can be integrated with the wireless device or wirelessly connected to the wireless device to provide additional user input. A virtual keyboard can also be provided

using the touch screen.

Examples

[00124] The following examples pertain to specific technology embodiments and point out specific features, elements, or actions that can be used or otherwise combined in achieving such embodiments.

[00125] Example 1 includes an apparatus of a base station configured for beam forming in a new radio wireless system, the apparatus comprising one or more processors configured to: encode a first reference signal (BRS) for transmission at a selected angle, on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; encode a set of second RSs for transmission after the first RS beam, wherein each second RS is configured to be transmitted on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory the selected angle.

[00126] Example 2 includes the apparatus of example 1, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle associated with the selected angle of the first RS beam.

[00127] Example 3 includes the apparatus of example 1 or 2, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle within the beam width of the selected angle of the first RS beam.

[00128] Example 4 includes the apparatus of example 1 or 2, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a different angle associated with the selected angle of the first RS beam.

[00129] Example 5 includes the apparatus of example 1, wherein the first RS beam has a first beam forming gain, and the second RS beam has a second beam forming gain that is greater than the first beam forming gain.

[00130] Example 6 includes the apparatus of example 1 or 2, wherein each of the second RS beams have a different beamforming gain.

[00131] Example 7 includes the apparatus of example 1, wherein the one or more processors are configured to encode the first RS in a first beam training region of a time-frequency resource and a second beam training region of the time-frequency resource.

[00132] Example 8 includes the apparatus of example 2 or 7, wherein the one or more processors are configured to encode the second set of RSs in the first beam training region and the second beam training region at a location after the first RS.

[00133] Example 9 includes the apparatus of example 2 or 7, wherein the one or more processors are configured to encode the first RS in the first beam training region and the second beam training region, wherein a sync region is located in a frequency resource of the time-frequency resource located between the first beam training region and the second beam training region.

[00134] Example 10 includes the apparatus of example 1, wherein the one or more processors are further configured to associate each RS in the set of second RSs with a selected second RS beam having one or more of a selected angle and a beam forming gain.

[00135] Example 11 includes the apparatus of example 1, wherein the one or more processors are further configured to: encode each RS in the first RS and the set of second RSs in a frequency resource comprising one or more resource elements that are contiguous or non-contiguous in the frequency domain; associate each RS in the first RS and the set of second RSs in a bitmap with a first RS beam or a selected second RS beam having one or more of a selected angle and a beam forming gain; wherein each bit in the bitmap corresponds to one or more of a time, a frequency, or a code resource of the time-frequency resources.

[00136] Example 12 includes the apparatus of example 1, wherein the one or more processors are further configured to associate each RS in the set of first RSs with a physical broadcast and synchronization signals blocks (PBCH/SS blocks) and each RS in the second RSs with channel state information reference signals (CSI-RS).

[00137] Example 13 includes an apparatus of a user equipment (UE), configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: decode a first reference signal (RS) configured to be received at a selected

angle on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; decode a set of second RSs received after the first RS beam wherein the each second RS is configured to be received on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory channel quality information (CQI) associated with the first RS and the set of second RSs.

[00138] Example 14 includes the apparatus of example 13, wherein the one or more processors are further configured to: perform RS measurements on the first RS and the set of second RSs; and, encode the RS measurements for transmission to a base station in the new radio wireless system.

[00139] Example 15 includes the apparatus of example 13 or 14, wherein the one or more processors are further configured to: determine a RS measurement of a RS having a maximum received power or received quality; associate the RS having the maximum received power or received quality with the first RS beam or one of the second RS beams; and encode the RS measurement of the RS having the maximum received power or the received quality and the associated first RS beam or second RS beam for transmission to the base station.

[00140] Example 16 includes an apparatus of a user equipment (UE), the apparatus configured to decode reference signals in a new radio system, comprising: one or more processors configured to: decode a plurality of mobility measurement resource configuration (MMRC) values from broadcast information received in a broadcast from a base station; and determine a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO) from the MMRC values.

[00141] Example 17 includes the apparatus of example 16, wherein the one or more processors are further configured to determine the MMO in terms of a frame number and a subframe number using: $\text{SFN mod } T = \text{floor}(\text{MMTC-offset}/N_s)$, where: $T=T\text{-sib}$, $T\text{-sib}$ is a mobility measurement timing configuration periodicity (MMTC-periodicity) obtained from the broadcast information; N_s is a number of subframes per frame that depends on a numerology of the 5G system; and measurement timing configuration offset (MMTC-offset) is an offset of the MMTC in terms of a number of subframes obtained from the broadcast information.

[00142] Example 18 includes the apparatus of example 16 or 17, wherein the one or more processors are further configured to perform physical downlink shared channel (PDSCH) rate matching while the UE is in a connected mode.

[00143] Example 19 includes the apparatus of example 16, wherein the one or more processors are further configured to perform radio resource monitoring (RRM) of the MRS while the UE is in a connected mode and in an idle mode.

[00144] Example 20 includes the apparatus of example 16, wherein the one or more processors are further configured to determine a minimum receive power for a cell associated with the 5G system from the broadcast information.

[00145] Example 21 includes the apparatus of example 16 or 17, wherein the one or more processors are further configured to perform initial cell selection in the 5G system based on the RE mapping for the MRS and mobility measurement parameters decoded from the broadcast information.

[00146] Example 22 includes the apparatus of example 16, wherein the one or more processors are further configured to decode a UE specific mobility measurement timing configuration (MMTC) periodicity received from the base station via higher layer signaling.

[00147] Example 23 includes the apparatus of example 16, wherein the one or more processors are further configured to decode a modified set of one or more MRSs for selected cells associated with the 5G system.

[00148] Example 24 includes the apparatus of example 16 or 17, wherein the one or more processors are further configured to: monitor selected MRSs based on higher layer signaling to perform measurements on the selected MRSs; and encode at least a subset of the measurements performed on the monitored MRSs for transmission to a base station associated with the MRSs.

[00149] Example 25 includes the apparatus of example 16 or 17, wherein the one or more processors are further configured to: associate an MRS with a physical cell identification (ID); and decode the MRS using the physical cell ID.

[00150] Example 26 includes an apparatus of a base station, configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors

configured to: perform a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO); and encode a plurality of mobility measurement resource configuration (MMRC) values, based on the RE mapping, in broadcast information to be broadcast from the base station, to one or more user equipment (UEs).

[00151] Example 27 includes the apparatus of example 26, wherein the one or more processors are further configured to: allocate resource elements for physical downlink shared channel (PDSCH) data transmission, wherein the PDSCH REs are mapped around REs that are dedicated for the MRS.

[00152] Example 28 includes the apparatus of example 26 or 27, wherein the one or more processors are further configured to map the REs to selected MMRCs, wherein each MMRC is comprised of: two REs in two adjacent symbols; eight consecutive REs interleaved in a frequency domain; and eight REs code division multiplexed using a length-8 orthogonal cover code (OCC).

[00153] Example 29 includes an apparatus of a base station configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: encode a first reference signal (BRS) for transmission at a selected angle, on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; encode a set of second RSs for transmission after the first RS beam, wherein each second RS is configured to be transmitted on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory the selected angle.

[00154] Example 30 includes the apparatus of example 29, wherein the one or more processors are configured to: encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle associated with the selected angle of the first RS beam; or encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle within the beam width of the selected angle of the first RS beam.

[00155] Example 31 includes the apparatus of example 29 or 30, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a different angle associated with the

selected angle of the first RS beam.

[00156] Example 32 includes the apparatus of example 29, wherein the first RS beam has a first beam forming gain, and the second RS beam has a second beam forming gain that is greater than the first beam forming gain, or each of the second RS beams have a different beamforming gain.

[00157] Example 33 includes the apparatus of example 29, wherein the one or more processors are configured to encode the first RS in a first beam training region of a time-frequency resource and a second beam training region of the time-frequency resource.

[00158] Example 34 includes the apparatus of example 30 or 33, wherein the one or more processors are configured to: encode the second set of RSs in the first beam training region and the second beam training region at a location after the first RS; or encode the first RS in the first beam training region and the second beam training region, wherein a sync region is located in a frequency resource of the time-frequency resource located between the first beam training region and the second beam training region.

[00159] Example 35 includes the apparatus of example 29, wherein the one or more processors are further configured to: encode each RS in the first RS and the set of second RSs in a frequency resource comprising one or more resource elements that are contiguous or non-contiguous in the frequency domain; associate each RS in the first RS and the set of second RSs in a bitmap with a first RS beam or a selected second RS beam having one or more of a selected angle and a beam forming gain; associate each RS in the set of first RSs with a physical broadcast and synchronization signals blocks (PBCH/SS blocks) and each RS in the second RSs with channel state information reference signals (CSI-RS); and associate each RS in the set of second RSs with a selected second RS beam having one or more of a selected angle and a beam forming gain; wherein each bit in the bitmap corresponds to one or more of a time, a frequency, or a code resource of the time-frequency resources.

[00160] Example 36 includes an apparatus of user equipment (UE), configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: decode a first reference signal (RS) configured to be received at a selected angle on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; decode a set of second RSs received

after the first RS beam wherein the each second RS is configured to be received on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory channel quality information (CQI) associated with the first RS and the set of second RSs.

[00161] Example 37 includes the apparatus of example 36, wherein the one or more processors are further configured to: perform RS measurements on the first RS and the set of second RSs; encode the RS measurements for transmission to a base station in the new radio wireless system; determine a RS measurement of a RS having a maximum received power or received quality; associate the RS having the maximum received power or received quality with the first RS beam or one of the second RS beams; and encode the RS measurement of the RS having the maximum received power or the received quality and the associated first RS beam or second RS beam for transmission to the base station.

[00162] Example 38 includes an apparatus of a user equipment (UE), the apparatus configured to decode reference signals in a new radio system, comprising: one or more processors configured to: decode a plurality of mobility measurement resource configuration (MMRC) values from broadcast information received in a broadcast from a base station; and determine a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO) from the MMRC values.

[00163] Example 39 includes the apparatus of example 38, wherein the one or more processors are further configured to determine the MMO in terms of a frame number and a subframe number using: $\text{SFN mod } T = \text{floor}(\text{MMTC-offset}/N_s)$, where: $T = T\text{-sib}$, $T\text{-sib}$ is a mobility measurement timing configuration periodicity (MMTC-periodicity) obtained from the broadcast information; N_s is a number of subframes per frame that depends on a numerology of the 5G system; and measurement timing configuration offset (MMTC-offset) is an offset of the MMTC in terms of a number of subframes obtained from the broadcast information.

[00164] Example 40 includes the apparatus of example 38 or 39, wherein the one or more processors are further configured to: perform physical downlink shared channel (PDSCH) rate matching while the UE is in a connected mode; or perform radio resource monitoring (RRM) of the MRS while the UE is in a connected mode and in an idle mode.

[00165] Example 41 includes the apparatus of example 38, wherein the one or more

processors are further configured to: determine a minimum receive power for a cell associated with the 5G system from the broadcast information; or decode a modified set of one or more MRSs for selected cells associated with the 5G system.

[00166] Example 42 includes the apparatus of example 38 or 39, wherein the one or more processors are further configured to: perform initial cell selection in the 5G system based on the RE mapping for the MRS and mobility measurement parameters decoded from the broadcast information; monitor selected MRSs based on higher layer signaling to perform measurements on the selected MRSs; encode at least a subset of the measurements performed on the monitored MRSs for transmission to a base station associated with the MRSs; or decode a UE specific mobility measurement timing configuration (MMTC) periodicity received from the base station via higher layer signaling.

[00167] Example 43 includes the apparatus of example 38 or 39, wherein the one or more processors are further configured to: associate an MRS with a physical cell identification (ID); and decode the MRS using the physical cell ID.

[00168] Example 44 includes an apparatus of a base station configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: encode a first reference signal (BRS) for transmission at a selected angle, on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; encode a set of second RSs for transmission after the first RS beam, wherein each second RS is configured to be transmitted on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory the selected angle.

[00169] Example 45 includes the apparatus of example 44, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle associated with the selected angle of the first RS beam.

[00170] Example 46 includes the apparatus of example 44, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle within the beam width of the selected angle of the first RS beam.

[00171] Example 47 includes the apparatus of example 44, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a different angle associated with the selected angle of the first RS beam.

[00172] Example 48 includes the apparatus of example 44, wherein the first RS beam has a first beam forming gain, and the second RS beam has a second beam forming gain that is greater than the first beam forming gain.

[00173] Example 49 includes the apparatus of example 44, wherein each of the second RS beams have a different beamforming gain.

[00174] Example 50 includes the apparatus of example 44, wherein the one or more processors are configured to encode the first RS in a first beam training region of a time-frequency resource and a second beam training region of the time-frequency resource.

[00175] Example 51 includes the apparatus of example 44, wherein the one or more processors are configured to encode the second set of RSs in the first beam training region and the second beam training region at a location after the first RS.

[00176] Example 52 includes the apparatus of example 44, wherein the one or more processors are configured to encode the first RS in the first beam training region and the second beam training region, wherein a sync region is located in a frequency resource of the time-frequency resource located between the first beam training region and the second beam training region.

[00177] Example 53 includes the apparatus of example 44, wherein the one or more processors are further configured to associate each RS in the set of second RSs with a selected second RS beam having one or more of a selected angle and a beam forming gain.

[00178] Example 54 includes the apparatus of example 44, wherein the one or more processors are further configured to: encode each RS in the first RS and the set of second RSs in a frequency resource comprising one or more resource elements that are contiguous or non-contiguous in the frequency domain; associate each RS in the first RS and the set of second RSs in a bitmap with a first RS beam or a selected second RS beam having one or more of a selected angle and a beam forming gain; wherein each bit in the

bitmap corresponds to one or more of a time, a frequency, or a code resource of the time-frequency resources.

[00179] Example 55 includes the apparatus of example 44, wherein the one or more processors are further configured to associate each RS in the set of first RSs with a physical broadcast and synchronization signals blocks (PBCH/SS blocks) and each RS in the second RSs with channel state information reference signals (CSI-RS).

[00180] Example 56 includes an apparatus of a user equipment (UE), configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: decode a first reference signal (RS) configured to be received at a selected angle on a first RS beam having a relatively wide beam width, wherein the first RS beam has a wider beam width than the second RS beam; decode a set of second RSs received after the first RS beam wherein the each second RS is configured to be received on a second RS beam having a narrower beam width than a beam width of the first RS beam; and a memory interface configured to send to a memory channel quality information (CQI) associated with the first RS and the set of second RSs.

[00181] Example 57 includes the apparatus of example 56, wherein the one or more processors are further configured to: perform RS measurements on the first RS and the set of second RSs; and, encode the RS measurements for transmission to a base station in the new radio wireless system.

[00182] Example 58 includes the apparatus of example 57, wherein the one or more processors are further configured to: determine a RS measurement of a RS having a maximum received power or received quality; associate the RS having the maximum received power or received quality with the first RS beam or one of the second RS beams; and encode the RS measurement of the RS having the maximum received power or the received quality and the associated first RS beam or second RS beam for transmission to the base station.

[00183] Example 59 includes an apparatus of a user equipment (UE), the apparatus configured to decode reference signals in a new radio system, comprising: one or more processors configured to: decode a plurality of mobility measurement resource configuration (MMRC) values from broadcast information received in a broadcast from a base station; and determine a resource element (RE) mapping for a mobility reference

signal (MRS) for a mobility measurement occasion (MMO) from the MMRC values.

[00184] Example 60 includes the apparatus of example 59, wherein the one or more processors are further configured to determine the MMO in terms of a frame number and a subframe number using: $\text{SFN mod } T = \text{floor}(\text{MMTC-offset}/N_s)$, where: $T=T\text{-sib}$, $T\text{-sib}$ is a mobility measurement timing configuration periodicity (MMTC-periodicity) obtained from the broadcast information; N_s is a number of subframes per frame that depends on a numerology of the 5G system; and measurement timing configuration offset (MMTC-offset) is an offset of the MMTC in terms of a number of subframes obtained from the broadcast information.

[00185] Example 61 includes the apparatus of example 60, wherein the one or more processors are further configured to perform physical downlink shared channel (PDSCH) rate matching while the UE is in a connected mode.

[00186] Example 62 includes the apparatus of example 60, wherein the one or more processors are further configured to perform radio resource monitoring (RRM) of the MRS while the UE is in a connected mode and in an idle mode.

[00187] Example 63 includes the apparatus of example 60, wherein the one or more processors are further configured to determine a minimum receive power for a cell associated with the 5G system from the broadcast information.

[00188] Example 64 includes the apparatus of example 60, wherein the one or more processors are further configured to perform initial cell selection in the 5G system based on the RE mapping for the MRS and mobility measurement parameters decoded from the broadcast information.

[00189] Example 65 includes the apparatus of example 60, wherein the one or more processors are further configured to decode a UE specific mobility measurement timing configuration (MMTC) periodicity received from the base station via higher layer signaling.

[00190] Example 66 includes the apparatus of example 60, wherein the one or more processors are further configured to decode a modified set of one or more MRSs for selected cells associated with the 5G system.

[00191] Example 67 includes the apparatus of example 59, wherein the one or more

processors are further configured to: monitor selected MRSs based on higher layer signaling to perform measurements on the selected MRSs; and encode at least a subset of the measurements performed on the monitored MRSs for transmission to a base station associated with the MRSs.

[00192] Example 68 includes the apparatus of example 59, wherein the one or more processors are further configured to: associate an MRS with a physical cell identification (ID); and decode the MRS using the physical cell ID.

[00193] Example 69 includes an apparatus of apparatus of a base station, configured for beam forming in a new radio wireless system, the apparatus comprising: one or more processors configured to: perform a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO); and encode a plurality of mobility measurement resource configuration (MMRC) values, based on the RE mapping, in broadcast information to be broadcast from the base station, to one or more user equipment (UEs).

[00194] Example 70 includes the apparatus of the base station of example 69, wherein the one or more processors are further configured to: allocate resource elements for physical downlink shared channel (PDSCH) data transmission, wherein the PDSCH REs are mapped around REs that are dedicated for the MRS.

[00195] Example 71 includes the apparatus of the base station or gNB of example 69, wherein the one or more processors are further configured to map the REs to selected MMRCs, wherein each MMRC is comprised of: two REs in two adjacent symbols; eight consecutive REs interleaved in a frequency domain; and eight REs code division multiplexed using a length-8 orthogonal cover code (OCC).

[00196] Various techniques, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, compact disc-read-only memory (CD-ROMs), hard drives, non-transitory computer readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the various techniques. In the case of program code execution on programmable computers, the computing device may include a processor, a storage medium readable by the processor (including volatile and non-

volatile memory and/or storage elements), at least one input device, and at least one output device. The volatile and non-volatile memory and/or storage elements may be a random-access memory (RAM), erasable programmable read only memory (EPROM), flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). In one example, selected components of the transceiver module can be located in a cloud radio access network (C-RAN). One or more programs that may implement or utilize the various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[00197] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[00198] It should be understood that many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very-large-scale integration (VLSI) circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00199] Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module may not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

[00200] Indeed, a module of executable code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

[00201] Reference throughout this specification to "an example" or "exemplary" means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment of the present technology. Thus, appearances of the phrases "in an example" or the word "exemplary" in various places throughout this specification are not necessarily all referring to the same embodiment.

[00202] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and example of the present technology may be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as defacto equivalents of one another, but are to be considered as separate and autonomous representations of the

present technology.

[00203] Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are provided, such as examples of layouts, distances, network examples, etc., to provide a thorough understanding of embodiments of the technology. One skilled in the relevant art will recognize, however, that the technology can be practiced without one or more of the specific details, or with other methods, components, layouts, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the technology.

While the forgoing examples are illustrative of the principles of the present technology in one or more particular applications, it will be apparent to those of ordinary skill in the art that numerous modifications in form, usage and details of implementation can be made without the exercise of inventive faculty, and without departing from the principles and concepts of the technology. Accordingly, it is not intended that the technology be limited, except as by the claims set forth below.

CLAIMS

What is claimed is:

1. An apparatus of a base station configured for beam forming in a new radio wireless system, the apparatus comprising:
 - one or more processors configured to:
 - encode a first reference signal for transmission at a selected angle, on a first RS beam having a relatively wide beam width;
 - encode a set of second RSs for transmission after the first RS beam, wherein each second RS is configured to be transmitted on a second RS beam having a narrower beam width than a beam width of the first RS beam; and
 - a memory interface configured to send to a memory the selected angle.
2. The apparatus of claim 1, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle associated with the selected angle of the first RS beam.
3. The apparatus of claim 1 or 2, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a selected angle within the beam width of the selected angle of the first RS beam.
4. The apparatus of claim 1 or 2, wherein the one or more processors are configured to encode the second set of RSs for transmission wherein each second RS beam is configured to be transmitted at a different angle associated with the selected angle of the first RS beam.
5. The apparatus of claim 1, wherein the first RS beam has a first beam forming gain, and the second RS beam has a second beam forming gain that is greater than

the first beam forming gain.

6. The apparatus of claim 1 or 2, wherein each of the second RS beams have a different beamforming gain.
7. The apparatus of claim 1, wherein the one or more processors are configured to encode the first RS in a first beam training region of a time-frequency resource and a second beam training region of the time-frequency resource.
8. The apparatus of claim 2 or 7, wherein the one or more processors are configured to encode the second set of RSs in the first beam training region and the second beam training region at a location after the first RS.
9. The apparatus of claim 2 or 7, wherein the one or more processors are configured to encode the first RS in the first beam training region and the second beam training region, wherein a sync region is located in a frequency resource of the time-frequency resource located between the first beam training region and the second beam training region.
10. The apparatus of claim 1, wherein the one or more processors are further configured to associate each RS in the set of second RSs with a selected second RS beam having one or more of a selected angle and a beam forming gain.
11. The apparatus of claim 1, wherein the one or more processors are further configured to:
 - encode each RS in the first RS and the set of second RSs in a frequency resource comprising one or more resource elements that are contiguous or non-contiguous in the frequency domain;
 - associate each RS in the first RS and the set of second RSs in a bitmap with a first RS beam or a selected second RS beam having one or more of a selected angle and a beam forming gain;

wherein each bit in the bitmap corresponds to one or more of a time, a frequency, or a code resource of the time-frequency resources.

12. The apparatus of claim 1, wherein the one or more processors are further configured to associate each RS in the set of first RSs with a physical broadcast and synchronization signals blocks (PBCH/SS blocks) and each RS in the second RSs with channel state information reference signals (CSI-RS).
13. The apparatus of a user equipment (UE), configured for beam forming in a new radio wireless system, the apparatus comprising:
 - one or more processors configured to:
 - decode a first reference signal (RS) configured to be received at a selected angle on a first RS beam having a relatively wide beam width;
 - decode a set of second RSs received after the first RS beam wherein the each second RS is configured to be received on a second RS beam having a narrower beam width than a beam width of the first RS beam; and
 - a memory interface configured to send to a memory channel quality information (CQI) associated with the first RS and the set of second RSs.
14. The apparatus of claim 13, wherein the one or more processors are further configured to:
 - perform RS measurements on the first RS and the set of second RSs; and
 - encode the RS measurements for transmission to a base station in the new radio wireless system.
15. The apparatus of claim 13 or 14, wherein the one or more processors are further configured to:
 - determine a RS measurement of a RS having a maximum received power or received quality;

associate the RS having the maximum received power or received quality with the first RS beam or one of the second RS beams; and
 encode the RS measurement of the RS having the maximum received power or the received quality and the associated first RS beam or second RS beam for transmission to the base station.

16. An apparatus of a user equipment (UE), the apparatus configured to decode reference signals in a new radio system, comprising:
 - one or more processors configured to:
 - decode a plurality of mobility measurement resource configuration (MMRC) values from broadcast information received in a broadcast from a base station; and
 - determine a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO) from the MMRC values.
17. The apparatus of claim 16, wherein the one or more processors are further configured to determine the MMO in terms of a frame number and a subframe number using: $\text{SFN mod } T = \text{floor}(\text{MMTC-offset}/N_s)$, where:
 - $T = T\text{-sib}$, $T\text{-sib}$ is a mobility measurement timing configuration periodicity (MMTC-periodicity) obtained from the broadcast information;
 - N_s is a number of subframes per frame that depends on a numerology of the 5G system; and
 - measurement timing configuration offset (MMTC-offset) is an offset of the MMTC in terms of a number of subframes obtained from the broadcast information.
18. The apparatus of claim 16 or 17, wherein the one or more processors are further configured to perform physical downlink shared channel (PDSCH) rate matching while the UE is in a connected mode.

19. The apparatus of claim 16, wherein the one or more processors are further configured to perform radio resource monitoring (RRM) of the MRS while the UE is in a connected mode and in an idle mode.
20. The apparatus of claim 16, wherein the one or more processors are further configured to determine a minimum receive power for a cell associated with the 5G system from the broadcast information.
21. The apparatus of claim 16 or 17, wherein the one or more processors are further configured to perform initial cell selection in the 5G system based on the RE mapping for the MRS and mobility measurement parameters decoded from the broadcast information.
22. The apparatus of claim 16, wherein the one or more processors are further configured to decode a UE specific mobility measurement timing configuration (MMTC) periodicity received from the base station via higher layer signaling.
23. The apparatus of claim 16, wherein the one or more processors are further configured to decode a modified set of one or more MRSs for selected cells associated with the 5G system.
24. The apparatus of claim 16 or 17, wherein the one or more processors are further configured to:
 - monitor selected MRSs based on higher layer signaling to perform measurements on the selected MRSs; and
 - encode at least a subset of the measurements performed on the monitored MRSs for transmission to a base station associated with the MRSs.
25. The apparatus of claim 16 or 17, wherein the one or more processors are further configured to:
 - associate an MRS with a physical cell identification (ID); and

decode the MRS using the physical cell ID.

26. The apparatus of a base station, configured for beam forming in a new radio wireless system, the apparatus comprising:
- one or more processors configured to:
 - perform a resource element (RE) mapping for a mobility reference signal (MRS) for a mobility measurement occasion (MMO); and
 - encode a plurality of mobility measurement resource configuration (MMRC) values, based on the RE mapping, in broadcast information to be broadcast from the base station, to one or more user equipment (UEs).
27. The apparatus of the base station of claim 26, wherein the one or more processors are further configured to:
- allocate resource elements for physical downlink shared channel (PDSCH) data transmission, wherein the PDSCH REs are mapped around REs that are dedicated for the MRS.
28. The apparatus of the base station of claim 26 or 27, wherein the one or more processors are further configured to map the REs to selected MMRCs, wherein each MMRC is comprised of:
- two REs in two adjacent symbols;
 - eight consecutive REs interleaved in a frequency domain; and
 - eight REs code division multiplexed using a length-8 orthogonal cover code (OCC).

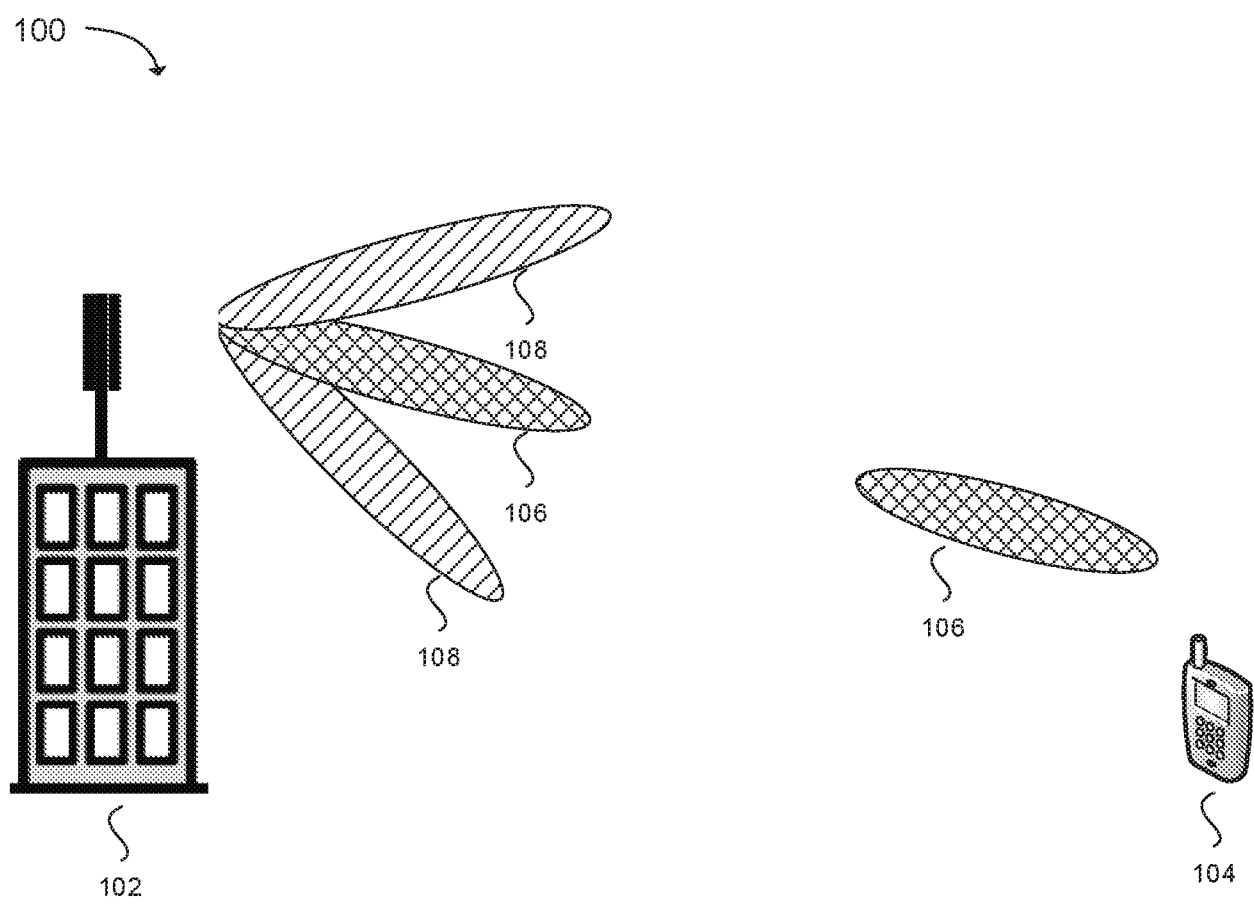


FIG. 1

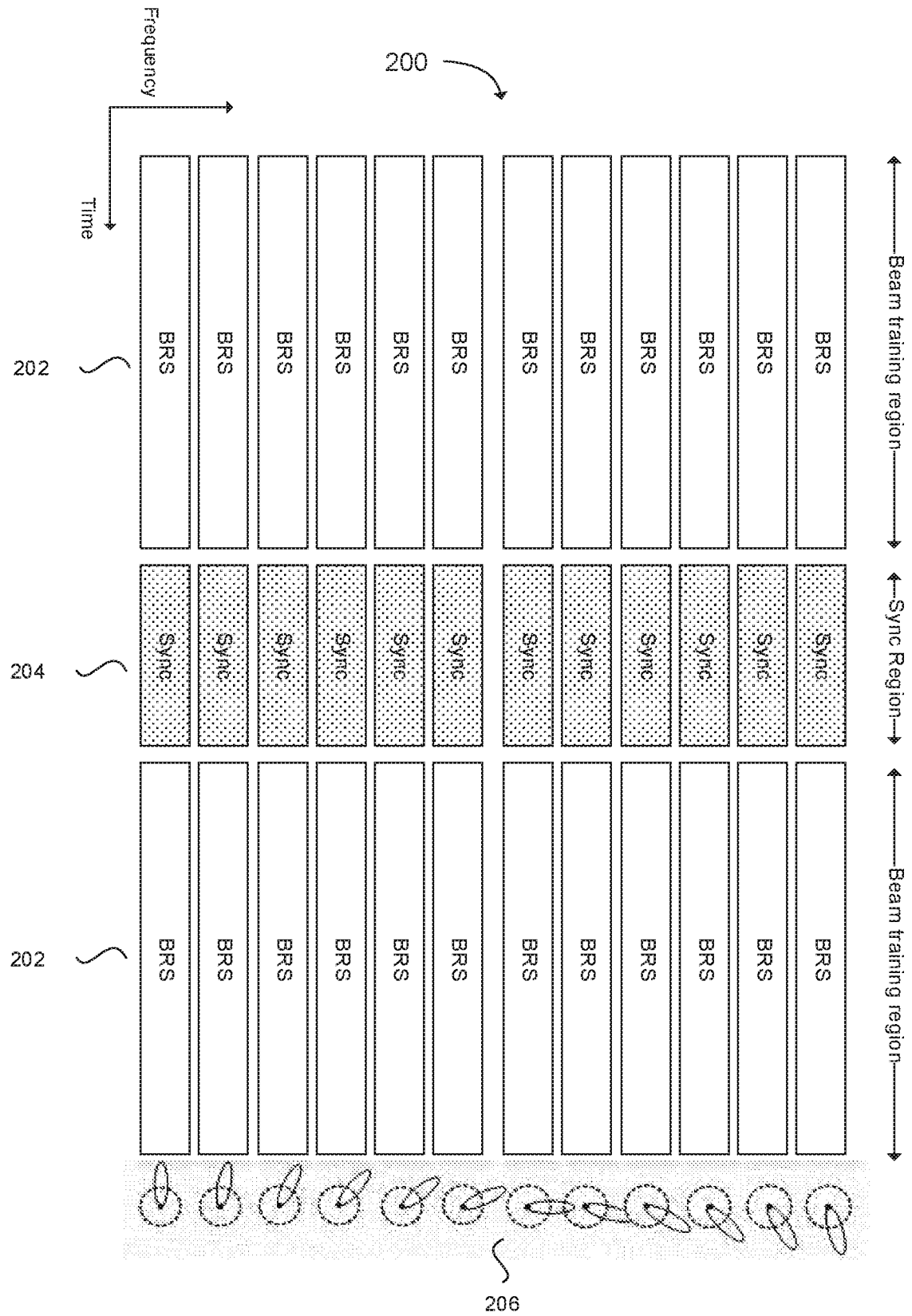


FIG. 2

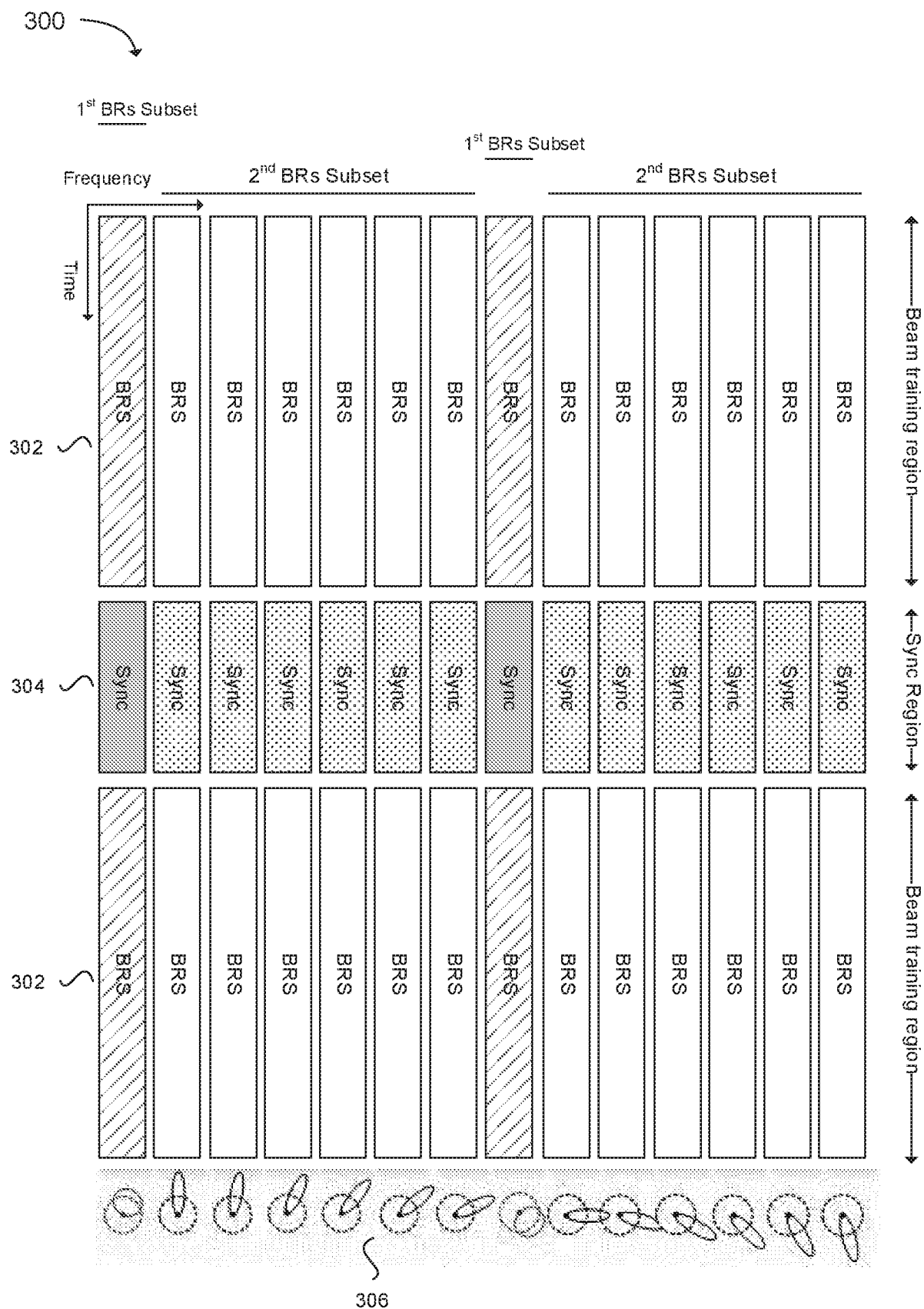


FIG. 3

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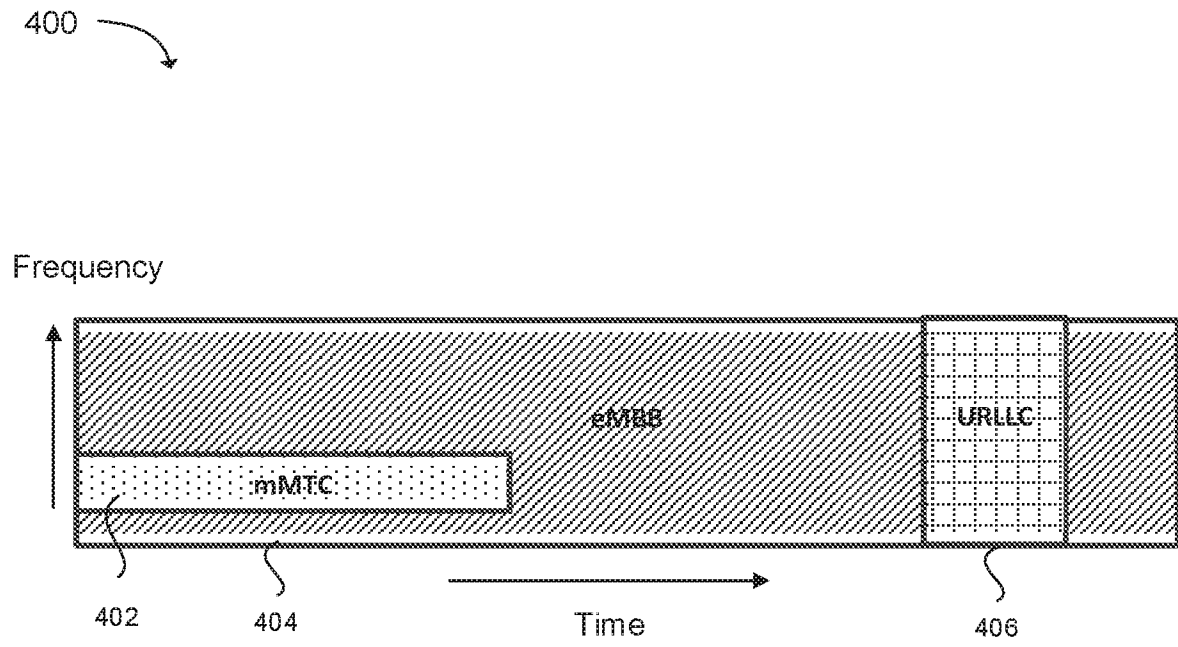


FIG. 4

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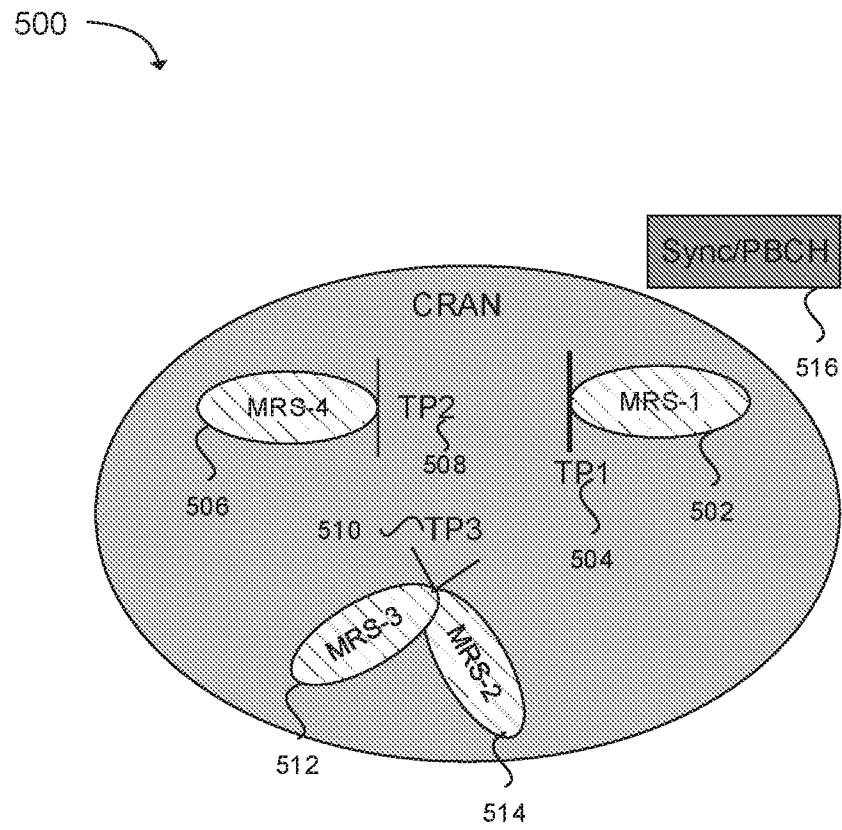


FIG. 5

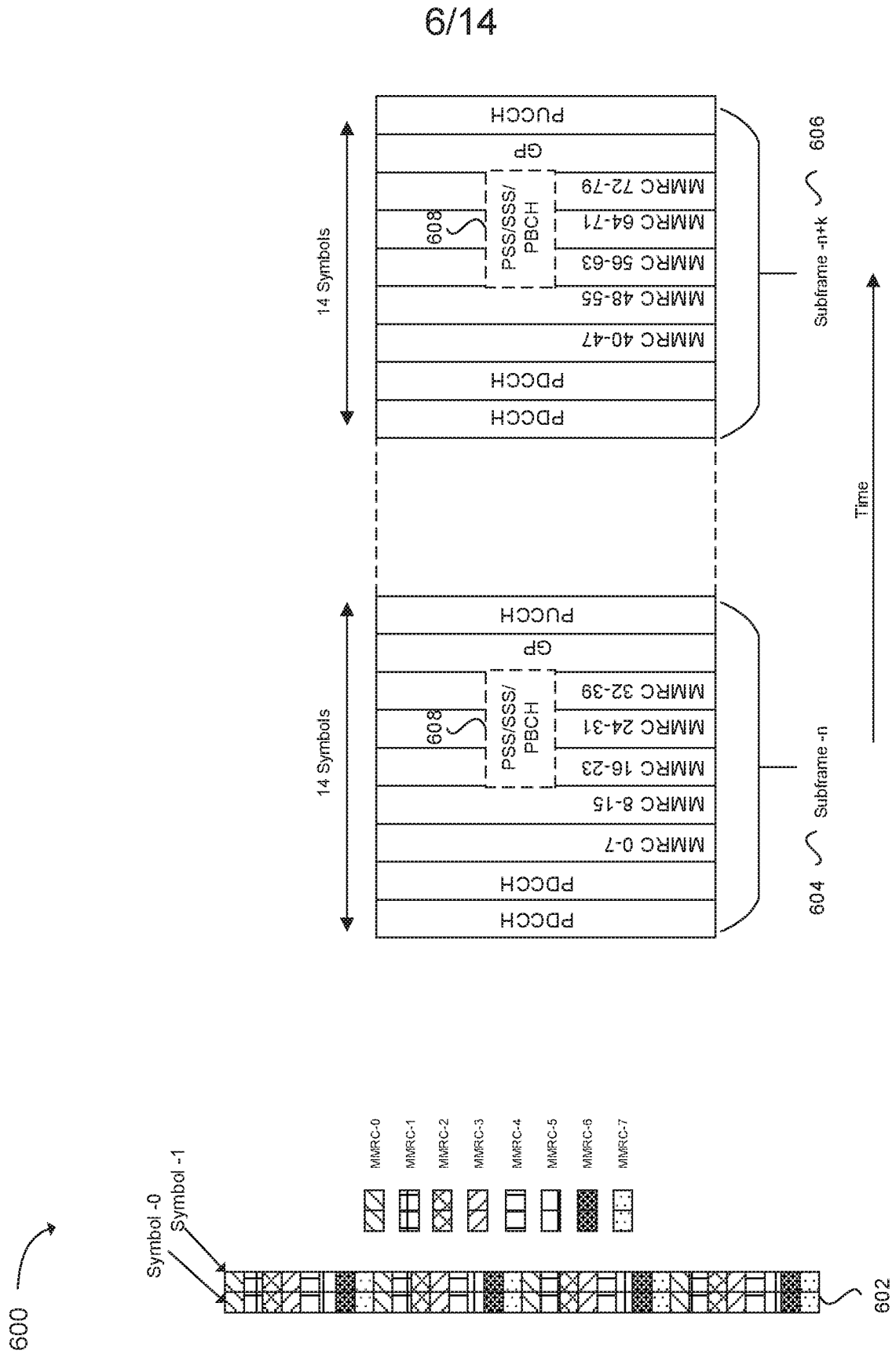


FIG. 6

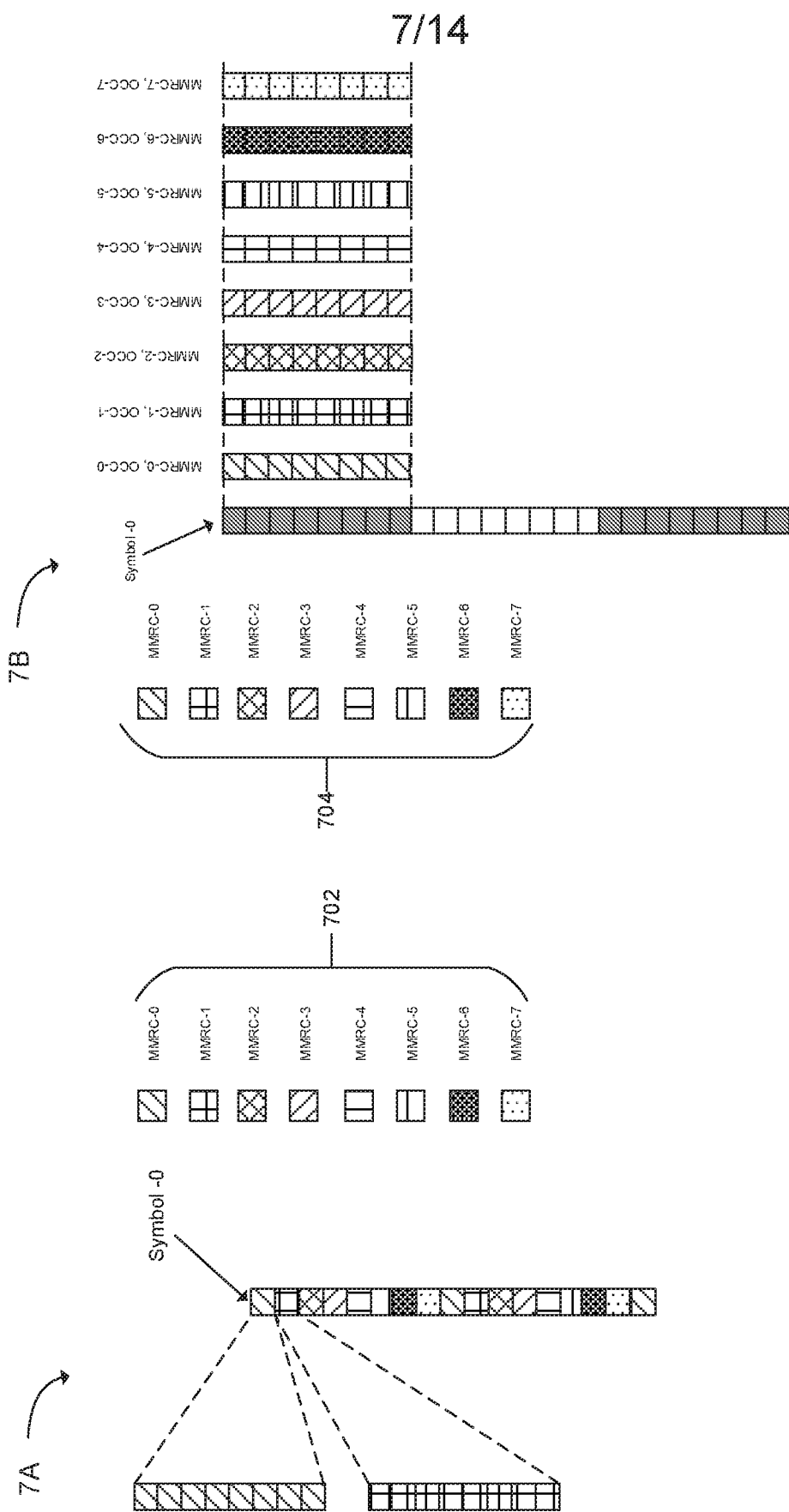


FIG. 7

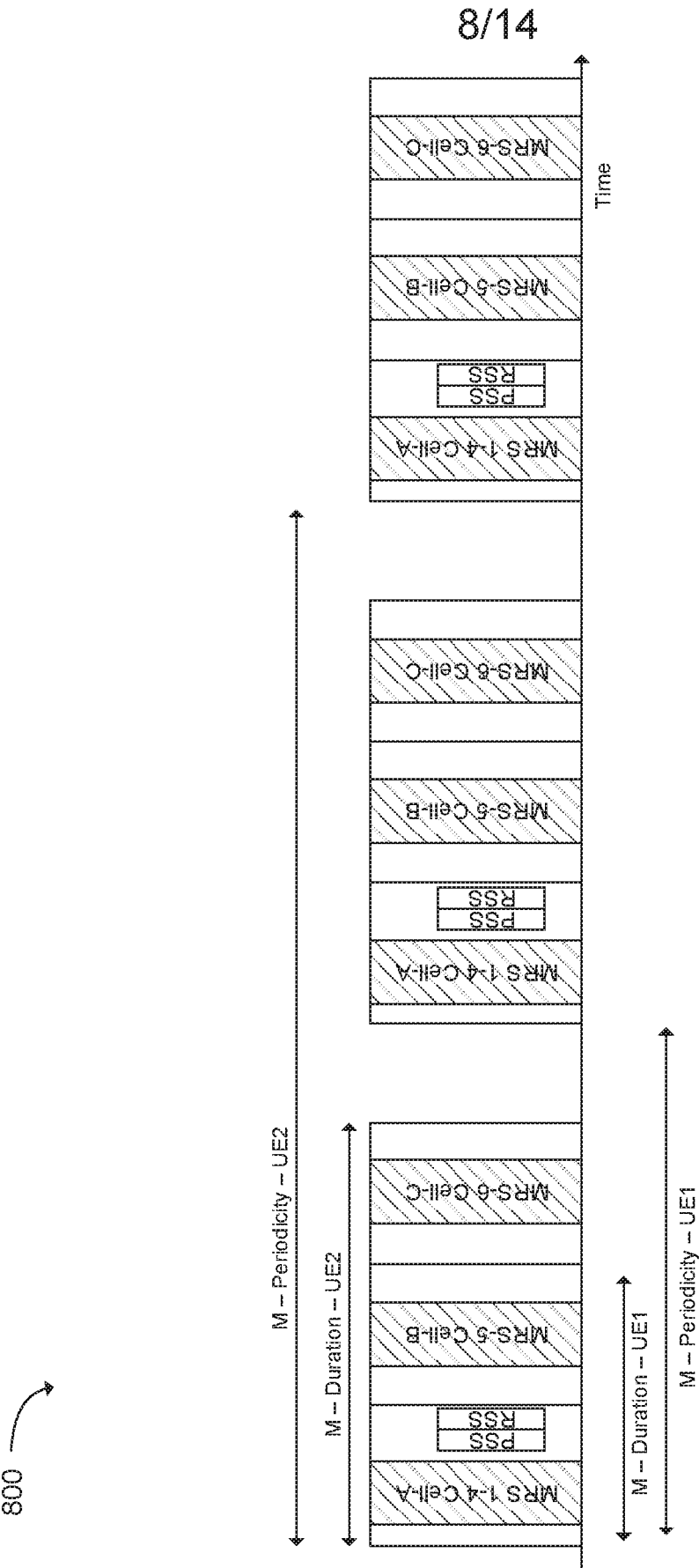


FIG. 8

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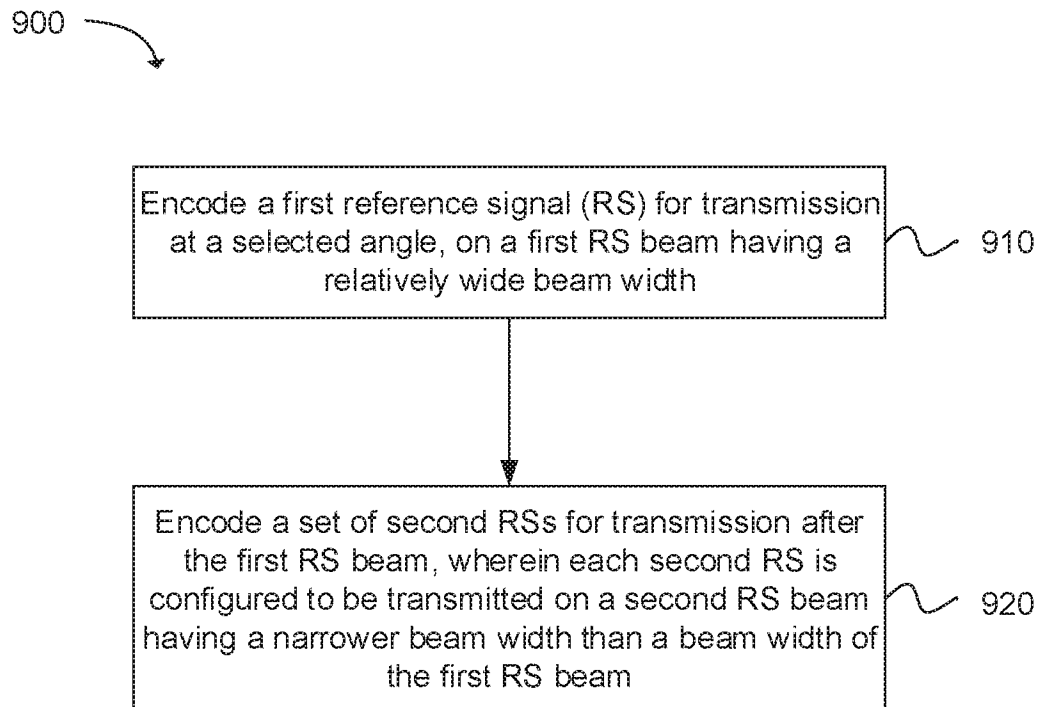


FIG. 9

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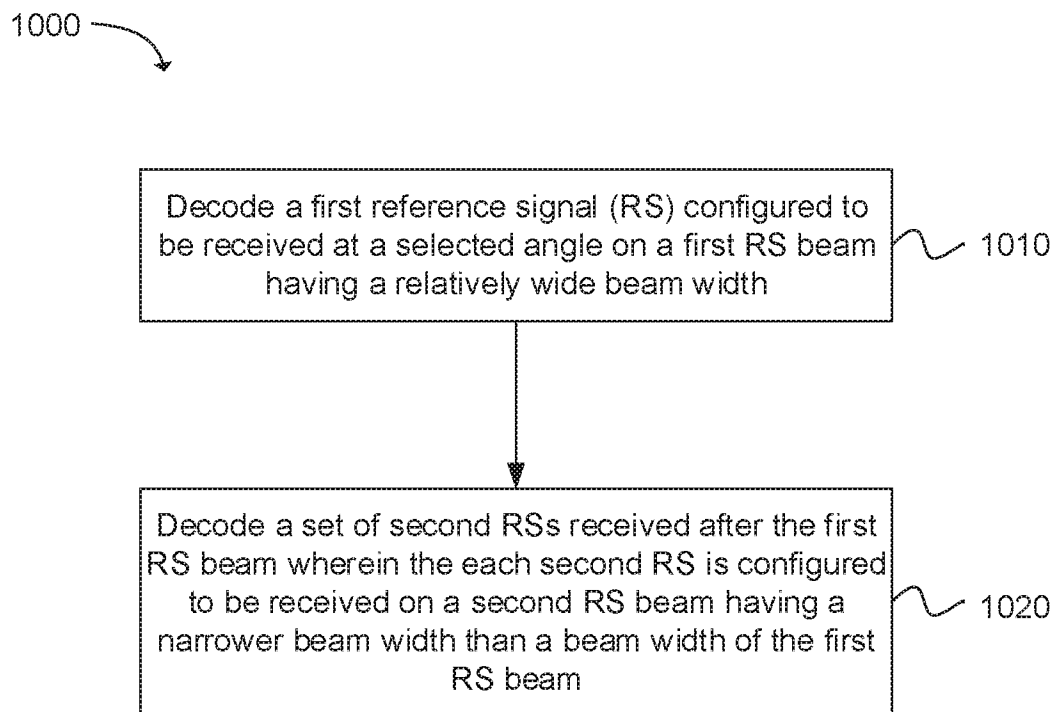


FIG. 10

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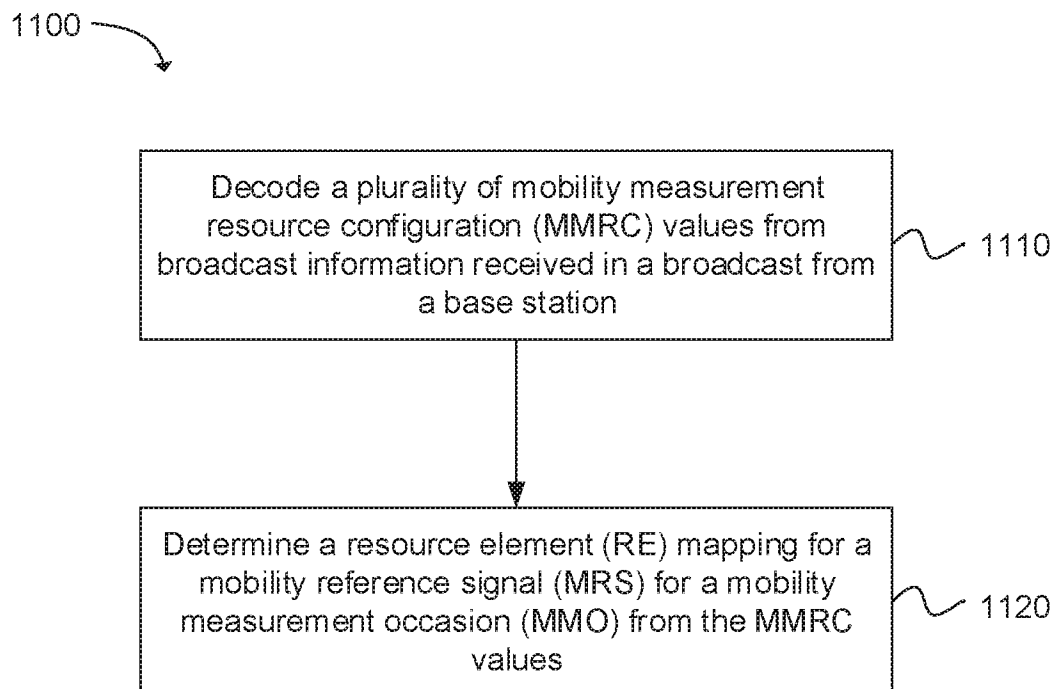


FIG. 11

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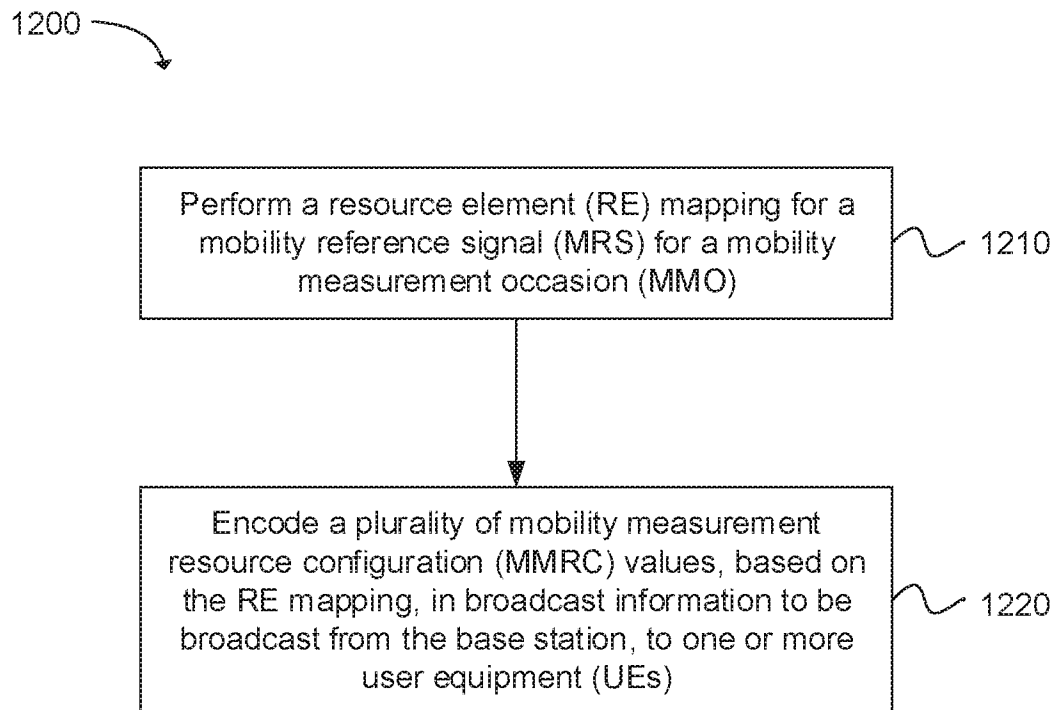


FIG. 12

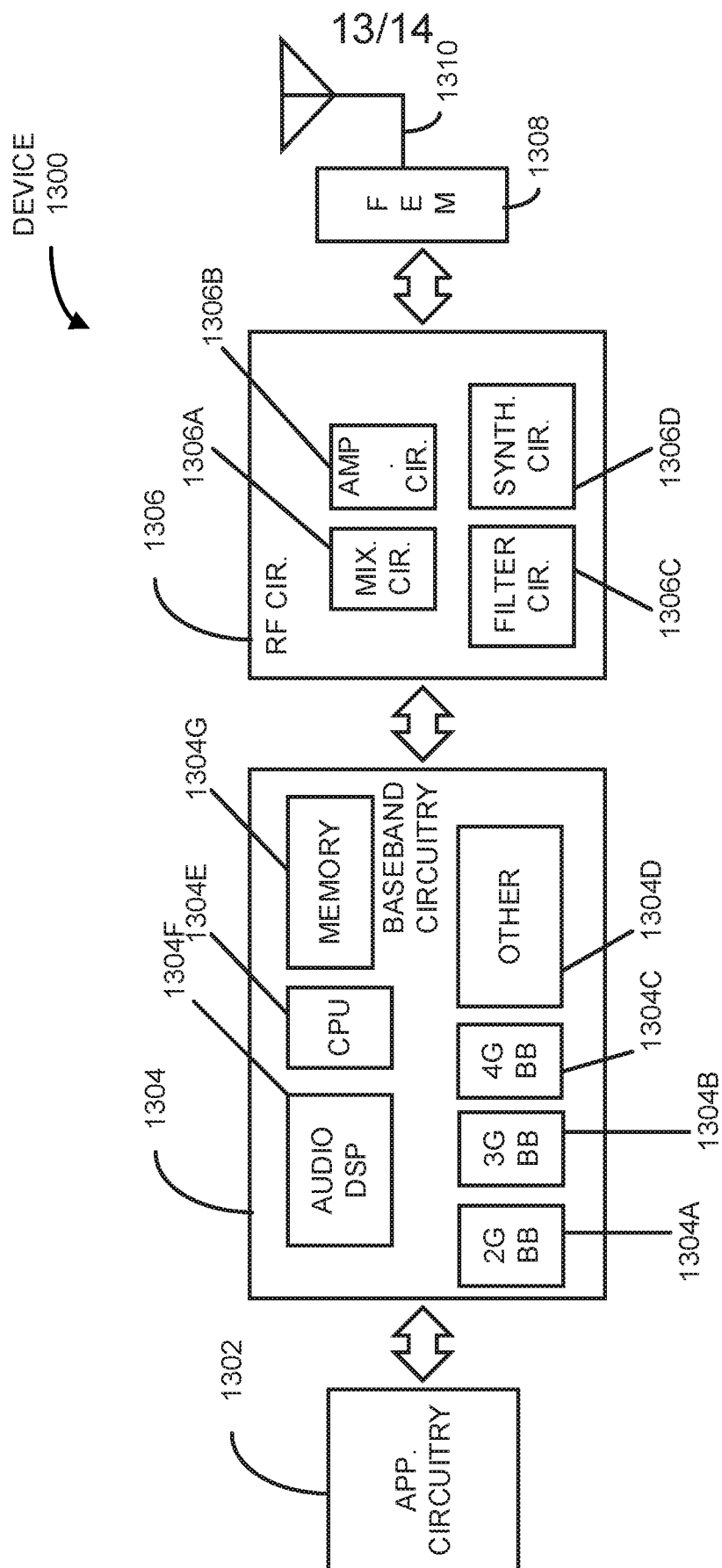


FIG. 13

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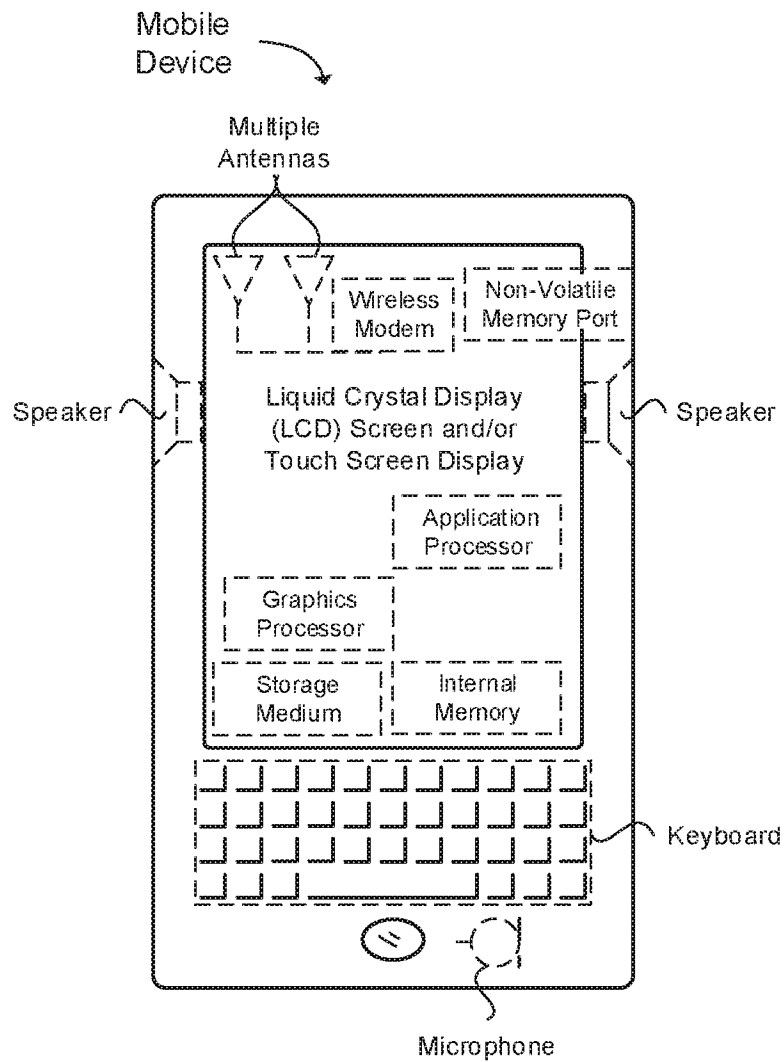


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/045967

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06
ADD. H04L5/00

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)
H04B H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/115376 A1 (NTT DOCOMO INC [JP]) 6 August 2015 (2015-08-06) figures 3,12,25 abstract paragraph [0021] - paragraph [0031] paragraph [0070] - paragraph [0086]	1-15
X,P	-& EP 3 101 942 A1 (NTT DOCOMO INC [JP]) 7 December 2016 (2016-12-07) figures 3,12,25 abstract paragraph [0021] - paragraph [0031] paragraph [0070] - paragraph [0086] -----	1-15



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
"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 October 2017

Date of mailing of the international search report

12/01/2018

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Neeb, Christoph

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/045967

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-15

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/045967

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015115376 A1	06-08-2015	EP 3101942 A1 JP 2015164281 A US 2016345216 A1 WO 2015115376 A1	07-12-2016 10-09-2015 24-11-2016 06-08-2015
EP 3101942 A1	07-12-2016	EP 3101942 A1 JP 2015164281 A US 2016345216 A1 WO 2015115376 A1	07-12-2016 10-09-2015 24-11-2016 06-08-2015

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15

implementing beam refinement training

2. claims: 16-28

implement resource configuration for mobility measurements
