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(54) **Title:** SYNCHRONIZATION SIGNALS FOR MULTIPLE NUMEROLOGIES

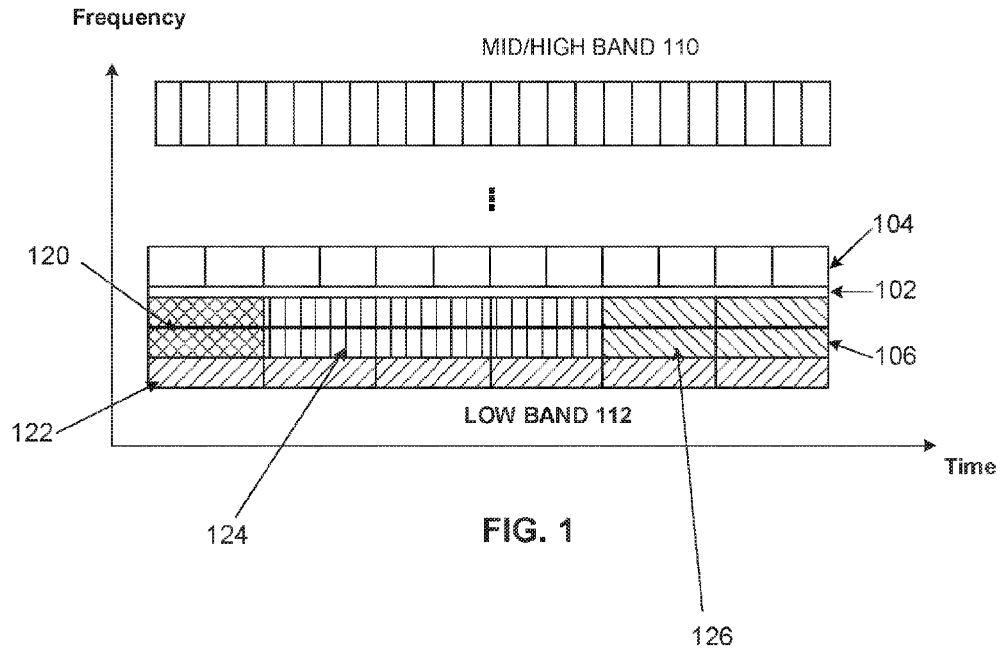

FIG. 1

(57) **Abstract:** Methods, apparatus, and computer-readable media are described to detect a first primary synchronization signal using a first numerology. The primary synchronization signal may use a common numerology to a wireless system. A downlink numerology is determined for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal. Data from the PDCCH is decoded based upon the downlink numerology.

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SYNCHRONIZATION SIGNALS FOR MULTIPLE NUMEROLOGIES

PRIORITY CLAIM

[0001] This application claims priority to United States Provisional Patent Application Serial No. 62/373,149, filed August 10, 2016, entitled "SYNCHRONIZATION SIGNAL AND PHYSICAL BROADCAST CHANNEL DESIGN FOR MULTIPLE NUMEROLOGIES"; United States Provisional Patent Application Serial No. 62/373,833, filed August 11, 2016, entitled "SIGNALING WITH NEW RADIO (NR) SPECTRUM AGGREGATION WITH MULTIPLE NUMEROLOGIES"; and to United States Provisional Patent Application Serial No. 62/379,661, filed August 25, 2106, entitled "SYNCHRONIZATION SIGNAL AND PBCH DESIGN FOR MULTIPLE NUMEROLOGIES," all of which are incorporated herein by reference in their entirety.

FIELD OF THE DISCLOSURE

[0002] Various embodiments generally may relate to the field of wireless communications.

BACKGROUND

[0003] Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. The next generation wireless communication system, fifth generation (5G), will provide access to information and sharing of data anywhere, anytime by various users and applications. 5G is expected to be a unified network/system that is targeted to meet vastly different and sometime conflicting performance dimensions and services. Such diverse multi-dimensional requirements are driven by different services and applications. In general, 5G will evolve based on 3GPP Long-Term Evolution (LTE) Advanced with additional potential technologies to enrich people lives with better, simpler and seamless wireless connectivity solutions. 5G is expected to deliver fast, rich contents and services.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present disclosure is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

[0005] FIG. 1 illustrates a design framework for a new radio (NR) flexible radio access technologies (RAT) according to some embodiments described herein.

[0006] FIG. 2 illustrates the time domain location of a primary synchronization signal (PSS) and a secondary synchronization signal (SSS) transmission for a frequency-division duplexing (FDD) system.

[0007] FIG. 3 illustrates a common synchronization signal for multiple numerologies according to some embodiments described herein.

[0008] FIG. 4 illustrates a common synchronization signal for multiple numerologies where interleaved frequency division multiple access (IFDMA) structure is used according to some embodiments described herein.

[0009] FIG. 5 illustrates a UE synchronization procedure in accordance with various embodiments.

[0010] FIG. 6 illustrates a UE synchronization procedure in accordance with various embodiments.

[0011] FIG. 7 illustrates a cover code for the PSS transmission for the determination of different numerologies for the SSS and PBCH transmission in accordance with various embodiments.

[0012] FIGS. 8A-8C illustrates using different timing gaps between the PSS and the SSS for the determination of different numerologies for the SSS transmission in accordance with various embodiments.

[0013] FIGS. 9A-9B illustrates using different position orders of the PSS and the SSS transmission for the determination of different numerologies in accordance with various embodiments.

[0014] FIGS. 10A-10C illustrates using different frequency gaps between the PSS and the SSS for the determination of different numerologies for the SSS transmission in accordance with various embodiments.

[0015] FIGS. 11A-11C uses a common numerology for both the PSS and the SSS, while timing gaps between the PSS and the SSS may be used to indicate the numerology for the transmission of PBCH in accordance with various embodiments.

[0016] FIG. 12 illustrates a process for spectrum aggregation in accordance with various embodiments.

[0017] FIG. 13 illustrates an architecture of a system 1300 of a network in accordance with some embodiments.

[0018] FIG. 14 illustrates example components of a device 1400 in accordance with some embodiments.

[0019] FIG. 15 illustrates example interfaces of baseband circuitry in accordance with some embodiments

[0020] FIG. 16 is an illustration of a control plane protocol stack in accordance with some embodiments.

[0021] FIG. 17 is an illustration of a user plane protocol stack in accordance with some embodiments.

[0022] The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail.

[0023] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

DESCRIPTION

[0024] The 5G new radio (NR) system is designed to support system operation over a wide range of frequency spectrum allocations, ranging from sub-6GHz up to 100 GHz. It is envisioned that spectrum aggregation instead/or in combination with carrier aggregation may be employed for NR links. In contrast to legacy carrier aggregation where different frequency parts are aggregated as different component carriers, the NR link can potentially be comprised of several non-continuous frequency spectrum parts. As a result, different frequency spectrum components can be directly aggregated into a single NR link, instead of separate full-fledged component carriers. It is also natural that different frequency parts will use band specific physical layer numerologies, e.g., a wider subcarrier spacing is more suitable for the high frequency spectrum parts, whereas a smaller subcarrier spacing used for lower frequency parts.

[0025] In various examples described below, a unified framework is defined by a new radio (NR) flexible radio access technologies (RAT) that provides support for the diverse requirements, applications, services, multiple frequency bands, licensed and unlicensed frequency and multiple partitions that may be used to support various 5G features. FIG. 1 illustrates a design framework for a new radio (NR) flexible radio access technologies (RAT) according to some embodiments described herein. As shown in FIG. 1, multiple partitions or applications in different or same frequency resource or frequency bands can be multiplexed in either time-division multiplexing (TDM), frequency-division multiplexing (FDM), code-division multiplexing (CDM) manner or a combination of the above. Further, different partitions may employ different subcarrier spacings, which can be tailored for different applications and use cases.

[0026] For example, the frequency spectrum may be divided in a mid/high band 110 and a low band 112. The frequency may be broken into various transmission time intervals (TTI). In an example, a band of frequency may support a short TTI partition 104, a normal TTI partition 102, and a long TTI partition 106. The different TTI partitions provide support for various applications/services that have different needs. For example, the short TTI partition 104 may be used to support mission critical machine-type communications (MTC). The long TTI partition 102 allows MTC that need coverage enhancement. The normal TTI partition 106 may be used to support mobile broadband. Applications 120, 122, 124, and 126 may reserve various

TTI. In FIG. 1, the applications 120 and 122 reserve TTIs that are FDM. While Applications 120, 124, and 126 reserve a TTI at the same frequency but TDM.

[0027] When multiple numerologies coexist within the system bandwidth, an evolved NodeB (gNB) or a new radio enhanced node (gNB) may operate the system using a base numerology. In an embodiment, a synchronization signal is shared across multiple frequency/time portions using different numerologies. Given that multiple numerologies may be used for NR system, a UE may not be aware of which subcarrier spacing is applied for a target network when the UE performs an initial access procedure. Various embodiments herein relate to the synchronization signal and physical broadcast channel (PBCH) design for multiple numerologies.

[0028] FIG. 2 illustrates the time domain location of a primary synchronization signal (PSS) and a secondary synchronization signal (SSS) transmission for a frequency-division duplexing (FDD) system. In the legacy LTE specification, downlink synchronization channel includes a Primary Synchronization Signal (PSS) and a Secondary Synchronization Signal (SSS). In particular, the PSS 204 and the SSS 206 are transmitted in the central six physical resource blocks (PRBs), which allow UEs to synchronize to the network without any a priori knowledge of the allocated bandwidth. The PSS and the SSS may include a sequence of length 62 symbols, mapped to the central 62 subcarriers around the DC subcarrier. In the time domain, the PSS and the SSS are transmitted every 5ms, and two SSS transmissions in each radio frame change in a specific manner, thus enabling the UE to establish the position of the 10ms radio frame boundary.

[0029] The PSS may be constructed from a frequency-domain Zadoff-Chu (ZC) sequence of length 63. The SSS sequences may be generated according to maximum length sequences (M-sequences), which can be created by cycling through every possible state of a shift register of length n. Note that the detection of the PSS and the SSS enables time and frequency synchronization, provides the UE with the physical layer identity of the cell and the cyclic prefix length, and informs the UE whether the cell uses Frequency Division Duplex (FDD) or Time Division Duplex (TDD).

[0030] As noted above, when first accessing a system a UE may not be aware of various network/system parameters such as subcarrier spacing. In an example, a common synchronization signal using a predetermined subcarrier spacing may be sent in a new radio access technology (NR) system. In particular, a resource region can be dedicatedly assigned for a synchronization signal and physical broadcast channel (PBCH) that employs a predefined or base numerology (e.g., 15kHz subcarrier spacing).

[0031] In addition, the numerology or subcarrier spacing in which a NR network operates may be indicated via the PSS and/or the SSS, or included implicitly or explicitly in the 5G master information block (xMIB). PSS/SSS and PBCH may use same or different predetermined numerologies. In various examples, a codeword representing the numerology or subcarrier spacing can be masked with cyclic redundancy check (CRC) in the PBCH. Alternatively, the numerology or subcarrier spacing in which the NR network operates may be included in the 5G system information block (xSIB).

[0032] FIG. 3 illustrates a common synchronization signal for multiple numerologies in accordance with one embodiment. Note that the numerology of the synchronization signal and the PBCH region 302 may be independent of other channels and signals 304.

[0033] FIG. 4 illustrates a common synchronization signal for multiple numerologies where interleaved frequency division multiple access (IFDMA) structure is used according to some embodiments described herein. In one embodiment, PSS/SSS/PBCH can be sent within an identical OFDM symbol duration 402 using

different frequency resources. According to the examples in FIG. 4, the synchronization and PBCH can be processed by the UE using receivers configured with 15/30/60 kHz subcarrier spacing numerologies 404, 406, and 408 respectively. The actual numerology used in the system according to the example may be transmitted in PBCH.

[0034] FIG. 5 illustrates a UE synchronization procedure in accordance with various embodiments. According to this scheme, UE may perform initial access assuming the predetermined numerology, which can help to simplify the implementation and complexity at UE receiver. At 510, the UE performs a first step of the initial synchronization using a predetermined numerology. For example, the predetermined numerology may be a numerology supported by all 5G systems. At 520, the UE performs the remaining steps of the synchronization using a predetermined numerology on a predetermined resource. For example, the UE may perform the synchronization using a common synchronization signal on a PBCH. At 530, during the synchronization process, the UE receives information on the numerology used for other channels and signals from synchronization signals and/or a broadcast channel. At 540, using the acquired numerology information the UE starts to receive data from the other channels and signals. The numerology of these channels may be different from the predetermined numerology.

[0035] In another embodiment, a common synchronization signal using a predetermined or base subcarrier spacing may be specified for a NR system according to the absolute carrier frequency. As a further detailed example, the common synchronization signal using a predetermined or base subcarrier spacing may be based per one or more particular frequency bands. This indicates that the synchronization signal or PBCH design may be different for carrier frequencies with different base numerologies and subcarrier spacings.

[0036] In one example, for a NR network operating at below 6GHz carrier frequency, 15kHz or 30kHz subcarrier spacing can be considered as base subcarrier spacing and can be used for synchronization signal, while for NR network operating at above 6GHz carrier frequency, 60kHz subcarrier spacing can be used for synchronization signal.

[0037] In another embodiment, a common numerology may be employed for the PSS transmission while different numerologies may be used for other synchronization signals, e.g., secondary synchronization signal (SSS). Further, PSS and/or SSS may provide numerology or subcarrier spacing information for the transmission of other synchronization signals including the SSS and PBCH.

[0038] FIG. 6 illustrates a UE synchronization procedure in accordance with various embodiments. At 610, the UE performs a first step of the initial synchronization using a predetermined numerology. For example, the predetermined numerology may be a numerology supported by all 5G systems. In addition, the first step may include detecting the PSS. At 620, the UE acquires information on the numerology used for the other synchronization signals and/or a broadcast channel. At 630, the UE completes the synchronization using the acquired information regarding the numerology used for the synchronization signals. As an example, the UE may detect the SSS. At 640, the UE acquires information on the numerology used for other physical channels and signals from the synchronization signals and/or the broadcast channel. At 650, the UE starts to receive data on other channels/signals using the acquired numerology information.

[0039] For initial access, UE may first attempt to detect PSS for timing synchronization using the common numerology or subcarrier spacing. After successful detection of the PSS, UE may directly derive the numerology (including transmission bandwidth, subcarrier spacing, sequence length, cyclic prefix length, etc.) or perform blind detection for other synchronization signals, e.g., the SSS to determine the numerology for the system. Note that transmission bandwidth for the SSS may be explicitly or implicitly derived from PSS. For instance, different root indexes or sequence used for the PSS can be used to indicate the transmission bandwidth of the SSS.

[0040] In one embodiment, different root indexes for the PSS transmission can be used to indicate the numerology or subcarrier spacing used for the transmission of the SSS and PBCH. In one example, for ZadoffChu sequence based PSS design, a first root index can be used to indicate that the PSS and the SSS use the same numerology or subcarrier spacing. A second root index can be used to indicate that the SSS uses a first numerology or subcarrier spacing, which is different from the numerology employed for the PSS transmission. A third root index can be used to indicate that the SSS uses a second numerology or subcarrier spacing, which is different from the numerology employed for the PSS transmission.

[0041] To reduce the detection complexity with one-shot detection, two numerologies may be represented by two different root indices having complex conjugate in either/both time or/and frequency domain. Such complex conjugate property can be also guaranteed by taking two root indices - ul and u2=Nzc-ul where ul is a first root index and u2 is a second root index, and Nzc is the generated sequence length of ZC sequence.

[0042] In another example, different cover codes can be applied for the PSS transmission to indicate the numerology or subcarrier spacing used for the transmission of the SSS and PBCH. FIG. 7 illustrates a cover code for the PSS transmission for the determination of different numerologies for the SSS and PBCH transmission in accordance with various embodiments. In this example, a first PSS 702 is transmitted using a first phase and a second PSS 704 is transmitted using a second phase. A UE may detect the first PSS 702 and the second PSS 704 and determine the phase difference between the two PSSs. The phase difference may indicate the numerologies for the SSS and PBCH transmissions.

[0043] In an example, [a0, ai] = [I, I] may be used to indicate that the PSS and the SSS use the same numerology. In cases where the UE detects around 0 degree, +/- 10 degrees, phase different between two consecutive PSS sequences, the UE may consider that [a0, a1] = [l, l] have been transmitted. [a0, a1] = [l, j] may be used to indicate that the SSS uses a first numerology or subcarrier spacing, which is different from the numerology employed for the PSS transmission. In cases the UE detects around +90 or -90 degree, +/- 10 degrees, phase different between two consecutive PSS sequences, the UE may consider that [a0, a1] = [l, j] have been transmitted. [a0, ai] = [l, -1] may be used to indicate that the SSS uses a second numerology or subcarrier spacing, which is different from the numerology employed for the PSS transmission.

[0044] In cases the UE detects around 180 degree, +/- 10 degrees, phase different between two consecutive PSS sequences, the UE may consider that [a0, a1] = [l, -1] have been transmitted. Other combinations of a0 and a1 are also possible, and the embodiments provided above can be similarly applied. Based on this structure, after successful detection of a PSS, the UE may derive the numerology for the transmission of the SSS and PBCH.

[0045] In another option, a relative time distance between a PSS and a SSS may be used to indicate the numerology for the SSS and PBCH transmission. FIGS. 8A-8C illustrates using different timing gaps between the PSS and the SSS for the determination of different numerologies for the SSS transmission in accordance with various embodiments. FIG. 8A shows an example where the PSS 802 and the SSS 804 are adjacent. This may indicate that the PSS and the SSS use the same numerology. FIG. 8B shows an example where a 1 symbol gap 810 (k = 1 and the gap may be defined using the base numerology for the transmission of the PSS) is applied between the PSS 802 and the SSS 804. This spacing may be used to indicate that the PSS 802 and the SSS 804 use different numerologies and the SSS 804 uses a first subcarrier spacing. In an example, the PSS 802 employs a 15kHz subcarrier spacing while the SSS

804 uses a 30kHz subcarrier spacing. FIG. 8C shows a two symbol gap 812 (k = 2 and the gap may be defined using the base numerology for the transmission of the PSS) between the PSS 802 and the SSS 804. This may indicate that the PSS 802 and the SSS 804 use different numerologies and the SSS uses a second subcarrier spacing. In an example, the PSS 802 employs a 15kHz subcarrier spacing while the SSS 804 uses a 60kHz subcarrier spacing.

[0046] According to this structure, after successful detection of the PSS using a common numerology, the UE may need to try multiple hypothesis to detect the SSS and the corresponding numerology. For example, the UE can try various different frequencies and/or timing to detect the SSS and/or the second synchronization signal after detecting the first synchronization signal.

[0047] FIGS. 9A-9B illustrates using different position orders of the PSS 902 and the SSS 904 transmission for the determination of different numerologies in accordance with various embodiments. As shown in FIG. 9, the position order of the PSS 902 and the SSS 904 transmission in time may be used to indicate the numerology for the SSS 904 and PBCH transmission. For instance, when the PSS 902 position is located before the SSS 904, this may be used to indicate that the PSS 902 and the SSS 904 use the same numerology. While if the PSS 902 position is located after the SSS 904, this may indicate that the PSS 902 and the SSS 904 use different numerologies.

[0048] In another example, a relative frequency distance between the PSS and the SSS can be used to indicate the numerology for the SSS and PBCH transmission. FIGS. 10A-10C illustrates using different frequency gaps between the PSS and the SSS for the determination of different numerologies for the SSS transmission in accordance with various embodiments. As an example, in FIG. 10A the PSS 1002 and the SSS 1004 are adjacent, which may indicate that the PSS 1002 and the SSS 1004 use the same numerology. In FIG. 10B, a Δf_0 frequency gap 1010 is applied between the PSS 1002 and the SSS 1004, which may indicate that the PSS 1002 and the SSS 1004 use different numerologies and the SSS 1004 uses a first subcarrier spacing. In one example, the PSS 1002 employs 15kHz subcarrier spacing while the SSS 1004 uses 30kHz subcarrier spacing.

[0049] In. FIG 10C, a Δf_1 frequency gap 1012 is applied between the PSS 1002 and the SSS 1004, which may indicate that the PSS 1002 and the SSS

1004 use different numerologies and the SSS 1004 uses a second subcarrier spacing. In an example, the PSS 1002 employs 15kHz subcarrier spacing while the SSS 1004 uses 60kHz subcarrier spacing.

[0050] In another example, one or more of the above techniques may be combined to indicate the numerology or subcarrier for the transmission of the SSS and PBCH.

[0051] Similar to the techniques as mentioned above, embodiment of the determination of numerology used for the transmission of PBCH may include any of the following. Different PSS or SSS sequences may be used to carry information for the numerology or sub carrier spacing used for the transmission of the PBCH. A relative time distance or position order between the PSS and the SSS transmission may be used to indicate the numerology or sub carrier spacing used for the transmission of the PBCH. A relative frequency distance or position order between the PSS and the SSS transmission may be used to indicate the numerology or sub carrier spacing used for the transmission of PBCH. A combination of the above techniques may be used to indicate the numerology or sub carrier spacing used for the transmission of PBCH.

[0052] In another example, a common numerology may be employed for the PSS and the SSS transmission while different numerologies may be used for the PBCH. Further, the PSS and/or the SSS may provide numerology or subcarrier spacing information for the transmission of the PBCH. FIGS. 11A-11C uses a common numerology for both the PSS and the SSS, while timing gaps between the PSS and the SSS may be used to indicate the numerology for the transmission of PBCH in accordance with various embodiments.

[0053] FIG. 11A shows an example where the PSS 1102 and the SSS 1104 are adjacent. This may indicate that the PBCH use the same numerology as the PSS 1102 and the SSS 1104. FIG. 11B shows an example where a 1 symbol gap 1110 ($k = 1$ and the gap may be defined using the base numerology for the transmission of the PSS) is applied between the PSS 1102 and the SSS 1104. This spacing may be used to indicate that the PBCH uses a different numerology from the PSS 1102 and the SSS 1104. In an example, the PSS 1102 and the SSS 1104 employ a 15kHz subcarrier spacing while the PBCH uses a 30kHz subcarrier spacing. FIG. 11C shows a two symbol gap 1112 ($k = 2$ and the gap may be defined using the base numerology for the transmission of the PSS) between the PSS 1102 and the SSS 1104. This may indicate that the PSS 1102 and the SSS 1104 use a different numerology from the PBCH. In an example, the PSS 1102 and the SSS 1104 employ a 15kHz subcarrier spacing while the PBCH use a 60kHz subcarrier spacing.

[0054] Various embodiments regarding a NR link including multiple frequency portions using different numerologies, which share a synchronization signal transmitting the identity of the NR carrier are described. From the complexity and energy efficiency point of view, a synchronization signal (SS) as well as the broadcast channel (BCH) carrying the essential system access information may be transmitted in a lower frequency part, so that NR user equipment (UEs) may camp fast on a network and receive more system information so as to further conduct the UE specific connection reconfiguration process. This may lead to a better user experience in terms of the time needed for the initial access to the network. Another benefit for the NR SS and BCH being preferably transmitted in a lower frequency portion is due to the objective that a 5G NR carrier aims to simultaneously support UEs with different device capabilities. For instance, UEs may have different capabilities to access different frequency spectrum portions of the NR link. Upon being connected with the 5G network, the UE may be further configured with UE specific radio resources to exploit those frequency resources accessible to the UE.

[0055] Embodiments described below disclose signaling procedures for the NR UE to attach and communicate with a NR gNB using aggregated spectrum portions, which may use different numerologies. Various embodiments disclose signaling to realize a spectrum portion aggregation in NR systems, where different available spectrum portions are aggregated to serve the UE' s high traffic demands in accordance to the individual UE capability. In an example, the control plane functions, in particular those functions associated with initial access and wide area mobility management, may be accomplished by using the NR frequency resources in a master system bandwidth. The master system bandwidth may be in a low frequency part, preferably in a sub-6 GHz allocation. The data plane traffic, as well as the relevant physical layer control signaling, may be served by the aggregated spectrum portions. The signaling to support spectrum aggregation may be communicated by the master system bandwidth using the same numerology as the SS and BCH of the attached NR link.

[0056] With the spectrum portion aggregation, the NR link may aggregate different spectrum portions, operating with different numerologies, to the same NR link for a UE specific capability. As a result, different UEs with various UE capabilities may have different perceptions of the NR link composition by a variety of spectrum portions and carrier aggregations. In other words, some parts of the NR link composition may be only visible to those UEs having the required HW/SW capability. The low frequency spectrum portions and operation may be sufficient for the control plane capacity requirements. Conducting the NR control plane functions in a master system bandwidth of the located in a low frequency part may significantly reduce the system design complexity, due to the fact that the control plane functions may be more reliably accomplished. In particular, as this can be executed without any special beamforming techniques optimized for high frequency communications. Different available spectrum portions in high frequency bands may be flexibly configured to fit to the UE capabilities, on a demand basis to provide the high data throughput. As such, control and data plane separation, which is deemed as one of appealing 5G NR techniques, may be achieved.

[0057] FIG. 12 illustrates a process for spectrum aggregation in accordance with various embodiments. At step 1210, a UE 1202 does an initial access using a low frequency synchronization signal, broadcast channel, and random access channel. These signals and channels may be provided on a number of NR anchor carriers that are supported by NR eNBs to provide control plane functions including initial access and mobility. The SS and the BCH may be transmitted in the NR anchor carriers. In an example, mobility reference signals such as LTE discovery signals may be transmitted in the NR anchor carriers as well. In an example, the SS and BCH use low frequency, *e.g.*, below 6Ghz, and may use the same numerology, *e.g.*, 15khz subcarrier spacing. In an example, the bandwidth used by the SS and BCH is 5MHz or less. The BCH may only carry system information for the UE 1202 to be able to access and remain on the network. For example, the BCH may include the system frame number, master system bandwidth based on SS numerology.

[0058] At 1220, the UE 1202 performs an initial radio resource control (RRC) connection with the NR eNB 1204. For example, a RACH procedure may be done using the radio resources in the master system bandwidth. At 1230, after the initial RRC connection is established, the UE 1202 signals the UE capability to the NR eNB 1204. For example, the UE 1202 may communicate its RF band capability to the NR eNB 1204. At 1240, based on the UE capability, the NR eNB 1204 may configure a set of discovery signals or CSI-RI to be monitored by the UE 1202. The UE 1202 may also be further requested to provide the measurement results of the configured discovery signals. For example, a reference signal received power (RSRP) measurement may be reported. The discovery signals may be configured to use a particular subcarrier spacing, *e.g.*, numerology, and/or a time-frequency resource elements of configured downlink reference signal (DRS) or channel state information reference signal (CSI-RS).

[0059] At 1250, the UE 1202 reports its measurement results of the configured discovery signals to the NR eNB 1204. The measurement results may include a RSRP and/or a reference signal received quality (RSRQ) result or a CSI-RS. At 1260, the NR eNB 1204 using the received measurement results may aggregate spectrum as the additional radio resources to the NR link to serve the UE data plane. The spectrum aggregation configuration may use UE dedicated RRC signaling. The RRC signaling may include various configuration parameters such as the numerology, RF frequency band(s), bandwidth of aggregated spectrum portions, etc. The configuration may also include control channel configuration for the uplink (UL) and downlink (DL) data scheduling for the aggregated spectrum. The RACH channel configuration for UL timing alignment may also be provided to the UE via the RRC signaling. Beaming form information regarding the aggregated spectrum may also be provided to the UE via the RRC signaling. For example, any of beamforming operation, beam reference signal (BRS) configuration, and beam refinement RS (BRRS) configuration for DL beam refinement may be provided via the RRC signaling. In addition, the BRS configuration may include the number of beams per aggregated spectrum and the beam scanning cycle. The CSI-RS configuration for DL CSI may also be communicated to the UE via the RRC signaling. In addition, the SRS configuration for the UL CSI estimation and beamforming operation in the aggregation spectrum may be provided via the RRC signaling.

[0060] At 1270, the NR eNB may schedule data traffic as well as relevant physical layer control signaling in the aggregated spectrum. At 1280, the UE monitors the updated control channel search space partially located in the aggregated spectrum. According to the information received in the control channel transmitted in the aggregated spectrum, the UE conducts the relevant functions such as data packet reception and associated HARQ acknowledgement or dynamic scheduled CSI-RS/SRS reception/transmission. In an example, the signaling messages sent in 1210-1260 are transmitted in the master system bandwidth of the NR anchor carrier.

[0061] FIG. 13 illustrates an architecture of a system 1300 of a network in accordance with some embodiments. The system 1300 is shown to include a user equipment (UE) 1301 and a UE 1302. The UEs 1301 and 1302 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface.

[0062] In some embodiments, any of the UEs 1301 and 1302 can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[0063] The UEs 1301 and 1302 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 1310 — the RAN 1310 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen

RAN (NG RAN), or some other type of RAN. The UEs 1301 and 1302 utilize connections 1303 and 1304, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 1303 and 1304 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

[0064] In this embodiment, the UEs 1301 and 1302 may further directly exchange communication data via a ProSe interface 1305. The ProSe interface 1305 may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[0065] The UE 1302 is shown to be configured to access an access point (AP) 1306 via connection 1307. The connection 1307 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 1306 would comprise a wireless fidelity (WiFi®) router. In this example, the AP 1306 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[0066] The RAN 1310 can include one or more access nodes that enable the connections 1303 and 1304. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). The RAN 1310 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 1311, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 1312.

[0067] Any of the RAN nodes 1311 and 1312 can terminate the air interface protocol and can be the first point of contact for the UEs 1301 and 1302. In some embodiments, any of the RAN nodes 1311 and 1312 can fulfill various logical functions for the RAN 1310 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[0068] In accordance with some embodiments, the UEs 1301 and 1302 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes 1311 and 1312 over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[0069] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 1311 and 1312 to the UEs 1301 and 1302, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[0070] The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs 1301 and 1302. The physical downlink control channel (PDCCH) may carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 1301 and 1302 about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 102 within a cell) may be performed at any of the RAN nodes 1311 and 1312 based on channel quality information fed back from any of the UEs 1301 and 1302. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1301 and 1302.

[0071] The PDCCH may use control channel elements (CCEs) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as resource element groups (REGs). Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the downlink control information (DCI) and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[0072] Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more enhanced the control channel elements (ECCEs). Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an enhanced resource element groups (EREGs). An ECCE may have other numbers of EREGs in some situations.

[0073] The RAN 1310 is shown to be communicatively coupled to a core network (CN) 1320 —via an S1 interface 1313. In embodiments, the CN 1320 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment the S1 interface 1313 is split into two parts: the S1-U interface 1314, which carries traffic data between the RAN nodes 1311 and 1312 and the serving gateway (S-GW) 1322, and the S1-mobility management entity (MME) interface 1315, which is a signaling interface between the RAN nodes 1311 and 1312 and MMEs 1321.

[0074] In this embodiment, the CN 1320 comprises the MMEs 1321, the S-GW 1322, the Packet Data Network (PDN) Gateway (P-GW) 1323, and a home subscriber server (HSS) 1324. The MMEs 1321 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 1321 may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS 1324 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN 1320 may comprise one or several HSSs 1324, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1324 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[0075] The S-GW 1322 may terminate the S1 interface 1313 towards the RAN 1310, and routes data packets between the RAN 1310 and the CN 1320. In addition, the S-GW 1322 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

[0076] The P-GW 1323 may terminate an SGi interface toward a PDN. The P-GW 1323 may route data packets between the EPC network 1323 and external networks such as a network including the application server 1330 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 1325. Generally, the application server 1330 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW 1323 is shown to be communicatively coupled to an application server 1330 via an IP communications interface 1325. The application server 1330 can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 1301 and 1302 via the CN 1320.

[0077] The P-GW 1323 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 1326 is the policy and charging control element of the CN 1320. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 1326 may be communicatively coupled to the application server 1330 via the P-GW 1323. The application server 1330 may signal the PCRF 1326 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 1326 may provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server 1330.

[0078] FIG. 14 illustrates example components of a device 1400 in accordance with some embodiments. In some embodiments, the device 1400 may include application circuitry 1402, baseband circuitry 1404, Radio Frequency (RF) circuitry 1406, front-end module (FEM) circuitry 1408, one or more antennas 1410, and power management circuitry (PMC) 1412 coupled together at least as shown. The components of the illustrated device 1400 may be included in a UE or a RAN node. In some embodiments, the device 1400 may include less elements (e.g., a RAN node may not utilize application circuitry 1402, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 1400 may include additional elements such as, for example, memory/storage, display, camera, sensor, 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).

[0079] The application circuitry 1402 may include one or more application processors. For example, the application circuitry 1402 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 or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device 1400. In some embodiments, processors of application circuitry 1402 may process IP data packets received from an EPC.

[0080] The baseband circuitry 1404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1404 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 1406 and to generate baseband signals for a transmit signal path of the RF circuitry 1406. Baseband processing circuity 1404 may interface with the application circuitry 1402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1406. For example, in some embodiments, the baseband circuitry 1404 may include a third generation (3G) baseband processor 1404A, a fourth generation (4G) baseband processor 1404B, a fifth generation (5G) baseband processor 1404C, or other baseband processor(s) 1404D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry 1404 (e.g., one or more of baseband processors 1404A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1406. In other embodiments, some or all of the functionality of baseband processors 1404A-D may be included in modules stored in the memory 1404G and executed via a Central Processing Unit (CPU) 1404E. 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 1404 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1404 may include convolution, tail-biting convolution, turbo, Viterbi, 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.

[0081] In some embodiments, the baseband circuitry 1404 may include one or more audio digital signal processor(s) (DSP) 1404F. The audio DSP(s) 1404F may be 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 1404 and the application circuitry 1402 may be implemented together such as, for example, on a system on a chip (SOC).

[0082] In some embodiments, the baseband circuitry 1404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) 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 1404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0083] RF circuitry 1406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1408 and provide baseband signals to the baseband circuitry 1404. RF circuitry 1406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1404 and provide RF output signals to the FEM circuitry 1408 for transmission.

[0084] In some embodiments, the receive signal path of the RF circuitry 1406 may include mixer circuitry 1406A, amplifier circuitry 1406B and filter circuitry 1406C. In some embodiments, the transmit signal path of the RF circuitry 1406 may include filter circuitry 1406C and mixer circuitry 1406A. RF circuitry 1406 may also include synthesizer circuitry 1406D for synthesizing a frequency for use by the mixer circuitry 1406A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1406A of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1408 based on the synthesized frequency provided by synthesizer circuitry 1406D. The amplifier circuitry 1406B may be configured to amplify the down-converted signals and the filter circuitry 1406C 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 1404 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 1406A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0085] In some embodiments, the mixer circuitry 1406A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1406D to generate RF output signals for the FEM circuitry 1408. The baseband signals may be provided by the baseband circuitry 1404 and may be filtered by filter circuitry 1406C.

[0086] In some embodiments, the mixer circuitry 1406A of the receive signal path and the mixer circuitry 1406A of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 1406A of the receive signal path and the mixer circuitry 1406A 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 1406A of the receive signal path and the mixer circuitry 1406A may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1406A of the receive signal path and the mixer circuitry 1406A of the transmit signal path may be configured for super-heterodyne operation.

[0087] 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 1406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1404 may include a digital baseband interface to communicate with the RF circuitry 1406.

[0088] 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.

[0089] In some embodiments, the synthesizer circuitry 1406D 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 1406D may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0090] The synthesizer circuitry 1406D may be configured to synthesize an output frequency for use by the mixer circuitry 1406A of the RF circuitry 1406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1406D may be a fractional N/N+1 synthesizer.

[0091] 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 1404 or the applications processor 1402 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 1402.

[0092] Synthesizer circuitry 1406D of the RF circuitry 1406 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 Nd equal packets of phase, where Nd 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.

[0093] In some embodiments, synthesizer circuitry 1406D 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 1406 may include an IQ/polar converter.

[0094] FEM circuitry 1408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1410, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1406 for further processing. FEM circuitry 1408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1406 for transmission by one or more of the one or more antennas 1410. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1406, solely in the FEM 1408, or in both the RF circuitry 1406 and the FEM 1408.

[0095] In some embodiments, the FEM circuitry 1408 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 an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1406). The transmit signal path of the FEM circuitry 1408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1410).

[0096] In some embodiments, the PMC 1412 may manage power provided to the baseband circuitry 1404. In particular, the PMC 1412 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 1412 may often be included when the device 1400 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 1412 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[0097] While FIG. 14 shows the PMC 1412 coupled only with the baseband circuitry 1404. However, in other embodiments, the PMC 14 12 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 1402, RF circuitry 1406, or FEM 1408.

[0098] In some embodiments, the PMC 1412 may control, or otherwise be part of, various power saving mechanisms of the device 1400. For example, if the device 1400 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 1400 may power down for brief intervals of time and thus save power.

[0099] If there is no data traffic activity for an extended period of time, then the device 1400 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 1400 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 1400 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00100] 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.

[00101] Processors of the application circuitry 1402 and processors of the baseband circuitry 1404 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1404, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1404 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.

[00102] FIG. 15 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry 1404 of FIG. 14 may comprise processors 1404A-1404E and a memory 1404G utilized by said processors. Each of the processors 1404A-1404E may include a memory interface, 1504A-1504E, respectively, to send/receive data to/from the memory 1404G.

[00103] The baseband circuitry 1404 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 1512 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 1404), an application circuitry interface 1514 (e.g., an interface to send/receive data to/from the application circuitry 1402 of FIG. 14), an RF circuitry interface 1516 (e.g., an interface to send/receive data to/from RF circuitry 1406 of FIG. 14), a wireless hardware connectivity interface 1518 (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 1520 (e.g., an interface to send/receive power or control signals to/from the PMC 1412).

[00104] FIG. 16 is an illustration of a control plane protocol stack in accordance with some embodiments. In this embodiment, a control plane 1600 is shown as a communications protocol stack between the UE 1301 (or alternatively, the UE 1302), the RAN node 1311 (or alternatively, the RAN node 1312), and the MME 1321.

[00105] The PHY layer 1601 may transmit or receive information used by the MAC layer 1602 over one or more air interfaces. The PHY layer 1601 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC layer 1605. The PHY layer 1601 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and Multiple Input Multiple Output (MIMO) antenna processing.

[00106] The MAC layer 1602 may perform mapping between logical channels and transport channels, multiplexing of MAC service data units (SDUs) from one or more logical channels onto transport blocks (TB) to be delivered to PHY via transport channels, de-multiplexing MAC SDUs to one or more logical channels from transport blocks (TB) delivered from the PHY via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), and logical channel prioritization.

[00107] The RLC layer 1603 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC layer 1603 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC layer 1603 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[00108] The PDCP layer 1604 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[00109] The main services and functions of the RRC layer 1605 may include broadcast of system information (e.g., included in Master Information Blocks (MIBs) or System Information Blocks (SIBs) related to the non-access stratum (NAS)), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting. Said MIBs and SIBs may comprise one or more information elements (IEs), which may each comprise individual data fields or data structures.

[00110] The UE 1301 and the RAN node 1311 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange control plane data via a protocol stack comprising the PHY layer 1601, the MAC layer 1602, the RLC layer 1603, the PDCP layer 1604, and the RRC layer 1605.

[00111] The non-access stratum (NAS) protocols 1606 form the highest stratum of the control plane between the UE 1301 and the MME 1321. The NAS protocols 1606 support the mobility of the UE 1301 and the session management procedures to establish and maintain IP connectivity between the UE 1301 and the P-GW 1323.

[00112] The S1 Application Protocol (S1-AP) layer 1615 may support the functions of the S1 interface and comprise Elementary Procedures (EPs). An EP is a unit of interaction between the RAN node 1311 and the CN 1320. The S1-AP layer services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[00113] The Stream Control Transmission Protocol (SCTP) layer (alternatively referred to as the SCTP/IP layer) 1614 may ensure reliable delivery of signaling messages between the RAN node 1311 and the MME 1321 based, in part, on the IP protocol, supported by the IP layer 1613. The L2 layer 1612 and the L1 layer 1611 may refer to communication links (e.g., wired or wireless) used by the RAN node and the MME to exchange information.

[00114] The RAN node 1311 and the MME 1321 may utilize an S1-MME interface to exchange control plane data via a protocol stack comprising the L1 layer 1611, the L2 layer 1612, the IP layer 1613, the SCTP layer 1614, and the S1-AP layer 1615.

[00115] FIG. 17 is an illustration of a user plane protocol stack in accordance with some embodiments. In this embodiment, a user plane 1700 is shown as a communications protocol stack between the UE 1301 (or alternatively, the UE 1302), the RAN node 1311 (or alternatively, the RAN node 1312), the S-GW 1322, and the P-GW 1323. The user plane 1700 may utilize at least some of the same protocol layers as the control plane 1600. For example, the UE 1301 and the RAN node 1311 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange user plane data via a protocol stack comprising the PHY layer 1601, the MAC layer 1602, the RLC layer 1603, the PDCP layer 1604.

[00116] The General Packet Radio Service (GPRS) Tunneling Protocol for the user plane (GTP-U) layer 1704 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP and IP security (UDP/IP) layer 1703 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 1311 and the S-GW 1322 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising the L1 layer 1611, the L2 layer 1612, the UDP/IP layer 1703, and the GTP-U layer 1704. The S-GW 1322 and the P-GW 1323 may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising the L1 layer 1611, the L2 layer 1612, the UDP/IP layer 1703, and the GTP-U layer 1704. As discussed above with respect to FIG. 16, NAS protocols support the mobility of the UE 1301 and the session management procedures to establish and maintain IP connectivity between the UE 1301 and the P-GW 1323.

[00117] Additional notes and examples:

[00118] Example 1 is an apparatus for a user equipment (UE), the apparatus comprising: memory; and processing circuitry configured to: detect a first primary synchronization signal using a first numerology; determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and decode data from the PDCCH based upon the downlink numerology.

[00119] In Example 2, the subject matter of Example 1 includes, the processing circuitry further configured to detect a secondary synchronization signal.

[00120] In Example 3, the subject matter of Example 2 includes, the processing circuitry further configured to determine a second numerology of the secondary synchronization signal based upon the first primary synchronization signal.

[00121] In Example 4, the subject matter of Example 3 includes, wherein the processing circuitry is further configured to decode radio resource control (RRC) signaling, the RRC signaling comprising information used to determine the downlink numerology.

[00122] In Example 5, the subject matter of Examples 3–4 includes, the processing circuitry further configured to detect a second primary synchronization signal, the first primary synchronization signal having a first phase, the second primary synchronization signal having a second phase, the second numerology based on a comparison of the first phase and the second phase.

[00123] In Example 6, the subject matter of Example 5 includes, the processing circuitry further configured to determine a numerology of a broadcast channel based upon a comparison of the first phase and the second phase.

[00124] In Example 7, the subject matter of Examples 3–6 includes, the processing circuitry further configured to: attempt to detect the secondary synchronization signal using the first numerology at a first time; and detect the secondary synchronization signal using the second numerology at a second time later than the first time, the first numerology different than the second numerology.

[00125] In Example 8, the subject matter of Example 7 includes, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the second time.

[00126] In Example 9, the subject matter of Examples 3–8 includes, the secondary synchronization signal detected before the primary synchronization signal, the second numerology based on an order of detection of the primary synchronization signal and the secondary synchronization signal.

[00127] In Example 10, the subject matter of Example 9 includes, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the order of detection of the primary synchronization signal and the secondary synchronization signal.

[00128] In Example 11, the subject matter of Examples 3–10 includes, the processing circuitry configured to determine a frequency gap between the primary synchronization signal and the secondary synchronization signal, the second numerology based upon the frequency gap.

[00129] In Example 12, the subject matter of Examples 9–11 includes, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the frequency gap.

[00130] In Example 13, the subject matter of Examples 1–12 includes, the primary synchronization signal using a common numerology to a wireless system.

[00131] Example 14 is a non-transitory computer-readable medium comprising instructions to cause a user equipment (UE), upon execution of the instructions by processing circuitry of the UE, to: detect a first primary synchronization signal using a first numerology; determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and decode data from the PDCCH based upon the downlink numerology.

[00132] In Example 15, the subject matter of Example 14 includes, the instructions further cause the processing circuitry to detect a secondary synchronization signal.

[00133] In Example 16, the subject matter of Example 15 includes, the instructions further cause the processing circuitry to determine a second numerology of the secondary synchronization signal based upon the first primary synchronization signal.

[00134] In Example 17, the subject matter of Example 16 includes, the instructions further cause the processing circuitry to decode radio resource control (RRC) signaling, the RRC signaling comprising information used to determine the downlink numerology.

[00135] In Example 18, the subject matter of Examples 16–17 includes, the instructions further cause the processing circuitry to detect a second primary synchronization signal, the first primary synchronization signal having a first phase, the second primary synchronization signal having a second phase, the second numerology based on a comparison of the first phase and the second phase.

[00136] In Example 19, the subject matter of Example 18 includes, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon a comparison of the first phase and the second phase.

[00137] In Example 20, the subject matter of Examples 16–19 includes, the instructions further cause the processing circuitry to: attempt to detect the secondary synchronization signal using the first numerology at a first time; and detect the secondary synchronization signal using the second numerology at a second time later than the first time, the first numerology different than the second numerology.

[00138] In Example 21, the subject matter of Example 20 includes, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon the second time.

[00139] In Example 22, the subject matter of Examples 16–21 includes, the secondary synchronization signal detected before the primary synchronization signal, the second numerology based on an order of detection of the primary synchronization signal and the secondary synchronization signal.

[00140] In Example 23, the subject matter of Example 22 includes, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon the order of detection of the primary synchronization signal and the secondary synchronization signal.

[00141] In Example 24, the subject matter of Examples 16–23 includes, the instructions further cause the processing circuitry to determine a frequency gap between the primary synchronization signal and the secondary synchronization signal, the second numerology based upon the frequency gap.

[00142] In Example 25, the subject matter of Examples 22–24 includes, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon the frequency gap.

[00143] In Example 26, the subject matter of Examples 14–25 includes, the primary synchronization signal using a common numerology to a wireless system.

[00144] Example 27 is an apparatus comprising means for performing any of the operations of Examples 14-26.

[00145] Example 28 is an apparatus for an evolved node, the apparatus comprising: memory; and processing circuitry configured to: encode a first primary synchronization signal using a first numerology; encode a secondary synchronization signal using a second numerology; determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and encode data from the PDCCH based upon the downlink numerology.

[00146] In Example 29, the subject matter of Example 28 includes, wherein the processing circuitry is further configured to encode radio resource control (RRC) signaling, the RRC signaling comprising information used to encode information indicating the downlink numerology.

[00147] In Example 30, the subject matter of Examples 28–29 includes, a transceiver.

[00148] In Example 31, the subject matter of Example 30 includes, the processing circuitry further configured to encode a second primary synchronization signal using a second phase, the first primary synchronization signal encoded using a first phase, a comparison of the first phase and the second phase indicating the second numerology.

[00149] In Example 32, the subject matter of Example 31 includes, the processing circuitry further configured to encode data for transmission on a broadcast channel using a numerology indicated by a comparison of the first phase and the second phase.

[00150] In Example 33, the subject matter of Examples 30–32 includes, the primary synchronization signal to be transmitted at a first time, the secondary synchronization signal to be transmitted at a second time, a difference between the first time and the second time indicating the second numerology.

[00151] In Example 34, the subject matter of Example 33 includes, the processing circuitry further configured to encode data for transmission on a broadcast channel using a numerology indicated by the difference between the first time and the second time.

[00152] In Example 35, the subject matter of Examples 30–34 includes, the secondary synchronization signal to be transmitted before a corresponding primary synchronization signal, the second numerology indicated by an order of transmission of the primary synchronization signal and the secondary synchronization signal.

[00153] In Example 36, the subject matter of Example 35 includes, the processing circuitry further configured to encode data for transmission on a broadcast channel using a numerology indicated by the order of transmission of the primary synchronization signal and the secondary synchronization signal.

[00154] In Example 37, the subject matter of Examples 30–36 includes, the processing circuitry configured to introduce a frequency gap between the primary synchronization signal and the secondary synchronization signal, the second numerology indicated by the frequency gap.

[00155] In Example 38, the subject matter of Example 37 includes, the processing circuitry further configured to encode data for transmission on a broadcast channel using a numerology indicated by the frequency gap.

[00156] In Example 39, the subject matter of Examples 30–38 includes, the primary synchronization signal using a common numerology to a wireless system.

[00157] Example 40 is a non-transitory computer-readable medium comprising instructions to cause an evolved node, upon execution of the instructions by processing circuitry of the for an evolved node, to: encode a first primary synchronization signal using a first numerology; encode a secondary synchronization signal using a second numerology; determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and encode data from the PDCCH based upon the downlink numerology.

[00158] In Example 41, the subject matter of Example 40 includes, the instructions further cause the processing circuitry to encode radio resource control (RRC) signaling, the RRC signaling comprising information used to encode information indicating the downlink numerology.

[00159] In Example 42, the subject matter of Examples 40–41 includes, a transceiver.

[00160] In Example 43, the subject matter of Example 42 includes, the instructions further cause the processing circuitry to encode a second primary synchronization signal using a second phase, the first primary synchronization signal encoded using a first phase, a comparison of the first phase and the second phase indicating the second numerology.

[00161] In Example 44, the subject matter of Example 43 includes, the instructions further cause the processing circuitry to encode data for transmission on a broadcast channel using a numerology indicated by a comparison of the first phase and the second phase.

[00162] In Example 45, the subject matter of Examples 42–44 includes, the primary synchronization signal to be transmitted at a first time, the secondary synchronization signal to be transmitted at a second time, a difference between the first time and the second time indicating the second numerology.

[00163] In Example 46, the subject matter of Example 45 includes, the instructions further cause the processing circuitry to encode data for transmission on a broadcast channel using a numerology indicated by the difference between the first time and the second time.

[00164] In Example 47, the subject matter of Examples 42–46 includes, the secondary synchronization signal to be transmitted before a corresponding primary synchronization signal, the second numerology indicated by an order of transmission of the primary synchronization signal and the secondary synchronization signal.

[00165] In Example 48, the subject matter of Example 47 includes, the instructions further cause the processing circuitry to encode data for transmission on a broadcast channel using a numerology indicated by the order of transmission of the primary synchronization signal and the secondary synchronization signal.

[00166] In Example 49, the subject matter of Examples 42–48 includes, the processing circuitry configured to introduce a frequency gap between the primary synchronization signal and the secondary synchronization signal, the second numerology indicated by the frequency gap.

[00167] In Example 50, the subject matter of Example 49 includes, the instructions further cause the processing circuitry to encode data for transmission on a broadcast channel using a numerology indicated by the frequency gap.

[00168] In Example 51, the subject matter of Examples 42–50 includes, the primary synchronization signal using a common numerology to a wireless system.

[00169] Example 52 is an apparatus comprising means for performing any of the operations of Examples 40-51.

[00170] Example 53 is at least one machine-readable medium including instructions that, when executed by processing circuitry, cause the processing circuitry to perform operations to implement of any of Examples 1–52.

[00171] Example 54 is an apparatus comprising means to implement of any of Examples 1–52.

[00172] Example 55 is a system to implement of any of Examples 1–52.

[00173] Example 56 is a method to implement of any of Examples 1–52.

[00174] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as "examples." Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described. Moreover, also contemplate are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[00175] Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) are supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[00176] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to suggest a numerical order for their objects.

[00177] The embodiments as described above may be implemented in various hardware configurations that may include a processor for executing instructions that perform the techniques described. Such instructions may be contained in a

machine-readable medium such as a suitable storage medium or a memory or other processor-executable medium.

[00178] The embodiments as described herein may be implemented in a number of environments such as part of a wireless local area network (WLAN), 3rd Generation Partnership Project (3GPP) Universal Terrestrial Radio Access Network (UTRAN), or Long-Term-Evolution (LTE) or a Long-Term-Evolution (LTE) communication system, although the scope of the disclosure is not limited in this respect. An example LTE system includes a number of mobile stations, defined by the LTE specification as User Equipment (UE), communicating with a base station, defined by the LTE specifications as an gNB.

[00179] Antennas referred to herein may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, antennas may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result between each of antennas and the antennas of a transmitting station. In some MIMO embodiments, antennas may be separated by up to 1/10 of a wavelength or more.

[00180] In some embodiments, a receiver as described herein may be configured to receive signals in accordance with specific communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11 standards and/or proposed specifications for WLANs, although the scope of the disclosure is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some embodiments, the receiver may be configured to receive signals in accordance with the IEEE 802.16-2004, the IEEE 802.16(e) and/or IEEE 802.16(m) standards for wireless metropolitan area networks (WMANs) including variations and evolutions thereof, although the scope of the disclosure is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some embodiments, the receiver may be configured to receive signals in accordance with the Universal Terrestrial Radio Access Network (UTRAN) LTE communication standards. For more information with respect to the IEEE 802.11 and IEEE 802.16 standards, please refer to "IEEE Standards for Information Technology -- Telecommunications and Information Exchange between Systems" - Local Area Networks - Specific Requirements – Part 11 "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY), ISO/IEC 8802-11: 1999", and Metropolitan Area Networks - Specific Requirements – Part 16: "Air Interface for Fixed Broadband Wireless Access Systems," May 2005 and related amendments/versions. For more information with respect to UTRAN LTE standards, see the 3rd Generation Partnership Project (3GPP) standards for UTRAN-LTE, including variations and evolutions thereof.

[00181] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with others. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth every feature disclosed herein as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

1. An apparatus for a user equipment (UE), the apparatus comprising:

memory; and

processing circuitry configured to:

detect a first primary synchronization signal using a first numerology;

determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and

decode data from the PDCCH based upon the downlink numerology.

2. The apparatus of claim 1, the processing circuitry further configured to detect a secondary synchronization signal.

3. The apparatus of claim 2, the processing circuitry further configured to determine a second numerology of the secondary synchronization signal based upon the first primary synchronization signal.

4. The apparatus of claim 3, wherein the processing circuitry is further configured to decode radio resource control (RRC) signaling, the RRC signaling comprising information used to determine the downlink numerology.

5. The apparatus of claim 3, the processing circuitry further configured to detect a second primary synchronization signal, the first primary synchronization signal having a first phase, the second primary synchronization signal having a second phase, the second numerology based on a comparison of the first phase and the second phase.

6. The apparatus of claim 5, the processing circuitry further configured to determine a numerology of a broadcast channel based upon a comparison of the first phase and the second phase.

7. The apparatus of claim 3, the processing circuitry further configured to:

attempt to detect the secondary synchronization signal using the first numerology at a first time; and

detect the secondary synchronization signal using the second numerology at a second time later than the first time, the first numerology different than the second numerology.

8. The apparatus of claim 7, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the second time.

9. The apparatus of claim 3, the secondary synchronization signal detected before the primary synchronization signal, the second numerology based on an order of detection of the primary synchronization signal and the secondary synchronization signal.

10. The apparatus of claim 9, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the order of detection of the primary synchronization signal and the secondary synchronization signal.

11. The apparatus of claim 3, the processing circuitry configured to determine a frequency gap between the primary synchronization signal and the secondary synchronization signal, the second numerology based upon the frequency gap.

12. The apparatus of claim 9, the processing circuitry further configured to determine a numerology of a broadcast channel based upon the frequency gap.

13. The apparatus of any of claims 1-12, the primary synchronization signal using a common numerology to a wireless system.

14. A non-transitory computer-readable medium comprising instructions to cause a user equipment (UE), upon execution of the instructions by processing circuitry of the UE, to:

detect a first primary synchronization signal using a first numerology;

determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and

decode data from the PDCCH based upon the downlink numerology.

15. The non-transitory computer-readable medium of claim 14, the instructions further cause the processing circuitry to detect a secondary synchronization signal.

16. The non-transitory computer-readable medium of claim 15, the instructions further cause the processing circuitry to determine a second numerology of the secondary synchronization signal based upon the first primary synchronization signal.

17. The non-transitory computer-readable medium of claim 16, the instructions further cause the processing circuitry to decode radio resource control (RRC) signaling, the RRC signaling comprising information used to determine the downlink numerology.

18. The non-transitory computer-readable medium of claim 16, the instructions further cause the processing circuitry to detect a second primary synchronization signal, the first primary synchronization signal having a first phase, the second primary synchronization signal having a second phase, the second numerology based on a comparison of the first phase and the second phase.

19. The non-transitory computer-readable medium of claim 18, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon a comparison of the first phase and the second phase.

20. The non-transitory computer-readable medium of claim 16, the instructions further cause the processing circuitry to:

attempt to detect the secondary synchronization signal using the first numerology at a first time; and

detect the secondary synchronization signal using the second numerology at a second time later than the first time, the first numerology different than the second numerology.

21. The non-transitory computer-readable medium of claim 20, the instructions further cause the processing circuitry to determine a numerology of a broadcast channel based upon the second time.

22. An apparatus for an evolved node, the apparatus comprising:

memory; and

processing circuitry configured to:

encode a first primary synchronization signal using a first numerology;

encode a secondary synchronization signal using a second numerology;

determine a downlink numerology for a physical downlink control channel (PDCCH) based in part upon the first primary synchronization signal; and

encode data from the PDCCH based upon the downlink numerology.

23. The apparatus of claim 22, wherein the processing circuitry is further configured to encode radio resource control (RRC) signaling, the RRC signaling comprising information used to encode information indicating the downlink numerology.

24. The apparatus of any of claims 22-23, further comprising a transceiver.

25. The apparatus of claim 24, the processing circuitry further configured to encode a second primary synchronization signal using a second phase, the first primary synchronization signal encoded using a first phase, a comparison of the first phase and the second phase indicating the second numerology.

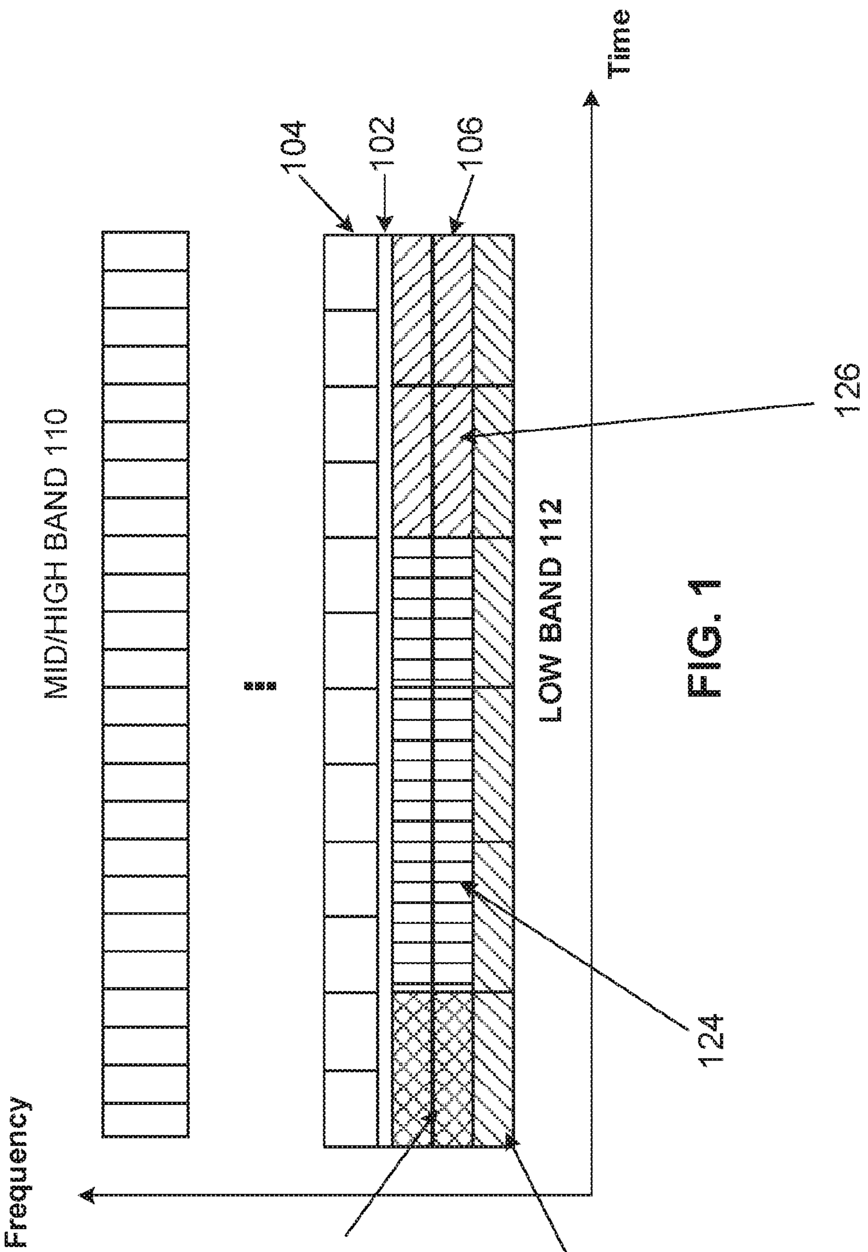

Time
104
102
106
MID/HIGH BAND 110
LOW BAND 112
126
124
Frequency
120
122

FIG. 1

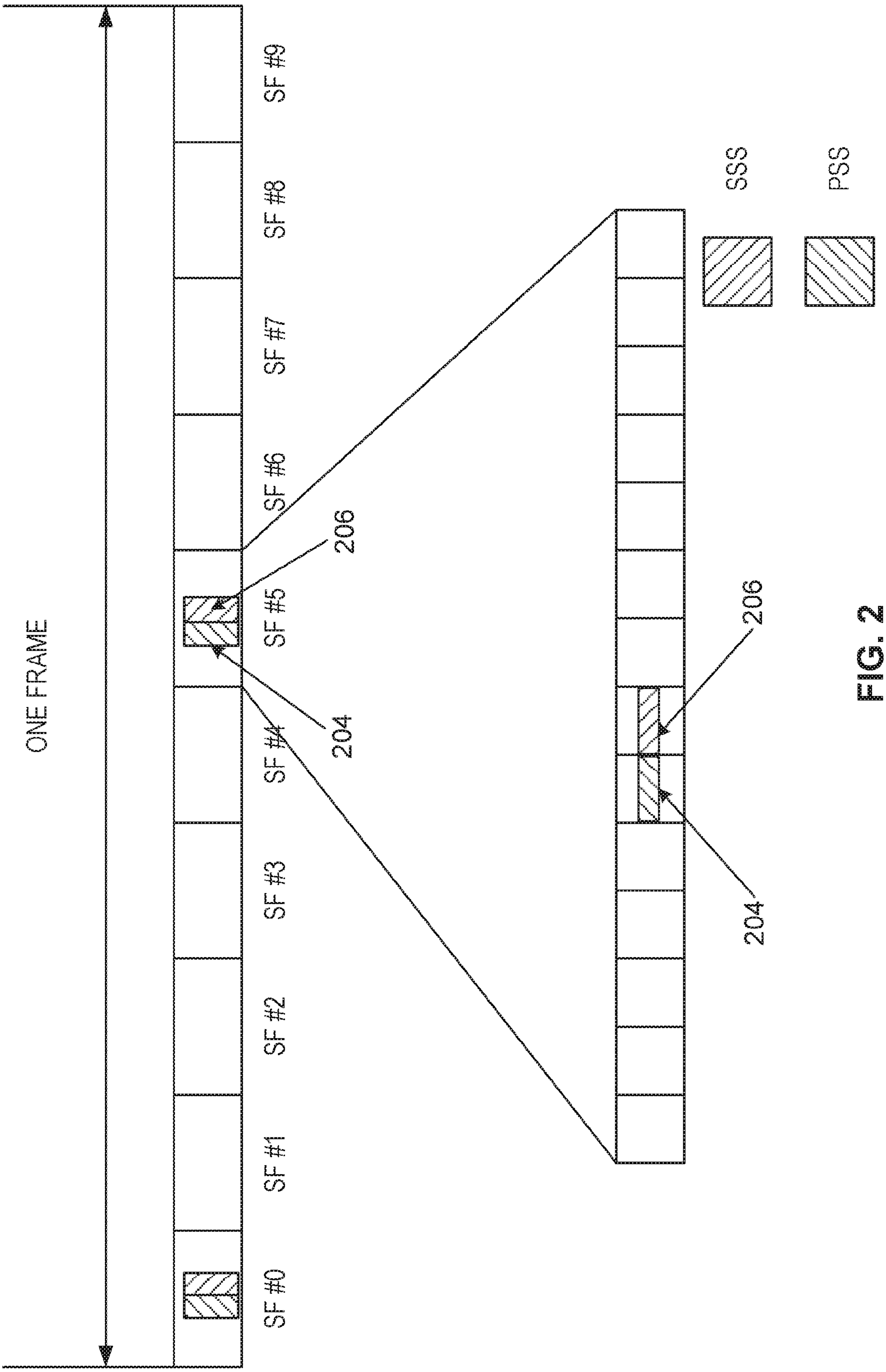

ONE FRAME
SF #0
SF #1
SF #2
SF #3
SF #4
SF #5
SF #6
SF #7
SF #8
SF #9
206
204
206
204
SSS
PSS

FIG. 2

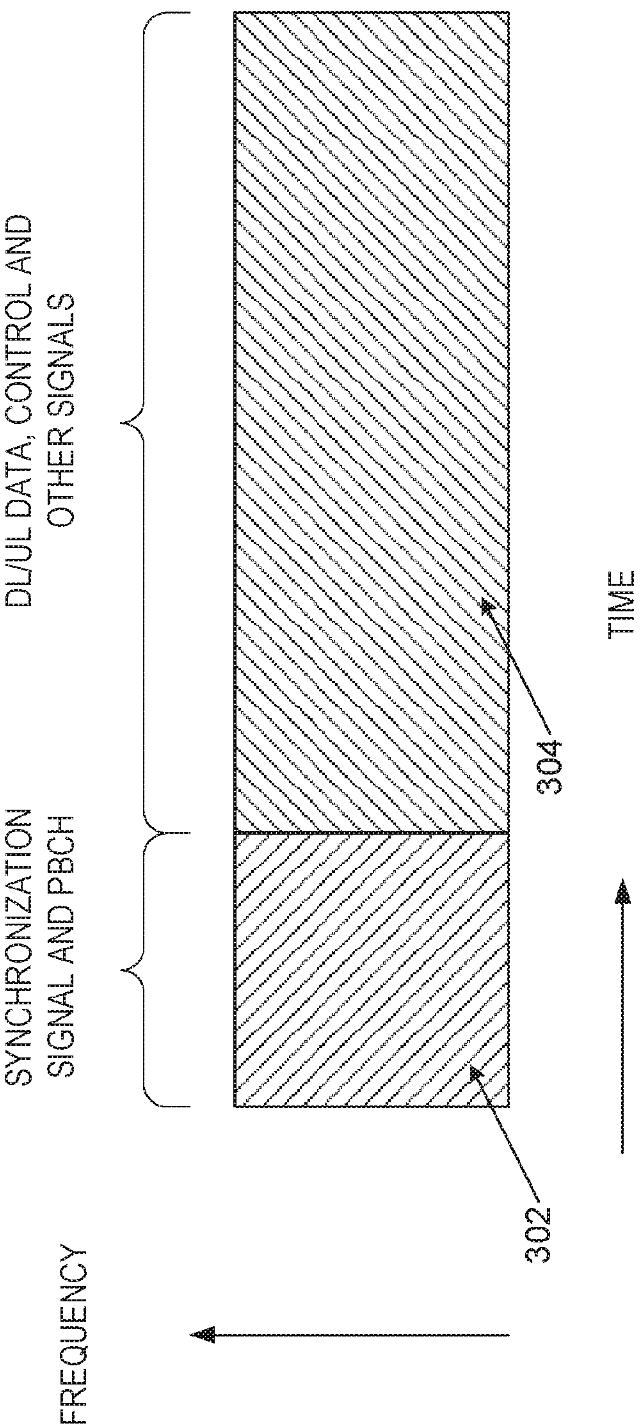

DL/UL DATA, CONTROL AND
OTHER SIGNALS
SYNCHRONIZATION
SIGNAL AND PBCH
TIME
304
302
FREQUENCY

FIG. 3

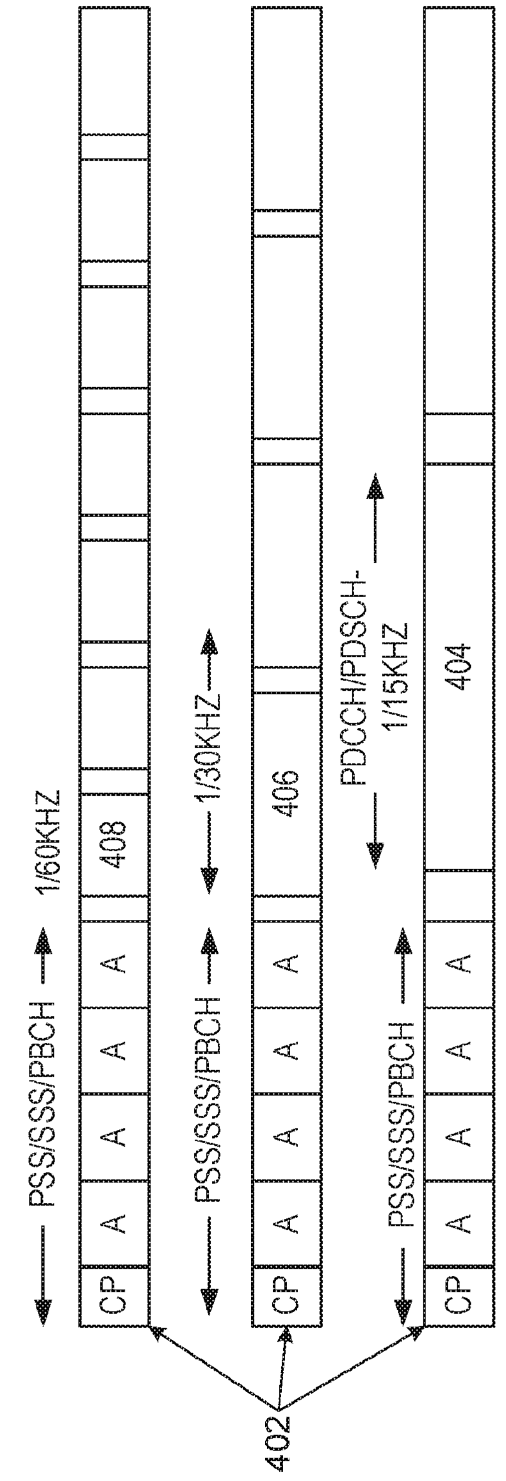

PSS/SSS/PBCH
1/60KHZ
408
PSS/SSS/PBCH
1/30KHZ
406
PSS/SSS/PBCH
PDCCH/PDSCH-
1/15KHZ
404
CP
A
402

FIG. 4

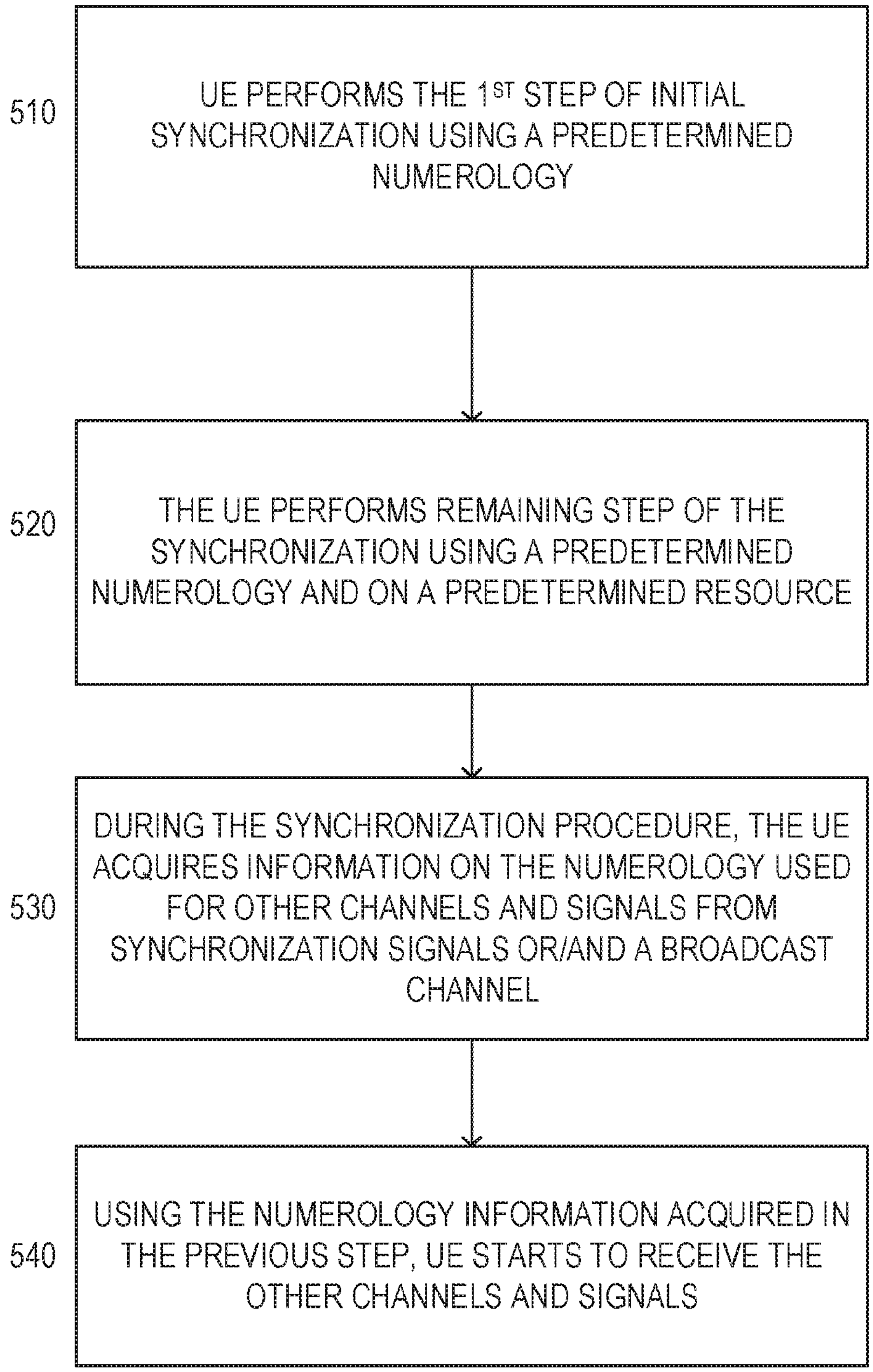

510
UE PERFORMS THE 1ST STEP OF INITIAL SYNCHRONIZATION USING A PREDETERMINED NUMEROLOGY
520
THE UE PERFORMS REMAINING STEP OF THE SYNCHRONIZATION USING A PREDETERMINED NUMEROLOGY AND ON A PREDETERMINED RESOURCE
530
DURING THE SYNCHRONIZATION PROCEDURE, THE UE ACQUIRES INFORMATION ON THE NUMEROLOGY USED FOR OTHER CHANNELS AND SIGNALS FROM SYNCHRONIZATION SIGNALS OR/AND A BROADCAST CHANNEL
540
USING THE NUMEROLOGY INFORMATION ACQUIRED IN THE PREVIOUS STEP, UE STARTS TO RECEIVE THE OTHER CHANNELS AND SIGNALS

FIG. 5

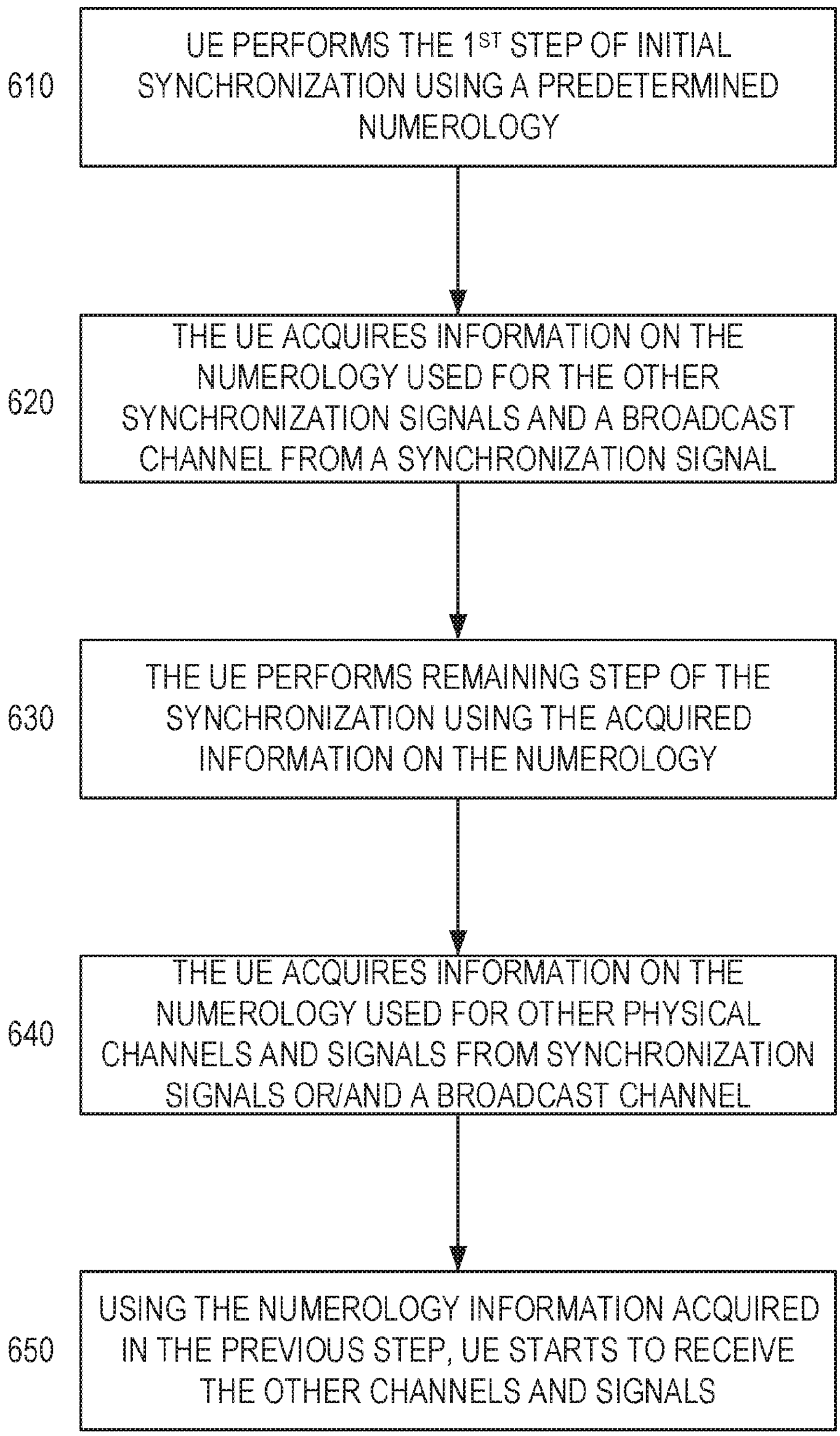
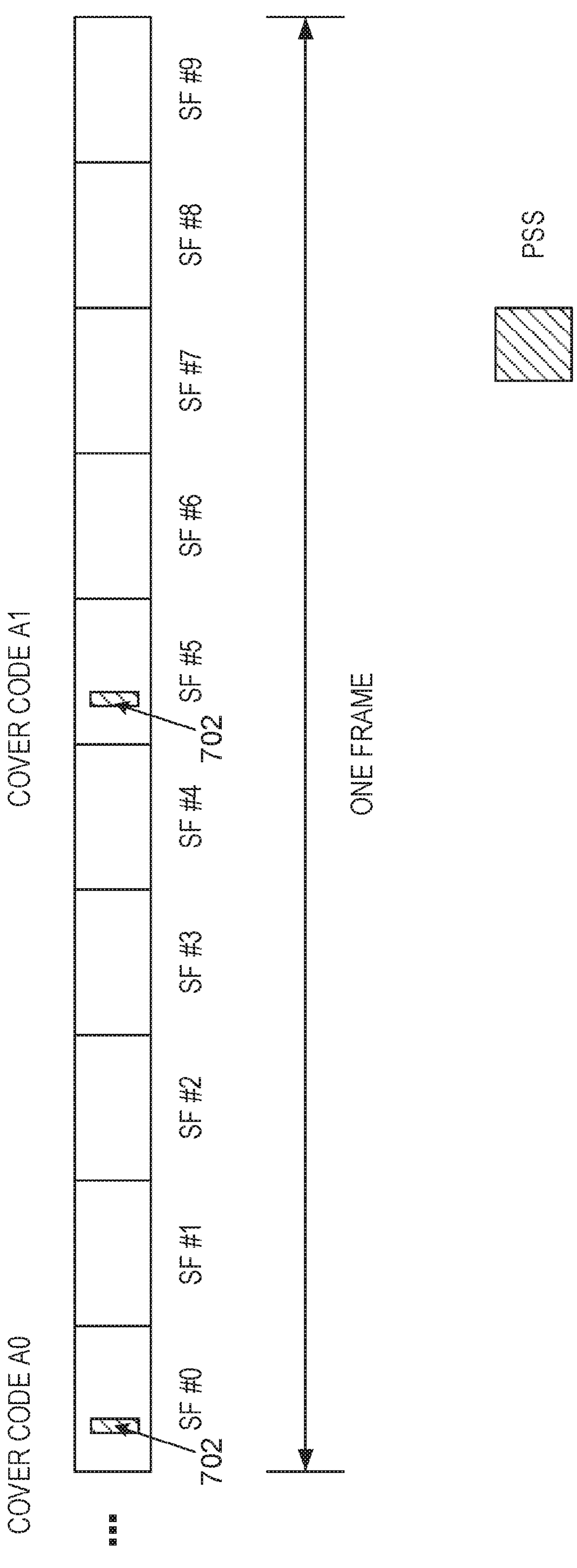

610
UE PERFORMS THE 1ST STEP OF INITIAL SYNCHRONIZATION USING A PREDETERMINED NUMEROLOGY
620
THE UE ACQUIRES INFORMATION ON THE NUMEROLOGY USED FOR THE OTHER SYNCHRONIZATION SIGNALS AND A BROADCAST CHANNEL FROM A SYNCHRONIZATION SIGNAL
630
THE UE PERFORMS REMAINING STEP OF THE SYNCHRONIZATION USING THE ACQUIRED INFORMATION ON THE NUMEROLOGY
640
THE UE ACQUIRES INFORMATION ON THE NUMEROLOGY USED FOR OTHER PHYSICAL CHANNELS AND SIGNALS FROM SYNCHRONIZATION SIGNALS OR/AND A BROADCAST CHANNEL
650
USING THE NUMEROLOGY INFORMATION ACQUIRED IN THE PREVIOUS STEP, UE STARTS TO RECEIVE THE OTHER CHANNELS AND SIGNALS

FIG. 6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COVER CODE A1
SF #0
SF #1
SF #2
SF #3
SF #4
SF #5
SF #6
SF #7
SF #8
SF #9
702
702
ONE FRAME
PSS

FIG. 7

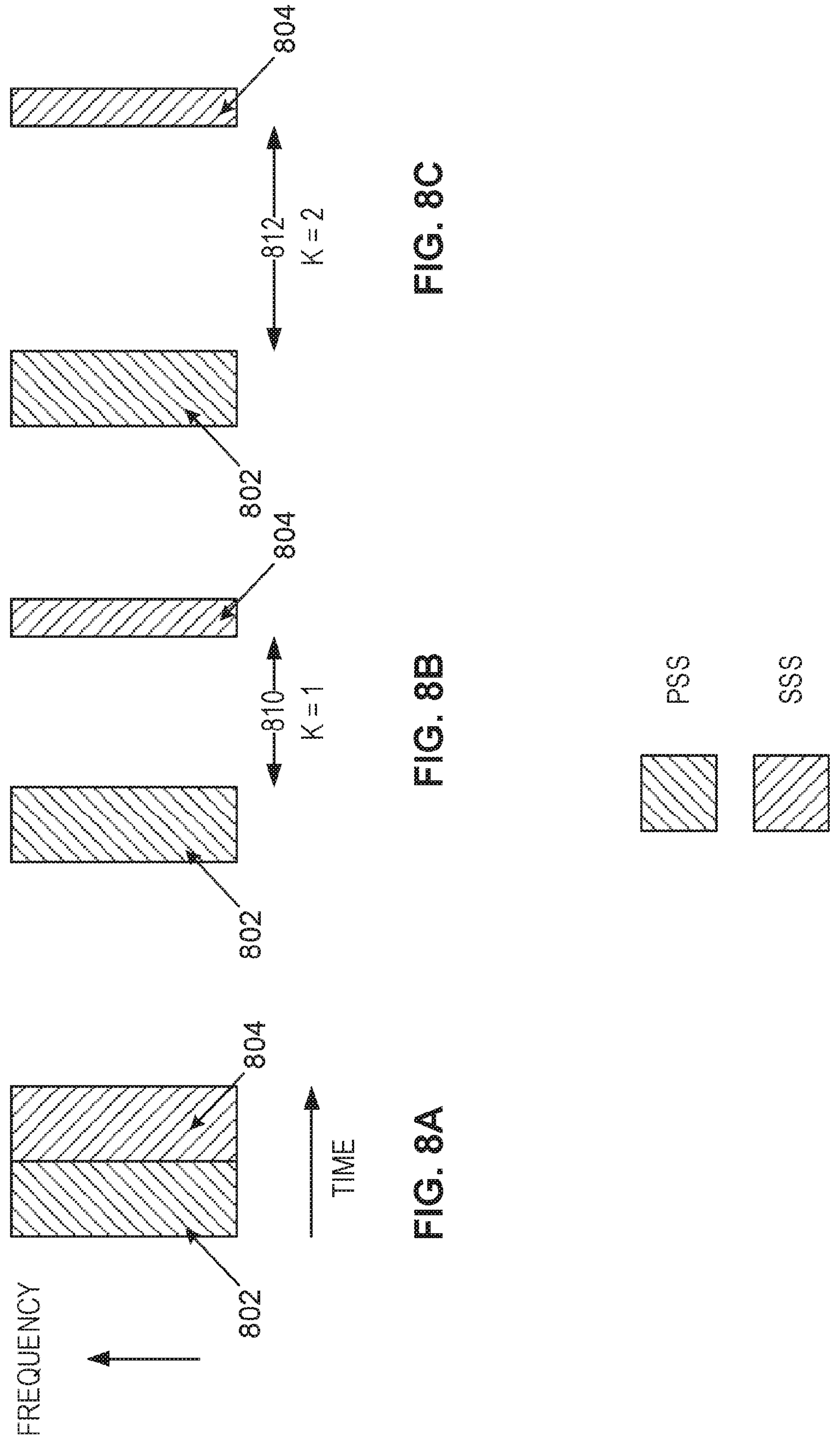


FIG. 8C

FIG. 8B

FIG. 8A

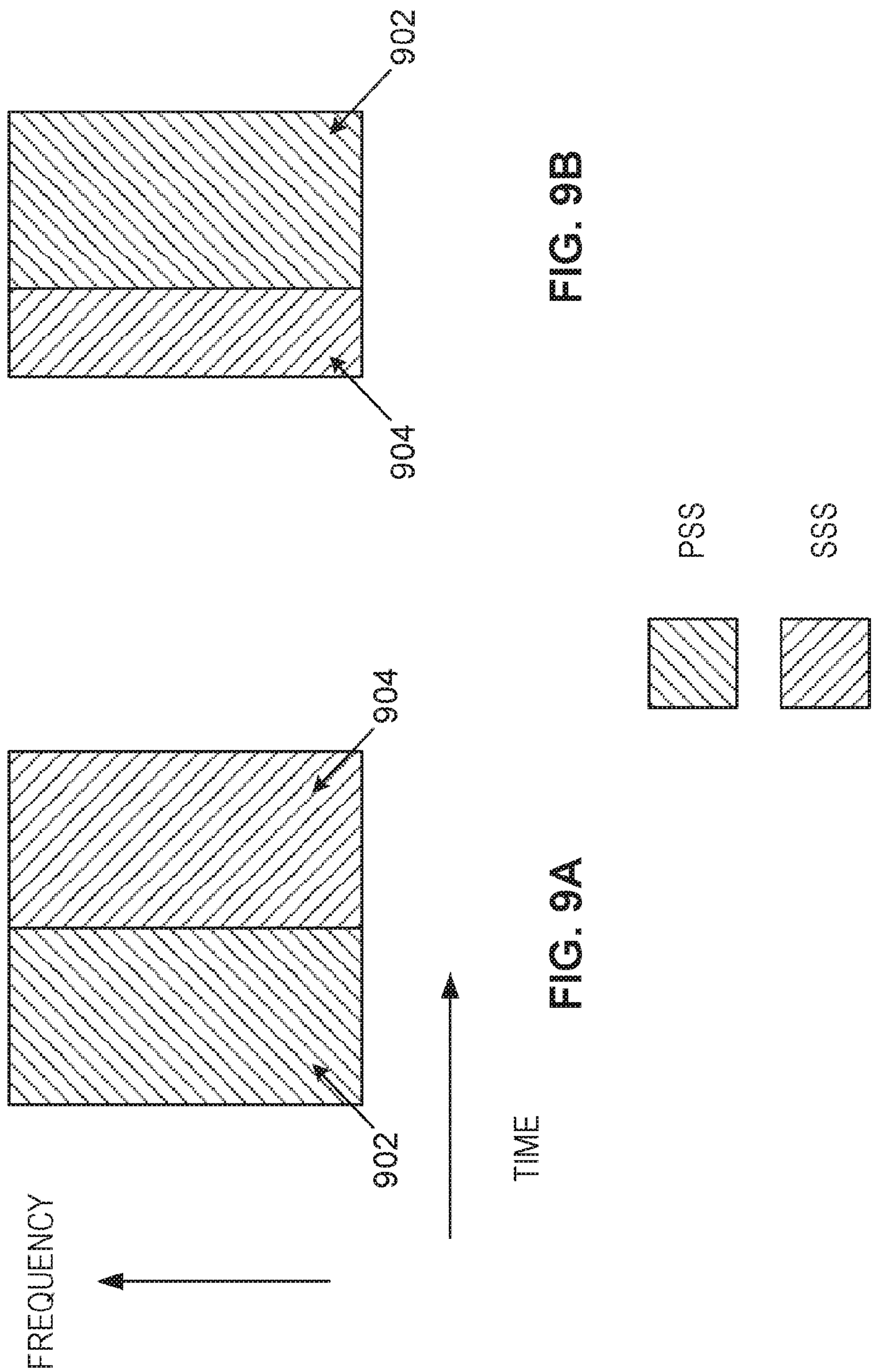


FIG. 9A

FIG. 9B

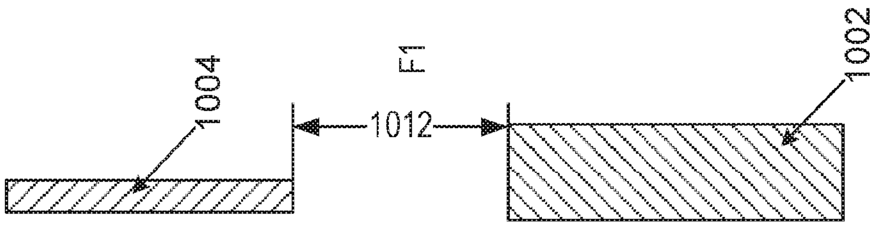


FIG. 10C

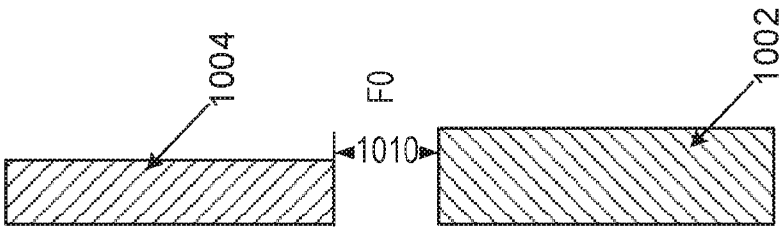


FIG. 10B

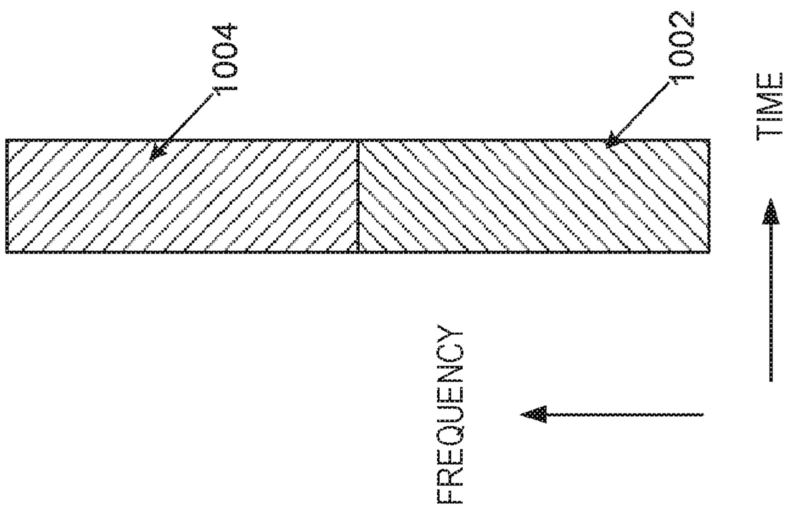


FIG. 10A

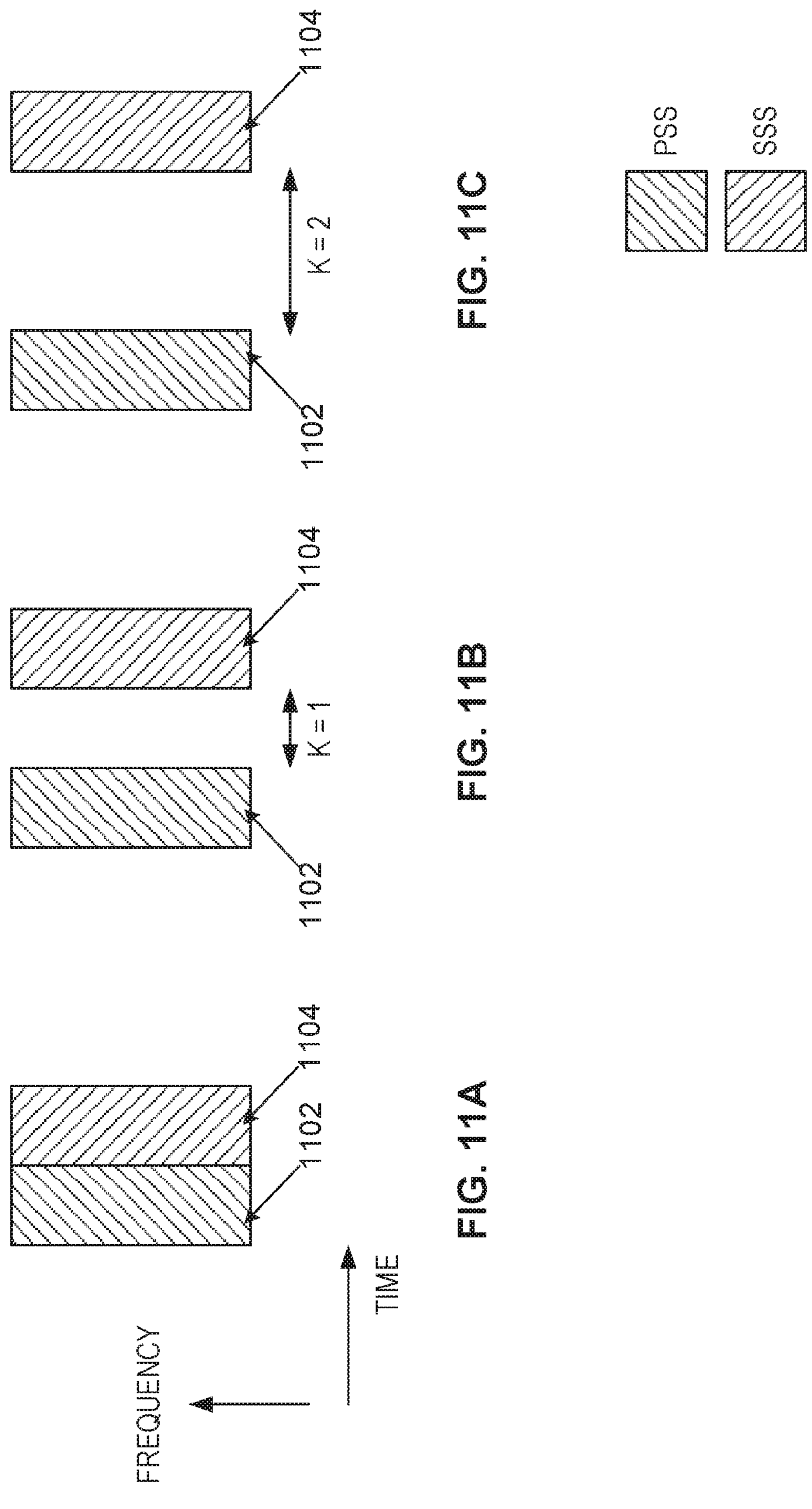


FIG. 11C

FIG. 11B

FIG. 11A

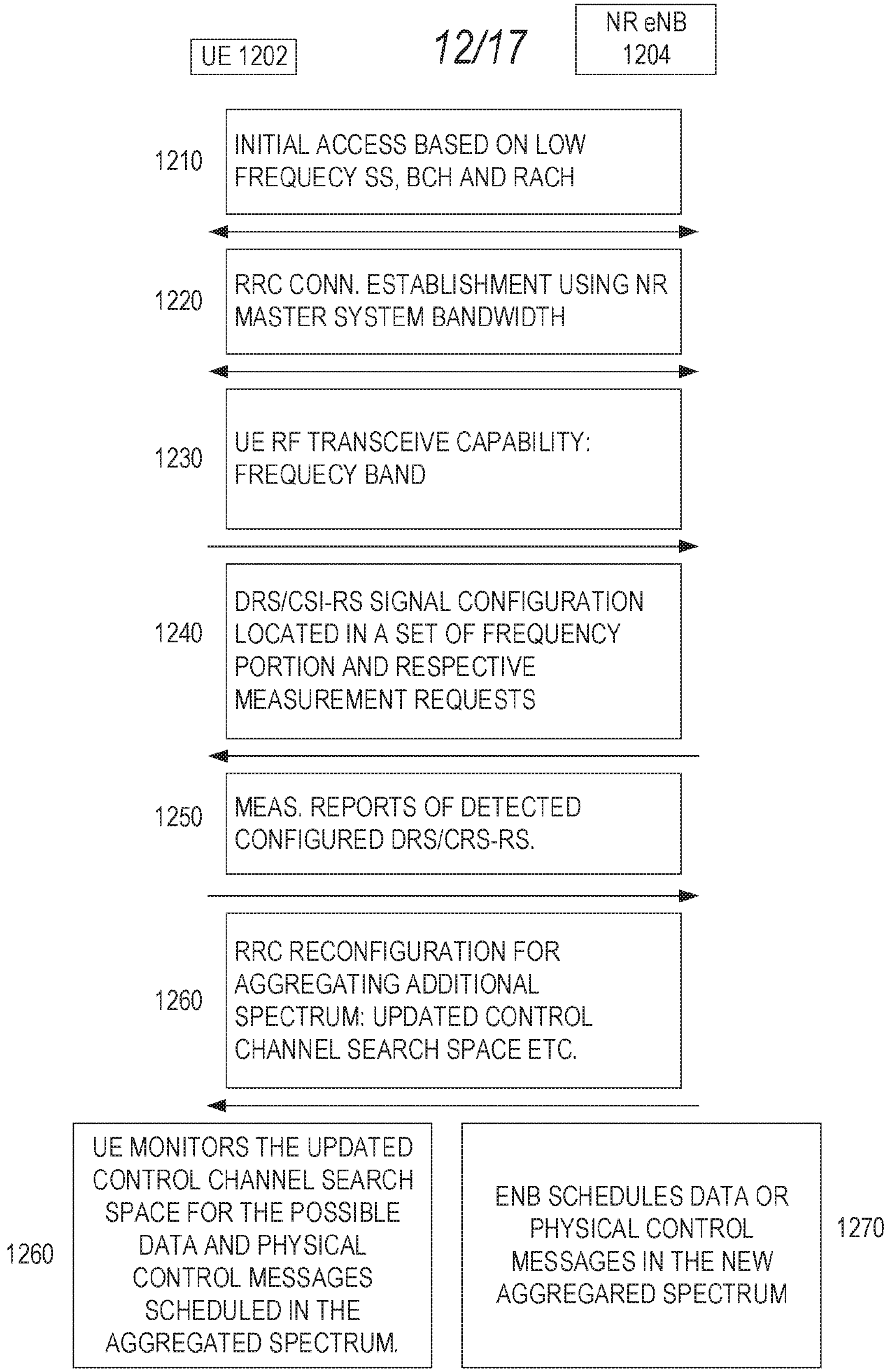
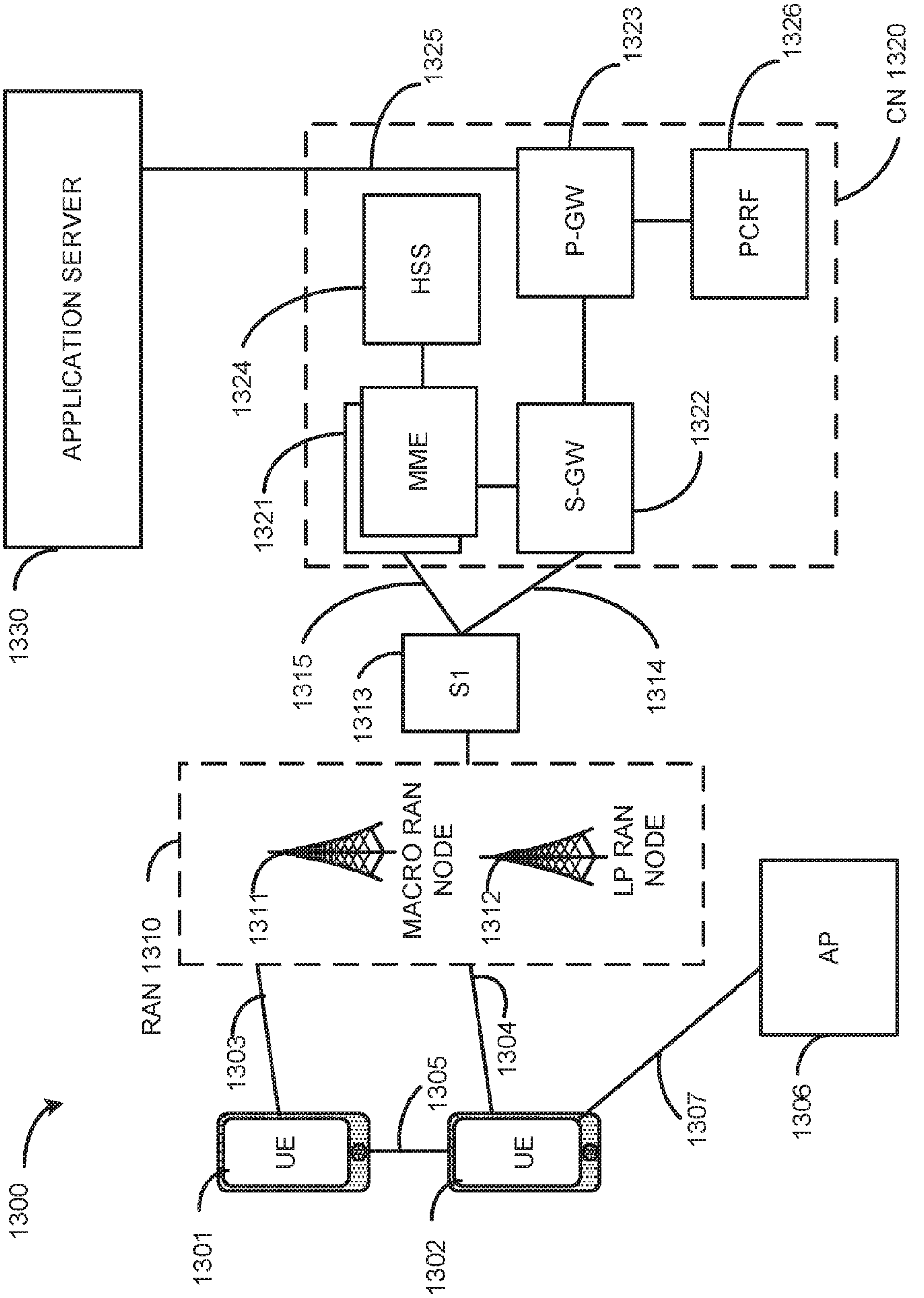

UE 1202
NR eNB 1204
1210
INITIAL ACCESS BASED ON LOW FREQUECY SS, BCH AND RACH
1220
RRC CONN. ESTABLISHMENT USING NR MASTER SYSTEM BANDWIDTH
1230
UE RF TRANSCEIVE CAPABILITY: FREQUECY BAND
1240
DRS/CSI-RS SIGNAL CONFIGURATION LOCATED IN A SET OF FREQUENCY PORTION AND RESPECTIVE MEASUREMENT REQUESTS
1250
MEAS. REPORTS OF DETECTED CONFIGURED DRS/CRS-RS.
1260
RRC RECONFIGURATION FOR AGGREGATING ADDITIONAL SPECTRUM: UPDATED CONTROL CHANNEL SEARCH SPACE ETC.
1260
UE MONITORS THE UPDATED CONTROL CHANNEL SEARCH SPACE FOR THE POSSIBLE DATA AND PHYSICAL CONTROL MESSAGES SCHEDULED IN THE AGGREGATED SPECTRUM.
ENB SCHEDULES DATA OR PHYSICAL CONTROL MESSAGES IN THE NEW AGGREGARED SPECTRUM
1270

FIG. 12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APPLICATION SERVER
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1325
HSS
1324
P-GW
1323
PCRF
1326
CN 1320
MME
1321
S-GW
1322
S1
1313
1315
1314
RAN 1310
MACRO RAN NODE
1311
LP RAN NODE
1312
AP
1306
UE
1301
UE
1302
1303
1304
1305
1307

FIG. 13

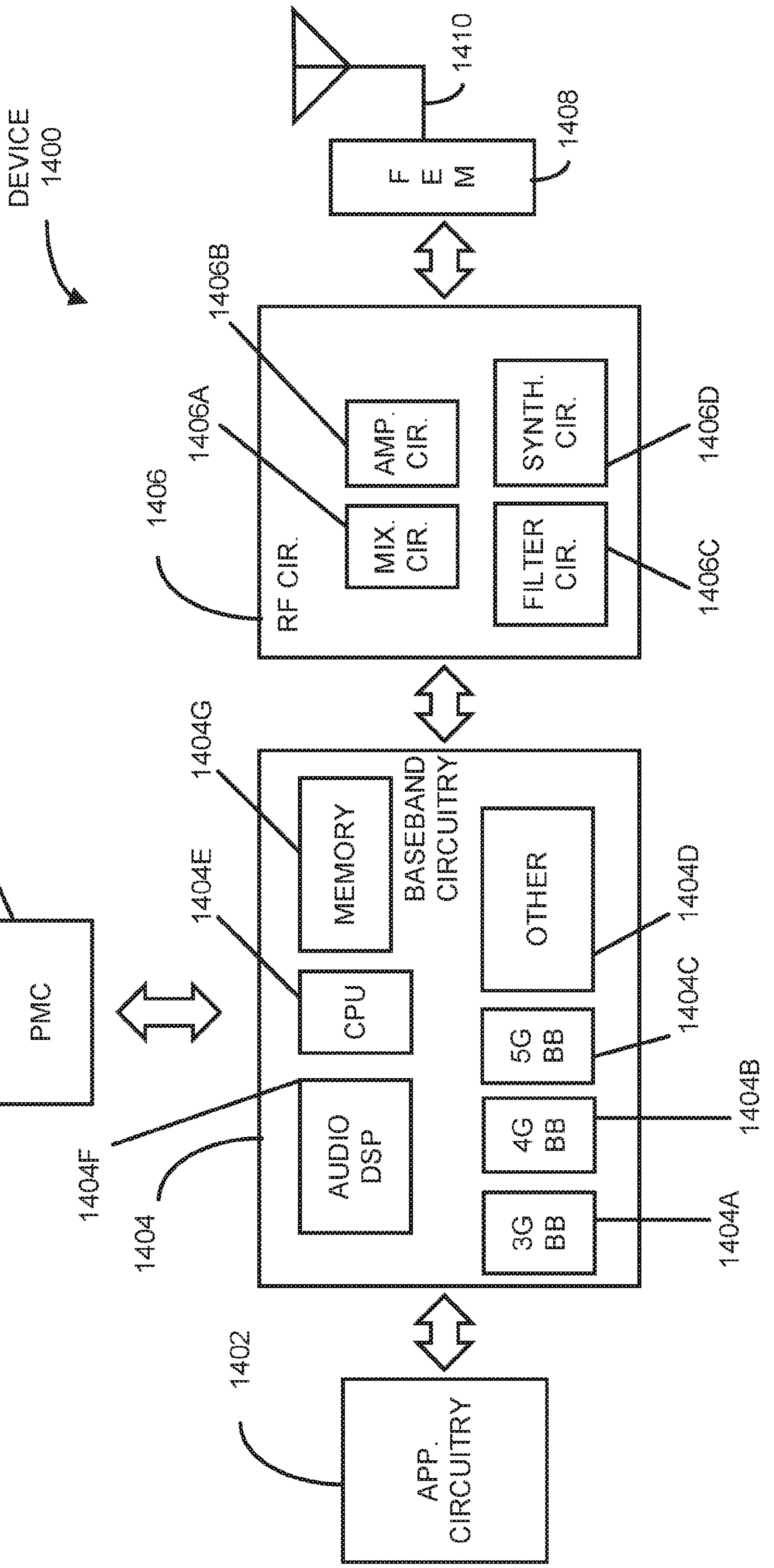
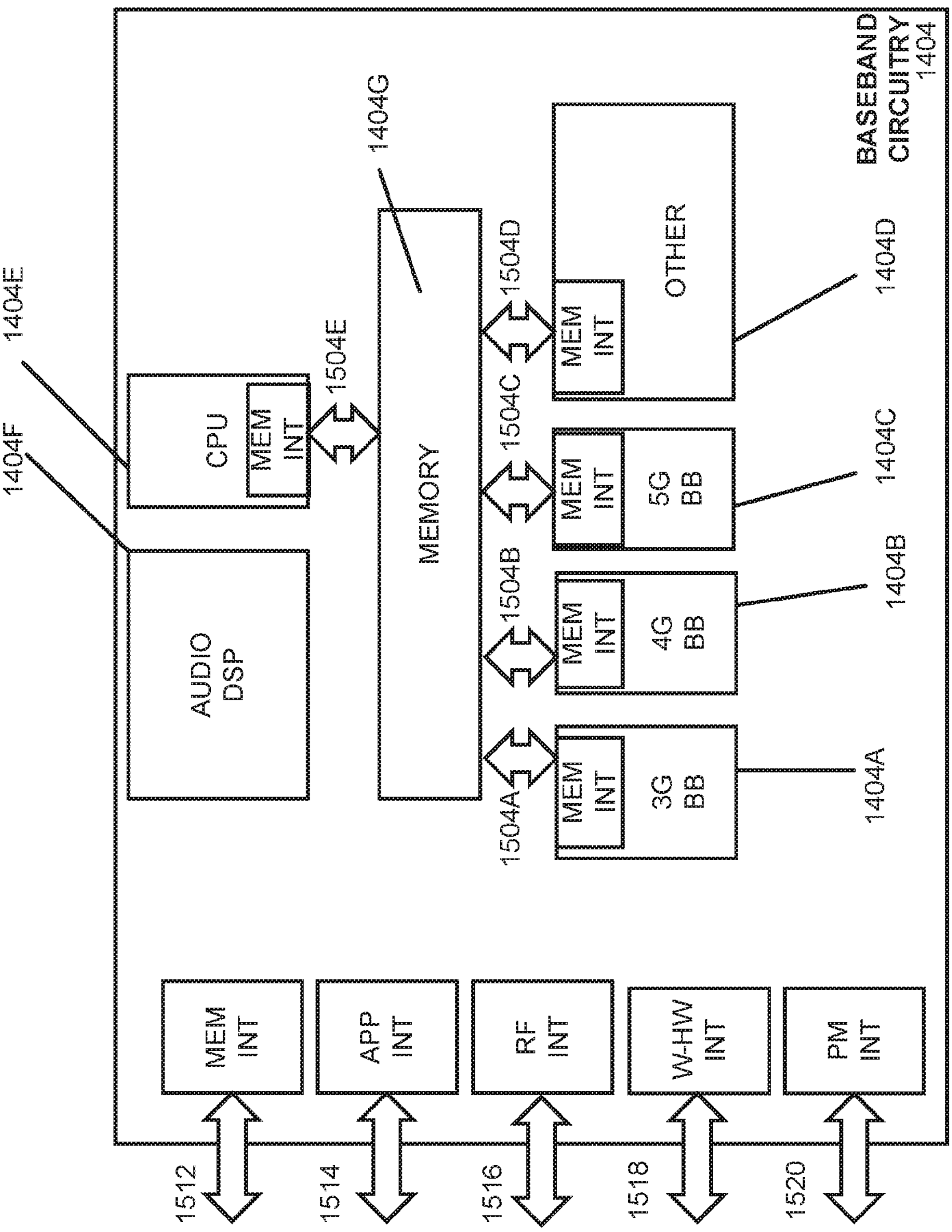

DEVICE 1400
1410
1408
FEM
RF CIR.
1406
MIX. CIR.
1406A
AMP. CIR.
1406B
FILTER CIR.
1406C
SYNTH. CIR.
1406D
BASEBAND CIRCUITRY
MEMORY
1404G
CPU
1404E
AUDIO DSP
1404F
1404
OTHER
1404D
5G BB
1404C
4G BB
1404B
3G BB
1404A
PMC
1412
APP. CIRCUITRY
1402

FIG. 14


BASEBAND
CIRCUITRY
1404
1404G
1404E
1404F
CPU
MEM
INT
1504E
AUDIO
DSP
MEMORY
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1504C
1504B
1504A
MEM
INT
OTHER
1404D
5G
BB
1404C
4G
BB
1404B
3G
BB
1404A
MEM
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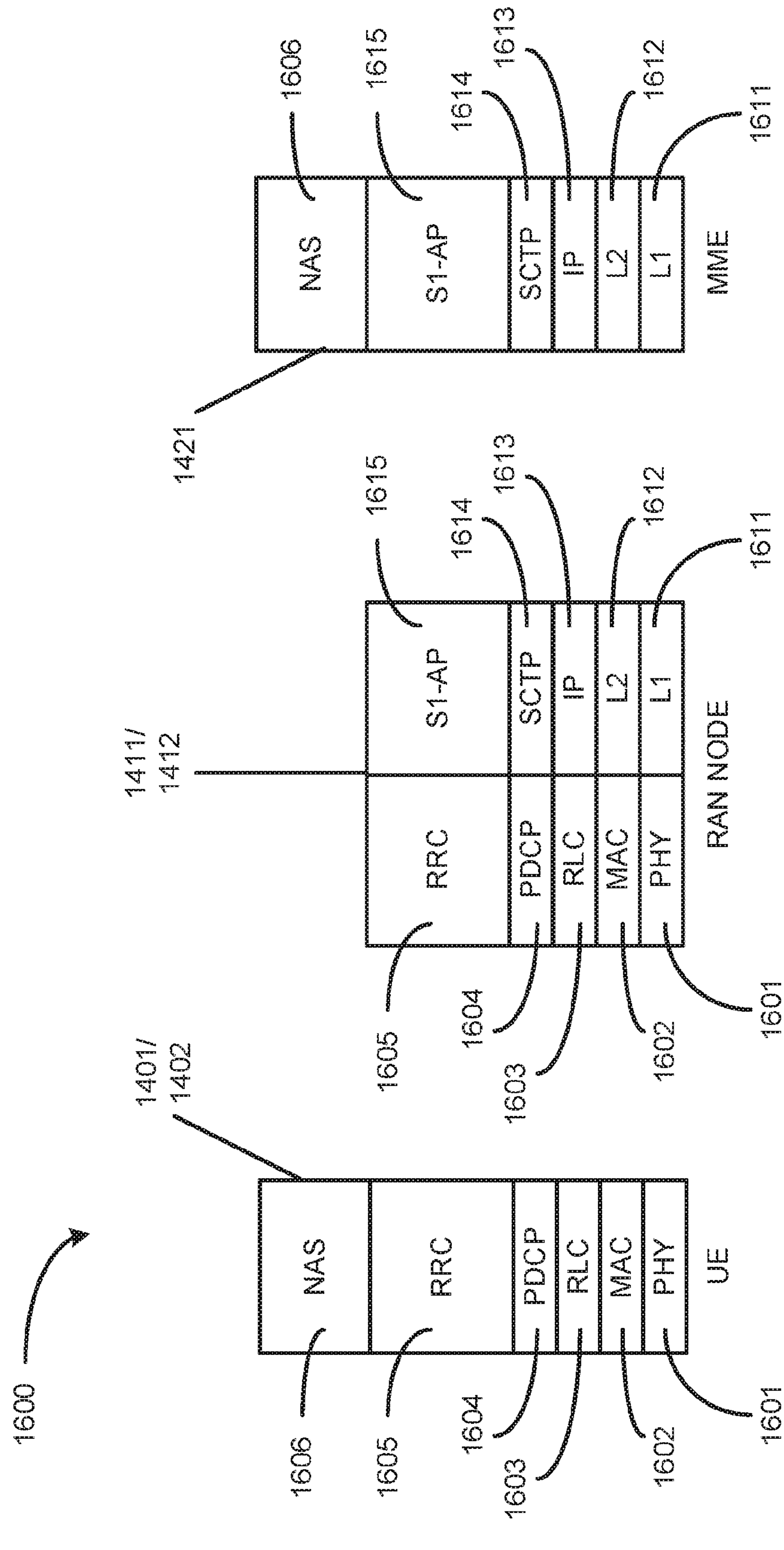
APP
INT
RF
INT
W-HW
INT
PM
INT
1512
1514
1516
1518
1520

FIG. 15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RRC
PDCP
RLC
MAC
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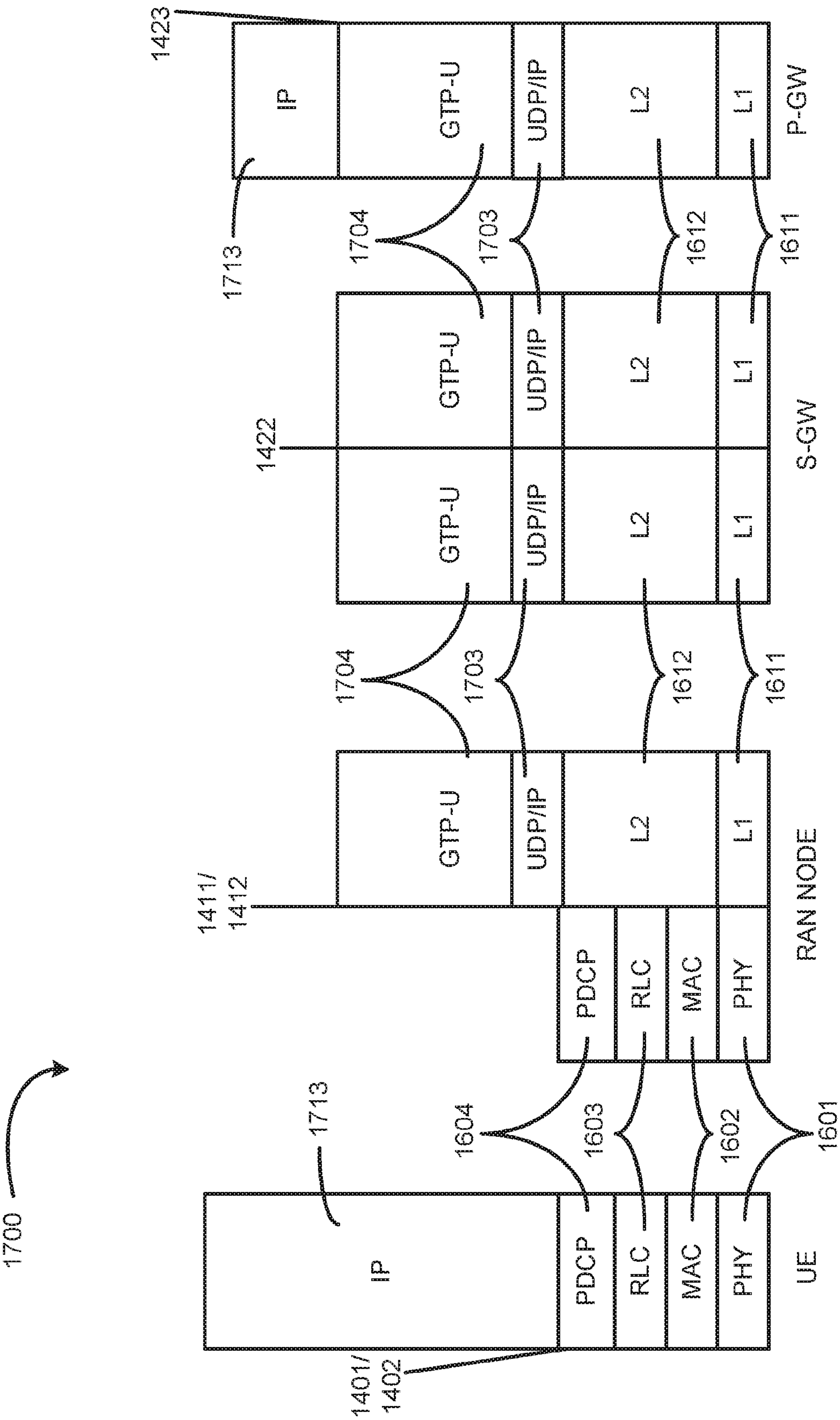
1601
1401/
1402
RAN NODE
RRC
PDCP
RLC
MAC
PHY
S1-AP
SCTP
IP
L2
L1
1605
1604
1603
1602
1601
1411/
1412
1615
1614
1613
1612
1611
MME
NAS
S1-AP
SCTP
IP
L2
L1
1421
1606
1615
1614
1613
1612
1611

FIG. 16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PDCP
RLC
MAC
PHY
GTP-U
UDP/IP
L2
L1
1411/
1412
1704
1703
1612
1611
S-GW
GTP-U
UDP/IP
L2
L1
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UDP/IP
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GTP-U
UDP/IP
L2
L1
1423

FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/046081

A. CLASSIFICATION OF SUBJECT MATTER

H04J 11/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J 11/00; H04Q 7/38; H04L 1/18; H04W 72/04; H04B 7/005

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: UE, first primary synchronization signal, first numerology, downlink numerology, PDCCH, decode

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2016-0150532 A1 (QUALCOMM INCORPORATED) 26 May 2016 See paragraphs [0059], [0062]; claim 1; and figure 1.	1-25
A	US 2014-0092792 A1 (HAKSEONG KIM et al.) 03 April 2014 See paragraphs [0038], [0056]; and claim 13.	1-25
A	US 2012-0195286 A1 (KITAE KIM et al.) 02 August 2012 See paragraphs [0042]-[0048]; and figure 2.	1-25
A	SONY, `Consideration on numerologies in LTE/LTE-A and NR`, R1-162565, 3GPP TSG RAN WG1 Meeting #84bis, Busan, Korea, 01 April 2016 See section 2.	1-25
A	WO 99-43100 A1 (QUALCOMM INCORPORATED) 26 August 1999 See claims 1-8.	1-25

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
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"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
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2017 (30.10.2017)	**31 October 2017 (31.10.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
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Facsimile No. +82-42-481-8578

Authorized officer

LEE, Seoung Young

Telephone No. +82-42-481-3535

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/046081

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Information on patent family members

International application No.

PCT/US2017/046081

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