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(74) Agent: NICHOLSON, JR., Wesley E.; Green, Howard & Mughal, LLP, 5 Centerpointe Drive, Suite 400, Lake Oswego, Oregon 97035 (US).


Fig. 4

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BACKGROUND

[0002] A variety of wireless cellular communication systems have been implemented, including 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications Systems, 3GPP Long-Term Evolution (LTE) systems, and 3GPP LTE-Advanced (LTE-A) systems. Next-generation wireless cellular communication systems based upon LTE and LTE-A systems are being developed, such as 5th Generation (5G) or New Radio (NR) wireless communication systems, or 5G or NR mobile network systems. Next-generation wireless cellular communication systems may provide support for self-contained Time-Division Duplex (TDD) slot structures (or subframe structures).

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The embodiments of the disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the disclosure. However, while the drawings are to aid in explanation and understanding, they are only an aid, and should not be taken to limit the disclosure to the specific embodiments depicted therein.

[0004] Fig. 1 illustrates scenarios of self-contained Time-Division Duplex (TDD) slot structures for Downlink (DL) transmission and Uplink (UL) transmission, in accordance with some embodiments of the disclosure.

[0005] Fig. 2 illustrates scenarios of self-contained TDD slot structures for DL transmission and UL transmission incorporating front-loaded Demodulation Reference Signal (DM-RS), in accordance with some embodiments of the disclosure.
Fig. 3 illustrates a scenario of DM-RS in transmission mode 10, in accordance with some embodiments of the disclosure.

Fig. 4 illustrates scenarios of DM-RS symbols of multiple numerologies, in accordance with some embodiments of the disclosure.

Fig. 5 illustrates scenarios of DM-RS Antenna Port (AP) mapping, in accordance with some embodiments of the disclosure.

Fig. 6 illustrates scenarios of DM-RS AP mapping, in accordance with some embodiments of the disclosure.

Fig. 7 illustrates a scenario of DM-RS using different numerologies in the same system bandwidth, in accordance with some embodiments of the disclosure.

Fig. 8 illustrates scenarios of multiplexing DM-RS and data symbols using a subcarrier spacing (SCS) larger than a reference SCS, in accordance with some embodiments of the disclosure.

Fig. 9 illustrates scenarios of multiplexing DM-RS and data symbols using an SCS larger than a reference SCS for high-speed designs, in accordance with some embodiments of the disclosure.

Fig. 10 illustrates scenarios of multiplexing DM-RS and data symbols using an SCS larger than a reference SCS for intra-slot frequency-hopping designs, in accordance with some embodiments of the disclosure.

Fig. 11 illustrates scenarios of multiplexing DM-RS and PDCCH using an SCS larger than a reference SCS for DL slot structures, in accordance with some embodiments of the disclosure.

Fig. 12 illustrates a scenario of multiplexing DM-RS and PDCCH in the same symbol in an FDM manner, in accordance with some embodiments of the disclosure.

Fig. 13 illustrates scenarios of multiplexing control channels and reference signals using an SCS larger than a reference SCS, in accordance with some embodiments of the disclosure.

Fig. 14 illustrates scenarios of symmetric DM-RS patterns utilizing Code-Division Multiplexing (CDM), and a hybrid of Time-Division Multiplexing (TDM) and Frequency-Division Multiplexing (FDM), for support of up to rank-four transmissions, in accordance with some embodiments of the disclosure.

Fig. 15 illustrates scenarios of symmetric DM-RS patterns utilizing CDM, and a hybrid of TDM and FDM, in accordance with some embodiments of the disclosure.
[0019] Fig. 16 illustrates an Evolved Node-B (eNB) and a User Equipment (UE), in accordance with some embodiments of the disclosure.

[0020] Fig. 17 illustrates hardware processing circuitries for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, and for accommodating DM-RS design utilizing a combination of CDM in the time domain and the frequency domain, in accordance with some embodiments of the disclosure.

[0021] Fig. 18 illustrates methods for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, in accordance with some embodiments of the disclosure.

[0022] Fig. 19 illustrates methods for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, in accordance with some embodiments of the disclosure.

[0023] Fig. 20 illustrates methods for a UE for accommodating DM-RS design utilizing a combination of CDM in the time domain and the frequency domain, in accordance with some embodiments of the disclosure.

[0024] Fig. 21 illustrates example components of a device, in accordance with some embodiments of the disclosure.

[0025] Fig. 22 illustrates example interfaces of baseband circuitry, in accordance with some embodiments of the disclosure.

DETAILED DESCRIPTION

[0026] Various wireless cellular communication systems have been implemented or are being proposed, including 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications Systems (UMTS), 3GPP Long-Term Evolution (LTE) systems, 3GPP LTE-Advanced systems, and 5th Generation (5G) or New Radio (NR) wireless communication systems, or 5G or NR mobile network systems. (As used herein, the terms "NR" and "5G" may be considered interchangeable, and may refer to NR, to 5G, or to both.)

[0027] NR wireless communication systems may provide access to information and sharing of data in a wide variety of locations and times by various users and applications. NR may present unified systems or networks targeted to meet a variety of differing and sometimes conflicting performance dimensions and services. Such diverse multi-dimensional requirements may be driven by different services and applications.
NR systems may develop from 3GPP LTE-Advanced systems with additional new Radio Access Technologies (RATs). 5G may thereby enable a wide variety of wireless devices and may deliver fast and rich services and content.

In accordance with some aspects of NR systems, self-contained TDD (Time-Division Duplex) slot structures may facilitate or enable low latency transmission for enhanced mobile broadband communication. Fig. 1 illustrates scenarios of self-contained Time-Division Duplex (TDD) slot structures for Downlink (DL) transmission and Uplink (UL) transmission, in accordance with some embodiments of the disclosure. (As used herein, the term "slot" may refer to a unit of transmission spanning a plurality of Orthogonal Frequency-Division Multiplexing (OFDM) symbols, which may be substantially similar to a subframe in a legacy LTE system or other wireless system.) In a scenario 100, a self-contained DL data slot structure may comprise an NR Physical Downlink Control Channel (PDCCH), an NR Physical Downlink Shared Channel (PDSCH), an NR Physical Uplink Control Channel (PUCCH), and a Guard Period (GP) between the PDSCH and the PUCCH to accommodate a DL-to-UL switching time and/or one or more round-trip propagation delays. For the self-contained DL data slot structure, the PDSCH may be scheduled by the PDCCH, and may be transmitted following the PDCCH (e.g., immediately following the PDCCH).

In a scenario 150, a self-contained UL data slot structure may comprise a PDCCH, an NR Physical Uplink Shared Channel (PUSCH), a GP between the PDCCH and the PUSCH to accommodate a DL-to-UL switching time and/or one or more round-trip propagation delays, and a PUCCH. For the self-contained UL data slot structure, the PUSCH may be scheduled by the PDCCH, and may be transmitted following the PDCCH.

To support self-contained transmission schemes (e.g., self-contained slot structures) for NR systems, Demodulation Reference Signal (DM-RS) patterns may be defined to allow a receiver to decode a packet in a timely manner. In UE receive-side processing, a UE may first receive pilot signals (e.g., DM-RS), then perform channel estimation, then obtain a Log-Likelihood Ratio (LLR) associated with one or more channels based on the channel estimates, then perform decoding to obtain an estimate of a packet. Some of these operations may be pipelined, but there may be delays introduced due to inter-dependency of the various operations. A system design may be disposed to avoiding or minimized such delays in order to facilitate or enable early decoding.

For purposes of channel estimation, it may be attractive to place the pilot signals (e.g., DM-RS) toward the beginning of a slot. Fig. 2 illustrates scenarios of self-
contained TDD slot structures for DL transmission and UL transmission incorporating front-loaded Demodulation Reference Signal (DM-RS), in accordance with some embodiments of the disclosure. In a scenario 200 (which may be similar to scenario 100), a self-contained DL data slot structure may comprise a PDCCH, a DM-RS (e.g., a DL DM-RS), a PDSCH, a PUCCH, and a GP between the PDSCH and the PUCCH. In a scenario 250 (which may be similar to scenario 150), a self-contained UL data slot structure may comprise a PDCCH, a DM-RS (e.g., a UL DM-RS), a GP between the PDCCH and the DM-RS, a PUSCH, and a PUCCH.

[0033] For the transmission of PDSCH or PUSCH within a self-contained slot (e.g., in scenario 200 and/or scenario 250), a higher density DM-RS may be located toward or at a beginning of a data transmission. In some embodiments, an additional reference signal (e.g., a Tracking Reference Signal (TRS)) may be transmitted, which may assist a receiver for purposes such as refined channel estimation for data occurring toward or at an end of a slot, frequency offset and Doppler spread tracking, and so on.

[0034] For NR systems, multiple numerologies may coexist in the same system bandwidth, which may then be targeted for various usage models, applications, or services. To enhance or provide more flexibility, and to assist in targeting NR systems for various channel conditions (e.g., frequency-selective channel conditions, time-varying channel conditions, and so on), DM-RS for some of the numerologies may use subcarrier spacing (SCS) for data channel and/or control channel that is different from a reference SCS. For example, of a larger SCS than the reference SCS may be utilized for the DM-RS. This may facilitate or allow one or more symbols to be allocated for the DM-RS transmission, which may then be used to enable a simpler frequency offset tracking algorithm.

[0035] Various aspects of the embodiments disclosed herein pertain to both DM-RS design and multiplexing of DM-RS with data and control channel for NR systems. In some embodiments, DM-RS patterns may use a larger SCS than an SCS of a reference numerology. Some embodiments may incorporate mechanisms to indicate a DM-RS structure using different numerologies. Some embodiments may incorporate mechanisms for multiplexing of DM-RS and data symbols. Some embodiments may incorporate mechanisms for multiplexing of PDCCH and DM-RS. Some embodiments may additionally incorporate mechanisms for multiplexing control channels and other reference signals. In various embodiments, various DM-RS design as well as the multiplexing of DM-RS with data and control channel may be applied for both DL transmission and UL transmission.
Meanwhile, Release 11 of the 3GPP specifications may support transmission mode 10 for up to rank-eight Single-User (SU) Multiple-Input Multiple-Output (SU-MIMO) transmission by incorporating DM-RS for PDSCH estimation. Fig. 3 illustrates a scenario of DM-RS in transmission mode 10, in accordance with some embodiments of the disclosure. In a scenario 300, a Resource Block (RB) may comprise a plurality of Resource Elements (REs) that span a plurality of subcarrier frequencies and a plurality of Orthogonal Frequency-Division Multiplexing (OFDM) symbols. Various REs of the RB may carry: a control channel (e.g., a legacy LTE control channel, such as PDCCH; PDSCH; and Cell-specific Reference Signal (CRS). Various other REs of the RB may carry DM-RS, which may correspond with various different Antenna Ports (APs). For example, some REs may carry DM-RS corresponding with APs 7, 8, 11, and 13, while other REs may carry DM-RS corresponding with APs 9, 10, 12, and 14.

As a result, various REs of the RB (across a time domain and a frequency domain) may be employed for rank-one transmission to rank-eight transmission. For example, rank-two SU-MIMO transmission may be performed with APs 7 and 8 assigned to the same resource elements (REs), and may incorporate a length-two orthogonal cover code (OCC). As another example, rank-four SU-MIMO transmission may utilize APs 9 and 10 in addition to APs 7 and 8 (which may be used for rank-two SU transmission). APs 7 and 8, and APs 9 and 10, may be assigned to different REs in a Frequency-Division Multiplexing (FDM) manner. In contrast, each AP group (e.g., a group with APs 7 and 8, and a group with APs 9 and 10) may share the same REs in a Code-Division Multiplexing (CDM) manner in a time domain with length-two OCC.

A gNB (which may be a 5G or NR Evolved Node-B (eNB)) and a UE may be disposed to take into account high mobility scenarios, and thus very large Doppler frequencies, which may cause rapidly time-varying channel conditions. Therefore, RE sharing in the time domain in a CDM manner might not guarantee satisfactory performance of channel estimation, and may thus impact PDSCH throughput.

Delay spread in NR systems may be substantially less than in legacy LTE systems; for example, delay spread may be relatively less for systems employing carrier frequencies beyond 6 Gigahertz (GHz) and high-directivity MIMO beamforming. However, NR systems may also be disposed to accommodating continuous support of legacy LTE, which may employ carrier frequencies below 6 GHz and relatively wide MIMO beamforming, and which in turn may create relatively large delay spreads in comparison with scenarios of more narrow beamforming (e.g., high-directivity MIMO beamforming).
Accordingly, various aspects of the embodiments disclosed herein pertain to DM-RS that may advantageously compensate for performance degradation associated with scenarios of high mobility, while simultaneously maintaining satisfactory performance for scenarios of large delay spread.

Various embodiments may incorporate front-loaded DM-RS. Some embodiments may support front-loaded DM-RS, such as DM-RS allocated in the first and second symbols of PDSCH with the support of more than eight DM-RS APs. In legacy LTE, DM-RS for transmission mode 10 may use length-four OCC in the time domain spanning four symbols (e.g., symbols 5, 6, 12, and 13 of an RB) such that the same REs may be exploited to support up to four DM-RS APs. However, such embodiments might be adequate to support the use of merely front-loaded DM-RS. Disclosed herein are various mechanisms and methods capable of advantageously supporting eight DM-RS APs for scenarios using merely front-loaded DM-RS.

Also disclosed herein are additional mechanisms and methods for DM-RS support for NR. Some embodiments may comprise a generic manner of DM-RS design utilizing a combination of CDM in the time domain and the frequency domain to compensate for different channel conditions (e.g., high mobility conditions versus large delay-spread conditions). Some embodiments may comprise a symmetric DM-RS pattern for four APs using CDM in both the time domain and the frequency domain (with a DM-RS RE density as high as, or higher than, a legacy LTE DM-RS RE density). Various embodiments may comprise symmetric DM-RS patterns or non-symmetric DM-RS patterns to support eight APs, as well as front-loaded DM-RS using CDM in both the time domain and the frequency domain. Some embodiments may comprise symmetric DM-RS patterns to support sixteen APs.

In the following description, numerous details are discussed to provide a more thorough explanation of embodiments of the present disclosure. It will be apparent to one skilled in the art, however, that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present disclosure.

Note that in the corresponding drawings of the embodiments, signals are represented with lines. Some lines may be thicker, to indicate a greater number of constituent signal paths, and/or have arrows at one or more ends, to indicate a direction of information flow. Such indications are not intended to be limiting. Rather, the lines are used in
connection with one or more exemplary embodiments to facilitate easier understanding of a circuit or a logical unit. Any represented signal, as dictated by design needs or preferences, may actually comprise one or more signals that may travel in either direction and may be implemented with any suitable type of signal scheme.

Throughout the specification, and in the claims, the term "connected" means a direct electrical, mechanical, or magnetic connection between the things that are connected, without any intermediary devices. The term "coupled" means either a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" or "module" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

The terms "substantially," "close," "approximately," "near," and "about" generally refer to being within +/- 10% of a target value. Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

It is to be understood that the terms so used are interchangeable under appropriate circumstances such that the embodiments of the invention described herein are, for example, capable of operation in other orientations than those illustrated or otherwise described herein.

The terms "left," "right," "front," "back," "top," "bottom," "over," "under," and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing permanent relative positions.

For purposes of the embodiments, the transistors in various circuits, modules, and logic blocks are Tunneling FETs (TFETs). Some transistors of various embodiments may comprise metal oxide semiconductor (MOS) transistors, which include drain, source, gate, and bulk terminals. The transistors may also include Tri-Gate and FinFET transistors, Gate All Around Cylindrical Transistors, Square Wire, or Rectangular Ribbon Transistors or other devices implementing transistor functionality like carbon nanotubes or spintronic devices. MOSFET symmetrical source and drain terminals i.e., are identical terminals and are interchangeably used here. A TFET device, on the other hand, has asymmetric Source
and Drain terminals. Those skilled in the art will appreciate that other transistors, for example, Bi-polar junction transistors-BJT PNP/NPN, BiCMOS, CMOS, etc., may be used for some transistors without departing from the scope of the disclosure.

For the purposes of the present disclosure, the phrases "A and/or B" and "A or B" mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

In addition, the various elements of combinatorial logic and sequential logic discussed in the present disclosure may pertain both to physical structures (such as AND gates, OR gates, or XOR gates), or to synthesized or otherwise optimized collections of devices implementing the logical structures that are Boolean equivalents of the logic under discussion.

In addition, for purposes of the present disclosure, the term "eNB" may refer to a legacy LTE capable Evolved Node-B (eNB), a next-generation or 5G capable eNB, a centimeter-wave (cmWave) capable eNB or a cmWave small cell, a millimeter-wave (mmWave) capable eNB or an mmWave small cell, an Access Point, and/or another base station for a wireless communication system. The term "gNB" may refer to a 5G-capable or NR-capable eNB. For some embodiments, the term "eNB" may also refer to a gNB. For purposes of the present disclosure, the term "UE" may refer to a legacy LTE capable User Equipment (UE), an mmWave capable UE, a cmWave capable UE, a Station (STA), and/or another mobile equipment for a wireless communication system. The term "UE" may also refer to a next-generation or 5G capable UE.

Various embodiments of eNBs and/or UEs discussed below may process one or more transmissions of various types. Some processing of a transmission may comprise demodulating, decoding, detecting, parsing, and/or otherwise handling a transmission that has been received. In some embodiments, an eNB or UE processing a transmission may determine or recognize the transmission’s type and/or a condition associated with the transmission. For some embodiments, an eNB or UE processing a transmission may act in accordance with the transmission’s type, and/or may act conditionally based upon the transmission’s type. An eNB or UE processing a transmission may also recognize one or more values or fields of data carried by the transmission. Processing a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission that has been received by an eNB or a UE through one or more layers of a protocol stack.
Various embodiments of eNBs and/or UEs discussed below may also generate one or more transmissions of various types. Some generating of a transmission may comprise modulating, encoding, formatting, assembling, and/or otherwise handling a transmission that is to be transmitted. In some embodiments, an eNB or UE generating a transmission may establish the transmission's type and/or a condition associated with the transmission. For some embodiments, an eNB or UE generating a transmission may act in accordance with the transmission's type, and/or may act conditionally based upon the transmission's type. An eNB or UE generating a transmission may also determine one or more values or fields of data carried by the transmission. Generating a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission to be sent by an eNB or a UE through one or more layers of a protocol stack.

In various embodiments, resources may span various RBs, Physical Resource Blocks (PRBs), and/or time periods (e.g., frames, subframes, and/or slots) of a wireless communication system. In some contexts, allocated resources (e.g., channels, Orthogonal Frequency-Division Multiplexing (OFDM) symbols, subcarrier frequencies, resource elements (REs), and/or portions thereof) may be formatted for (and prior to) transmission over a wireless communication link. In other contexts, allocated resources (e.g., channels, OFDM symbols, subcarrier frequencies, REs, and/or portions thereof) may be detected from (and subsequent to) reception over a wireless communication link.

With respect to various embodiments of the disclosure, a front-loaded DM-RS partem may advantageously facilitate or enable low-latency and/or self-contained transmission for both DL and UL. In scenarios in which multiple numerologies coexist in the same system bandwidth, it may be advantageous to apply an SCS for transmission of DM-RS that is larger than a reference SCS applied for data channel transmission (e.g., an SCS of 15 kHz). Application of the larger SCS may accommodate two or more symbols (e.g., symbols of a numerology associated with the non-reference SCS) to be allocated for DM-RS transmission within one symbol of the reference numerology. With such DM-RS structures, simpler frequency offset tracking algorithms may be employed.

Fig. 4 illustrates scenarios of DM-RS symbols of multiple numerologies, in accordance with some embodiments of the disclosure. A first scenario 110 may comprise a cyclic prefix (CP) and a DM-RS structured for a 15 kilohertz (kHz) SCS, a second scenario 120 may comprise CP and DM-RSes structured for a 30 kHz SCS, and a third scenario 130 may comprise CP and DM-RSes structured for a 60 kHz SCS.
With symbol boundary alignment, two DM-RS symbols using 30 kHz SCS (as in second scenario 120) or four DM-RS symbols using 60 kHz SCS (as in third scenario 130) may be embedded into one DM-RS symbol using 15 kHz SCS (as in first scenario 110). Similarly, two DM-RS symbols using 60 kHz SCS (as in third scenario 130) may be embedded into one DM-RS symbol using 30 kHz SCS (as in second scenario 120).

Accordingly, as discussed herein, when an SCS larger than a reference SCS (e.g., an SCS of a reference numerology) is applied for DM-RS, two or more symbols may be allocated for DM-RS transmission. Moreover, multiple DM-RS APs may also be multiplexed in a TDM manner, an FDM manner, a CDM manner, or a combination thereof.

Fig. 5 illustrates scenarios of DM-RS AP mapping, in accordance with some embodiments of the disclosure. In a first scenario 510, a second scenario 520, and a third scenario 530, 8 DM-RS APs may be defined, which may cover four DM-RS AP groups (e.g., APs 0 and 1, APs 2 and 3, APs 4 and 5, and APs 6 and 7, respectively).

In first scenario 510, FDM may be applied among the four DM-RS groups using 15 kHz SCS. In second scenario 520, a combination of TDM and FDM may be applied among the four DM-RS groups using 30 kHz SCS. In third scenario 530, TDM may be applied among the four DM-RS groups using a 60 kHz SCS. In addition, in first scenario 510, second scenario 520, and third scenario 530, an OCC of length 2 may be applied within each of the four DM-RS AP groups to differentiate the DM-RS APs.

Fig. 6 illustrates scenarios of DM-RS AP mapping, in accordance with some embodiments of the disclosure. In a first scenario 610, a second scenario 620, and a third scenario 630, 8 DM-RS APs may be defined, which may cover two DM-RS AP groups (e.g., APs 0, 1, 2, and 3, and APs 4, 5, 6, and 7, respectively).

In first scenario 610, FDM may be applied among the two DM-RS groups using 15 kHz SCS, and both an OCC of length 2 and an OCC of length 4 may be applied within each of the two DM-RS groups to differentiate the DM-RS APs. In second scenario 620, FDM may be applied among the two DM-RS groups using 30 kHz SCS, and an OCC length of 2 may be applied within each of the two DM-RS groups to differentiate the DM-RS APs. In third scenario 630, FDM may be applied among the two DM-RS groups using 60 kHz, and an OCC length of 4 may be applied within each of the two DM-RS groups to differentiate the DM-RS APs.

In various embodiments, to facilitate or allow a UE to estimate a frequency offset, the same precoder (e.g., a digital precoder, an analog precoder, or hybrid precoder) may be applied for the DM-RS AP in different DM-RS symbols using an SCS other than a
reference SCS. Channel estimation from one DM-RS AP may then be inferred from channel estimation from another DM-RS AP. This may facilitate or enable a UE to estimate a frequency offset using one or more DM-RS APs in different symbols. Some such configurations may be configured by higher layers, or may be dynamically indicated in Downlink Control Information (DCI).

For example, for DM-RS using 30 kHz SCS (as in second scenario 620), DM-RS APs 0 and 1 (which may be on the same subcarrier) may be multiplexed in a CDM manner using an OCC with a length of 2. To allow a UE to estimate a frequency offset, a gNB may inform a UE that a channel estimate from DM-RS AP 0 may be inferred from a channel estimate from DM-RS AP #1.

In some embodiments, DM-RS using different SCS may be made UE-specific. Furthermore, from a system-level perspective, DM-RS using different numerologies may be multiplexed within the same system bandwidth. **Fig. 7** illustrates a scenario of DM-RS using different numerologies in the same system bandwidth, in accordance with some embodiments of the disclosure. In a scenario 700, a portion of a system bandwidth may accommodate two UEs, a UE 1 and a UE 2. UE 1 may accommodate DM-RS using 15 kHz SCS. UE 2 may accommodate DM-RS using 30 kHz SCS. Accordingly, two DM-RS symbols may use 30 kHz SCS for UE 2 and may be multiplexed in an FDM manner, while one DM-RS symbol may use 15 kHz SCS for UE 1.

Various mechanisms and methods may indicate DM-RS support using different numerologies. In some embodiments, DM-RS using one numerology may be configured by higher layers in a UE-specific manner (via, for example, dedicated Radio Resource Control (RRC) signaling). In order to advantageously avoid a misalignment between a UE and a gNB, DM-RS transmission using a reference numerology may be considered as a default mode or fallback mode (or may be otherwise predetermined) before RRC connection setup.

For some embodiments, a UE may report its capabilities to support various numerologies. Subsequently, a gNB may configure DM-RS using one numerology among the supported numerologies via RRC signaling.

In some embodiments, DM-RS using one numerology may be dynamically indicated in DCI. As a further extension, a set of numerologies for DM-RS transmission may be configured by higher layers via RRC signaling, and/or a bit field in DCI may be used to indicate which numerology is applied for DM-RS transmission. Table 1 below illustrates an example of an indicator of numerology that may be used for DM-RS transmission.
<table>
<thead>
<tr>
<th>two-bit indicator DCI</th>
<th>DM-RS SCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>first value (e.g. “00”)</td>
<td>15 kHz</td>
</tr>
<tr>
<td>second value (e.g. “01”)</td>
<td>30 kHz</td>
</tr>
<tr>
<td>third value (e.g. “10”)</td>
<td>60 kHz</td>
</tr>
<tr>
<td>fourth value (e.g. “11”)</td>
<td>reserved</td>
</tr>
</tbody>
</table>

In some embodiments, DM-RS and data symbol using larger SCS may be multiplexed in the same symbol using reference SCS, which may advantageously reduce DM-RS overhead and improve the data rate. For example, DM-RS using an SCS larger than a reference SCS, along with one or more data symbols using the SCS larger than the reference SCS, may be located in a symbol prior to one or more data symbols in the reference SCS to enable early decoding. In various embodiments, whether to multiplex DM-RS and data symbol within the same symbol of the reference numerology (using the SCS larger than the reference SCS) may be configured by a higher layer via RRC signaling, or may be dynamically indicated in a DCI format.

Fig. 8 illustrates scenarios of multiplexing DM-RS and data symbols using an SCS larger than a reference SCS, in accordance with some embodiments of the disclosure. In a first scenario 810, a UE operating over a system bandwidth may accommodate DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS. In a second scenario 820, a UE operating over a system bandwidth may accommodate DM-RS using 60 kHz SCS, followed by one or more data symbols using 60 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS.

In first scenario 810 and second scenario 820, DM-RS may be positioned toward or at the beginning of an initial data symbol, and the DM-RS and one or more data symbols in that initial data symbol may be multiplexed (e.g., in a TDM manner). Since additional data symbols using an SCS larger than the reference SCS may be inserted in the slot, an overhead due to DM-RS may be reduced, which may thereby increase a data rate. (Although depicted as being positioned in a symbol having an index of 2, in various embodiments, DM-RS may be positioned in symbols having any of a variety of indexes.)
In various embodiments, a TRS may or may not be inserted in one or more of the data symbols using the SCS larger than the reference SCS.

In some embodiments, use of an SCS larger than a reference SCS may be determined based on a transmission duration, and/or based on a number of OFDM symbols used in a transmission. In cases of transmissions spanning a small number of OFDM symbols (e.g., 2 OFDM symbols or 4 OFDM symbols of a reference numerology), an SCS larger than an SCS of a reference numerology may be employed for the DM-RS according to a predefined or otherwise predetermined rule, or according to implicit or explicit signaling, and symbols other than the first symbol that is used for DM-RS may be used for data. A transmission length indicator carried via DCI may implicitly indicate the SCS used for the DM-RS symbol in combination with a predefined rule, without relying on an explicit indication of the SCS used for the DM-RS.

For some embodiments, to accommodate high-speed operation, additional DM-RS may be inserted (e.g., in a second half of the slot, or a second portion of the slot), which may advantageously improve a channel estimation and frequency and Doppler offset tracking performance. A larger SCS than the reference SCS may be applied for DM-RS (e.g., the additional DM-RS) to reduce the DM-RS overhead. Fig. 9 illustrates scenarios of multiplexing DM-RS and data symbols using an SCS larger than a reference SCS for high-speed designs, in accordance with some embodiments of the disclosure.

In a first scenario 910, a UE operating over a system bandwidth may, in a first part of a slot (e.g., a first half of the slot), accommodate DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS. The UE in scenario 910 may then, in a second part of the slot (e.g., a second half of the slot), accommodate an additional DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using the 15 kHz reference SCS.

In a second scenario 920, a UE operating over a system bandwidth may, in a first part of a slot (e.g., a first half of the slot), accommodate DM-RS using 60 kHz SCS, followed by one or more data symbols using 60 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS. The UE in scenario 920 may then, in a second part of the slot (e.g., a second half of the slot), accommodate an additional DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using the 15 kHz reference SCS.
Accordingly, in various embodiments, two DM-RS may be inserted in the data channel in one slot, which may advantageously improve channel estimation and frequency and Doppler offset tracking performance. For these two DM-RS, an SCS larger than a reference SCS may be applied.

For some embodiments, frequency hopping on a sub-slot basis may also be applied for data channel transmission to exploit the benefit of frequency diversity. In particular, different frequency resources may be allocated for data channel transmission for portions of (e.g., halves of) a slot. In each portion of a slot (e.g., each half of a slot), DM-RS may be inserted at the beginning of a data channel to enable early decoding. An SCS larger than a reference SCS may be applied for the DM-RS to reduce the DM-RS overhead, and the remainder of the symbol time (in the reference numerology) may be multiplexed with data symbols (in the numerology of the larger SCS). Fig. 10 illustrates scenarios of multiplexing DM-RS and data symbols using an SCS larger than a reference SCS for intra-slot frequency-hopping designs, in accordance with some embodiments of the disclosure.

In a first scenario 1010, a UE operating at a first band of frequencies within a system bandwidth may, in a first part of a slot (e.g., a first half of the slot), accommodate DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS. The UE may then hop to a second band of frequencies within the system bandwidth. The UE in scenario 1010 operating at the second band of frequencies may then, in a second part of the slot (e.g., a second half of the slot), accommodate an additional DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using the 15 kHz reference SCS.

In a second scenario 1020, a UE operating at a first band of frequencies within a system bandwidth may, in a first part of a slot (e.g., a first half of the slot), accommodate DM-RS using 60 kHz SCS, followed by one or more data symbols using 60 kHz SCS, followed by one or more data symbols using a 15 kHz reference SCS. The UE may then hop to a second band of frequencies within the system bandwidth. The UE in scenario 1020 operating at the second band of frequencies may then, in a second part of the slot (e.g., a second half of the slot), accommodate an additional DM-RS using 30 kHz SCS, followed by a data symbol using 30 kHz SCS, followed by one or more data symbols using the 15 kHz reference SCS.

For some embodiments, to advantageously further improve data rates, for a DL data subframe, PDCCH and DM-RS may be multiplexed within the same symbol of a reference numerology using an SCS larger than a reference SCS of the reference numerology.
Whether to multiplex PDCCH and DM-RS within the same symbol of a reference nomenclature using the SCS larger than the reference SCS may be configured by higher layers via RRC signaling or may be dynamically indicated in DCI. In the latter case, a two-step DCI may be considered, where the numerology used for the second-step DCI may be dynamically indicated in the first-step DCI.

Fig. 11 illustrates scenarios of multiplexing DM-RS and PDCCH using an SCS larger than a reference SCS for DL slot structures, in accordance with some embodiments of the disclosure. In a first scenario 1110, a UE operating over a system bandwidth may accommodate PDCCH using 30 kHz SCS, followed by DM-RS using 30 kHz SCS, within a first symbol of a reference nomenclature. Subsequently, the UE may accommodate one or more data symbols using a 15 kHz reference SCS. Accordingly, a total number of symbols (of the reference numerology) used for data may be 13.

In a second scenario 1120, a UE operating over a system bandwidth may accommodate PDCCH using 60 kHz SCS, followed by DM-RS using 60 kHz SCS, followed by one or more data symbols using 60 kHz SCS, within a first symbol of a reference nomenclature. Subsequently, the UE may accommodate one or more data symbols using a 15 kHz reference SCS. Accordingly, a total number of symbols (of the reference numerology) used for data may be 13.5.

For some embodiments (e.g., in embodiments in which DM-RS may be shared for both data channel and control channel), PDCCH and DM-RS may be multiplexed in an FDM manner. In some embodiments, PDCCH and DM-RS may use the same numerology. A receiver may estimate a channel based on DM-RS and use the estimation for the decoding of PDCCH and PDSCH.

Fig. 12 illustrates a scenario of multiplexing DM-RS and PDCCH in the same symbol in an FDM manner, in accordance with some embodiments of the disclosure. In a scenario 1200, a UE operating over a system bandwidth may accommodate DM-RS and PDCCH multiplexed in an FDM matter using a 15 kHz reference SCS, followed by one or more data symbols using a 15 kHz reference SCS.

Furthermore, the mechanisms and methods disclosed herein may be extended to embodiments in which PDCCH is multiplexed with DL reference signals including Channel State Information Reference Signal (CSI-RS), and to embodiments in which PUCCH is multiplexed with UL reference signals including Sounding Reference Signal (SRS). In various embodiments, multiplexing of control channel (e.g., PDCCH and/or PUCCH) and other reference signals (e.g., CSI-RS and/or SRS) in the same symbol may be
enabled or otherwise configured by higher layers via dedicated RRC signaling or may be dynamically indicated in DCI. For some embodiments, for two-stage DCI, multiplexing of control channel (e.g., PDCCH and/or PUCCH) and other reference signals (e.g., CSI-RS and/or SRS) in the same symbol may be dynamically indicated in a first-stage DCI.

In some embodiments, CSI-RS and/or SRS transmission using an SCS larger than a reference SCS may be dynamically indicated in DCI, such as by a field which indicates the numerology used for the CSI-RS and/or SRS transmission. Additionally, a set of supported SCSs (and/or supported numerologies) may be configured by higher layers, while DCI may be used to indicate an SCS to be used for CSI-RS or SRS transmission from the set of supported SCSs. Alternatively, a CSI-RS resource or SRS resource may include information regarding SCS (e.g., the indicator information).

Fig. 13 illustrates scenarios of multiplexing control channels and reference signals using an SCS larger than a reference SCS, in accordance with some embodiments of the disclosure. In a first scenario 1310, a UE operating over a system bandwidth may accommodate PDCCH using 30 kHz SCS, followed by a CSI-RS using 30 kHz SCS at or toward a first symbol of an RB (which may have a numerology comprising a 15 kHz SCS). In a second scenario 1320, a UE operating over a system bandwidth may accommodate an SRS using 30 kHz SCS, followed by a PUCCH using 30 kHz SCS at or toward a last symbol of an RB (which may have a numerology comprising a 15 kHz SCS).

Accordingly, in various embodiments, PDCCH and CSI-RS may use an SCS larger than a reference SCS and may be multiplexed in a TDM manner at or toward a first symbol of an RB. Moreover, in various embodiments, SRS and PUCCH may use an SCS larger than a reference SCS and may be multiplexed in a TDM manner at or toward a last symbol of an RB.

With respect to various embodiments of the disclosure, various DM-RS patterns disclosed herein may be employed. Fig. 14 illustrates scenarios of symmetric DM-RS patterns utilizing CDM, and a hybrid of Time-Division Multiplexing (TDM) and FDM, for support of up to rank-four transmissions, in accordance with some embodiments of the disclosure. A first DM-RS partem 1410 may span OFDM symbols 0 through 13 and subcarrier frequencies 0 through 11. First DM-RS partem 1410 may provide support for up to 4 APs. A first portion of the DM-RS may be front loaded (e.g., toward the beginning of RB symbols for data transmission), while a second portion of the DM-RS may be end-loaded (e.g., toward the end of RB symbols for data transmission). First DM-RS partem 1410 may
incorporate a combination of CDM in both the time domain and the frequency domain, and may support up to rank-four transmission.

A second DM-RS pattern 1420 may span OFDM symbols 0 through 13 and subcarrier frequencies 0 through 11. Second DM-RS pattern 1420 may provide support for up to 4 APs. A first portion of the DM-RS may be front loaded (e.g., toward the beginning of RB symbols for data transmission), while a second portion of the DM-RS may be end-loaded (e.g., toward the end of RB symbols for data transmission). Second DM-RS pattern 1420 may incorporate a combination of CDM in both the time domain and the frequency domain, and may support up to rank-four transmission.

Fig. 15 illustrates scenarios of symmetric DM-RS patterns utilizing CDM, and a hybrid of TDM and FDM, in accordance with some embodiments of the disclosure. A first DM-RS pattern 1510 may span OFDM symbols 0 through 13 and subcarrier frequencies 0 through 11. First DM-RS partem 1510 may provide support for up to 8 APs. A first portion of the DM-RS may be front loaded (e.g., toward the beginning of RB symbols for data transmission), while a second portion of the DM-RS may be end-loaded (e.g., toward the end of RB symbols for data transmission). Partem 1510 may incorporate a combination of CDM in both the time domain and the frequency domain.

A second DM-RS pattern 1520 may span OFDM symbols 0 through 13 and subcarrier frequencies 0 through 11. Second DM-RS pattern 1520 may provide support for up to 8 APs. A first portion of the DM-RS may be front loaded (e.g., toward the beginning of RB symbols for data transmission), while a second portion of the DM-RS may be end-loaded (e.g., toward the end of RB symbols for data transmission). Partem 1520 may incorporate a combination of CDM in both the time domain and the frequency domain.

The DM-RS patterns disclosed herein may advantageously compensate for performance degradation in high mobility scenarios, while maintaining performance targets for large delay spreads. The combination of CDM in the time domain and the frequency domain may advantageously facilitate satisfactory performance in either a scenario of high Doppler frequencies or a scenario of large delay spreads.

Various embodiments may comprise other DM-RS pattern that incorporate combinations of CDM in both the time domain and the frequency domain.

In some embodiments, a density of DM-RS REs within an RB (e.g., a DM-RS density) may be similar to, or higher than, a density of DM-RS REs of a legacy LTE RB, for scenarios of up to four DM-RS APs. In embodiments in which a DM-RS density may be the same as a legacy LTE DM-RS density, more than half of the DM-RS REs may be assigned to
CDM in the frequency domain, rather than in the time domain. This may advantageously accommodate NR channel conditions which may be rapidly time-varying, and may be occasionally highly frequency-selective, considering moderate delay spread caused by narrow beamforming but considerable numbers of use cases for high-mobility.

In some embodiments, DM-RS patterns may provide a fair RE allocation to CDM in the time domain and the frequency domain, while it utilizes greater number of REs than that of a legacy LTE DM-RS pattern.

Symmetric DM-RS patterns (such as first DM-RS pattern 1510) may provide fair performance of channel estimation among DM-RS APs, while non-symmetric DM-RS patterns (such as second DM-RS pattern 1520) may efficiently assign APs relying on their channel condition (e.g., scenarios of MU-MIMO). For example, in second DM-RS pattern 1520, the number of DM-RS REs used by APs 0-3 may be greater than the number of DM-RS REs used by APs 4-7. As a result, a gNB may assign APs 0-3 to UEs that may experience worse channel condition (in terms of channel estimation or throughput performance) than other paired UEs. On the other hand, paired UEs in relatively good channel conditions may be assigned APs 4-7 (which have fewer DM-RS REs than APs 0-3).

For some embodiments, DM-RS may be front-loaded, or allocated in the first one or two symbols of PDSCH REs. First DM-RS pattern 1510 and second DM-RS pattern 1520 may pertain, respectively, to symmetric DM-RS patterns and non-symmetric DM-RS patterns which may support up to eight DM-RS APs.

In some embodiments, support for up to 16 DM-RS APs may be realized by allocating different APs between the first and second symbols of PDSCH for REs associated with the same APs (e.g., in first DM-RS pattern 1510 and/or second DM-RS pattern 1520).

Fig. 16 illustrates an eNB and a UE, in accordance with some embodiments of the disclosure. Fig. 16 includes block diagrams of an eNB 1610 and a UE 1630 which are operable to co-exist with each other and other elements of an LTE network. High-level, simplified architectures of eNB 1610 and UE 1630 are described so as not to obscure the embodiments. It should be noted that in some embodiments, eNB 1610 may be a stationary non-mobile device.

eNB 1610 is coupled to one or more antennas 1605, and UE 1630 is similarly coupled to one or more antennas 1625. However, in some embodiments, eNB 1610 may incorporate or comprise antennas 1605, and UE 1630 in various embodiments may incorporate or comprise antennas 1625.
In some embodiments, antennas 1605 and/or antennas 1625 may comprise one or more directional or omni-directional antennas, including monopole antennas, dipole antennas, loop antennas, patch antennas, microstrip antennas, coplanar wave antennas, or other types of antennas suitable for transmission of RF signals. In some MIMO (multiple-input and multiple output) embodiments, antennas 1605 are separated to take advantage of spatial diversity.

ENB 1610 and UE 1630 are operable to communicate with each other on a network, such as a wireless network. ENB 1610 and UE 1630 may be in communication with each other over a wireless communication channel 1650, which has both a downlink path from ENB 1610 to UE 1630 and an uplink path from UE 1630 to ENB 1610.

As illustrated in Fig. 16, in some embodiments, ENB 1610 may include a physical layer circuitry 1612, a MAC (media access control) circuitry 1614, a processor 1616, a memory 1618, and a hardware processing circuitry 1620. A person skilled in the art will appreciate that other components not shown may be used in addition to the components shown to form a complete ENB.

In some embodiments, physical layer circuitry 1612 includes a transceiver 1613 for providing signals to and from UE 1630. Transceiver 1613 provides signals to and from UEs or other devices using one or more antennas 1605. In some embodiments, MAC circuitry 1614 controls access to the wireless medium. Memory 1618 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Hardware processing circuitry 1620 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 1616 and memory 1618 are arranged to perform the operations of hardware processing circuitry 1620, such as operations described herein with reference to logic devices and circuitry within ENB 1610 and/or hardware processing circuitry 1620.

Accordingly, in some embodiments, ENB 1610 may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

As is also illustrated in Fig. 16, in some embodiments, UE 1630 may include a physical layer circuitry 1632, a MAC circuitry 1634, a processor 1636, a memory 1638, a hardware processing circuitry 1640, a wireless interface 1642, and a display 1644. A person
skilled in the art would appreciate that other components not shown may be used in addition to the components shown to form a complete UE.

[00110] In some embodiments, physical layer circuitry 1632 includes a transceiver 1633 for providing signals to and from eNB 1610 (as well as other eNBs). Transceiver 1633 provides signals to and from eNBs or other devices using one or more antennas 1625. In some embodiments, MAC circuitry 1634 controls access to the wireless medium. Memory 1638 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Wireless interface 1642 may be arranged to allow the processor to communicate with another device. Display 1644 may provide a visual and/or tactile display for a user to interact with UE 1630, such as a touch-screen display. Hardware processing circuitry 1640 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 1636 and memory 1638 may be arranged to perform the operations of hardware processing circuitry 1640, such as operations described herein with reference to logic devices and circuitry within UE 1630 and/or hardware processing circuitry 1640.

[00111] Accordingly, in some embodiments, UE 1630 may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

[00112] Elements of Fig. 16, and elements of other figures having the same names or reference numbers, can operate or function in the manner described herein with respect to any such figures (although the operation and function of such elements is not limited to such descriptions). For example, Figs. 17 and 21-22 also depict embodiments of eNBs, hardware processing circuitry of eNBs, UEs, and/or hardware processing circuitry of UEs, and the embodiments described with respect to Fig. 16 and Figs. 17 and 21-22 can operate or function in the manner described herein with respect to any of the figures.

[00113] In addition, although eNB 1610 and UE 1630 are each described as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements and/or other hardware elements. In some embodiments of this disclosure, the functional elements can refer to one or more processes operating on one or more processing elements. Examples of software and/or hardware configured elements include Digital Signal Processors (DSPs), one or more microprocessors, DSPs, Field-Programmable Gate Arrays (FPGAs), Application
Specific Integrated Circuits (ASICs), Radio-Frequency Integrated Circuits (RFICs), and so on.

[00114] Fig. 17 illustrates hardware processing circuitries for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, and for accommodating DM-RS design utilizing a combination of CDM in the time domain and the frequency domain, in accordance with some embodiments of the disclosure. With reference to Fig. 16, a UE may include various hardware processing circuitries discussed herein (such as hardware processing circuitry NUMBER of Fig. 17), which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, in Fig. 16, UE 1630 (or various elements or components therein, such as hardware processing circuitry 1640, or combinations of elements or components therein) may include part of, or all of, these hardware processing circuitries.

[00115] In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 1636 (and/or one or more other processors which UE 1630 may comprise), memory 1638, and/or other elements or components of UE 1630 (which may include hardware processing circuitry 1640) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 1636 (and/or one or more other processors which UE 1630 may comprise) may be a baseband processor.

[00116] Returning to Fig. 17, an apparatus of UE 1630 (or another UE or mobile handset), which may be operable to communicate with one or more eNBs on a wireless network, may comprise hardware processing circuitry 1700. In some embodiments, hardware processing circuitry 1700 may comprise one or more antenna ports 1705 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 1650). Antenna ports 1705 may be coupled to one or more antennas 1707 (which may be antennas 1625). In some embodiments, hardware processing circuitry 1700 may incorporate antennas 1707, while in other embodiments, hardware processing circuitry 1700 may merely be coupled to antennas 1707.

[00117] Antenna ports 1705 and antennas 1707 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 1705 and antennas 1707 may be operable to provide transmissions
from UE 1630 to wireless communication channel 1650 (and from there to eNB 1610, or to another eNB). Similarly, antennas 1707 and antenna ports 1705 may be operable to provide transmissions from a wireless communication channel 1650 (and beyond that, from eNB 1610, or another eNB) to UE 1630.

[00118] Hardware processing circuitry 1700 may comprise various circuitries operable in accordance with the various embodiments discussed herein. With reference to Fig. 17, hardware processing circuitry 1700 may comprise a first circuitry 1710, a second circuitry 1720, and/or a third circuitry 1730.

[00119] In various embodiments, first circuitry 1710 may be operable to process a first set of DL symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal. First circuitry 1710 may also be operable to process a second set of DL symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel. The first subcarrier spacing may be different from the second subcarrier spacing. Hardware processing circuitry 1700 may also comprise an interface 1715 for receiving the first set of DL symbols and the second set of DL symbols from a receiving circuitry.

[00120] In some embodiments, the first numerology may have a first symbol time, the second numerology may have a second symbol time, and the first symbol time may be less than the second symbol time. For some embodiments, the first set of symbols may carry an additional data channel and/or an additional control channel, and a symbol time of the reference signal and a symbol time of the additional data channel may be in accordance with the first symbol time. In some embodiments, the reference signal may be a CSI-RS. For some embodiments, the reference signal is a DM-RS.

[00121] For some embodiments, multiple DM-RS APs may be multiplexed in the first set of DL symbols in a TDM manner, a FDM manner, and/or a CDM manner. In some embodiments, the data channel may be a PDSCH.

[00122] In some embodiments, first circuitry 1710 may be operable to process a transmission carrying at least one parameter associated with the first numerology. The transmission may be a transmission bearing RRC signaling and/or a transmission bearing DCI.

[00123] In various embodiments, second circuitry 1720 may be operable to generate a first set of UL symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal. Second circuitry 1720 may also be operable to generate a second set of UL symbols in accordance with a second numerology
having a second subcarrier spacing, the second set of symbols carrying a data channel. The first subcarrier spacing may be different from the second subcarrier spacing. Hardware processing circuitry 1700 may also comprise an interface for transmitting the first set of UL symbols and the second set of UL symbols to a transmitting circuitry.

[00124] In some embodiments, the first numerology may have a first symbol time, the second numerology may have a second symbol time, and the first symbol time may be less than the second symbol time. For some embodiments, the first set of symbols may carry an additional data channel and/or an additional control channel, and a symbol time of the reference signal and a symbol time of the additional data channel may be in accordance with the first symbol time. In some embodiments, the reference signal may be an SRS.

[00125] For some embodiments, the reference signal may be a DM-RS. In some embodiments, multiple DM-RS APs may be multiplexed in the first set of DL symbols in at least one of: a TDM manner, a FDM manner, or a CDM manner. For some embodiments, the data channel may be a PUSCH.

[00126] In some embodiments, first circuitry 1710 may also be operable to process a transmission carrying at least one parameter associated with the first numerology. The transmission may be a transmission bearing RRC signaling and/or a transmission bearing DCI.

[00127] In various embodiments, first circuitry 1710 may additionally be operable to process a first plurality of REs carrying DM-RS for a set of one or more APs, the first plurality of REs spanning a plurality of OFDM symbols. First circuitry 1710 may also be operable to process a second plurality of REs carrying DM-RS for the set of APs, the second plurality of REs spanning a plurality of subcarrier frequencies. Hardware processing circuitry may also comprise an interface for receiving the first plurality of REs and the second plurality of REs from a receiving circuitry.

[00128] In some embodiments, the set of APs may comprise a first AP corresponding with a first OCC and a second AP corresponding with a second OCC. Third circuitry 1730 may be operable to decode the DM-RS carried by the first plurality of REs for the first AP using the first OCC. Third circuitry 1730 may also be operable to decode the DM-RS carried by the second plurality of REs for the second AP using the second OCC. First circuitry 1710 may be operable to provide information regarding the first plurality of REs and the second plurality of REs to third circuitry 1730 by an interface 1715.

[00129] For some embodiments, the first plurality of REs may span a single subcarrier frequency, and the second plurality of REs may span a single OFDM symbol. In some
embodiments, a PRB may comprise both the first plurality of REs and the second plurality of REs. For some embodiments, a first PRB may comprise the first plurality of REs, and a second PRB may comprise the second plurality of REs.

[00130] In some embodiments, the set of APs may be a first set of APs, the plurality of OFDM symbols may be a first plurality of OFDM symbols, and the plurality of subcarrier frequencies may be a first plurality of subcarrier frequencies. For some embodiments, first circuitry 1710 may be operable to process a third plurality of REs carrying DM-RS for a second set of one or more APs, the third plurality of REs spanning a second plurality of OFDM symbols. First circuitry 1710 may also be operable to process a fourth plurality of REs carrying DM-RS for the second set of APs, the fourth plurality of REs spanning a second plurality of subcarrier frequencies.

[00131] For some embodiments, DM-RS for the first set of APs may be carried by more REs within a resource block than DM-RS for the second set of APs. In some embodiments, the first plurality of REs may be offset by a number of symbols from a first OFDM symbol in a first half of a RB, and the third plurality of REs may be offset by the number of symbols from a first OFDM symbol in a second half of the RB.

[00132] In some embodiments, first circuitry 1710, second circuitry 1720, and/or third circuitry 1730 may be implemented as separate circuitries. In other embodiments, first circuitry 1710, second circuitry 1720, and/or third circuitry 1730 may be combined and implemented together in a circuitry without altering the essence of the embodiments.

[00133] Fig. 18 illustrates methods for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, in accordance with some embodiments of the disclosure. Fig. 19 illustrates methods for a UE for accommodating DM-RS patterns using a different SCS than an SCS of a reference numerology, in accordance with some embodiments of the disclosure. Fig. 20 illustrates methods for a UE for accommodating DM-RS design utilizing a combination of CDM in the time domain and the frequency domain, in accordance with some embodiments of the disclosure. With reference to Fig. 16, methods that may relate to UE 1630 and hardware processing circuitry 1640 are discussed herein. Although the actions in the method 1800 of Fig. 18, method 1900 of Fig. 19, and method 2000 of Fig. 20 are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed in Figs. 18-20 are optional in accordance with certain embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of
operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause UE 1630 and/or hardware processing circuitry 1640 to perform an operation comprising the methods of Figs. 18-20. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media.

In some embodiments, an apparatus may comprise means for performing various actions and/or operations of the methods of Figs. 18-20.

Returning to Fig. 18, various methods may be in accordance with the various embodiments discussed herein. A method 1800 may comprise a processing 1810 and a processing 1815. In some embodiments, method 1800 may also comprise a processing 1820.

In processing 1810, a first set of DL symbols may be processed in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal. In processing 1815, a second set of DL symbols may be processed in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel. The first subcarrier spacing may be different from the second subcarrier spacing.

In some embodiments, the first numerology may have a first symbol time, the second numerology may have a second symbol time, and the first symbol time may be less than the second symbol time. For some embodiments, the first set of symbols may carry an additional data channel and/or an additional control channel, and a symbol time of the reference signal and a symbol time of the additional data channel may be in accordance with the first symbol time. In some embodiments, the reference signal may be a CSI-RS. For some embodiments, the reference signal is a DM-RS.

For some embodiments, multiple DM-RS APs may be multiplexed in the first set of DL symbols in a TDM manner, a FDM manner, and/or a CDM manner. In some embodiments, the data channel may be a PDSCH.

In some embodiments, in processing 1820, a transmission carrying at least one parameter associated with the first numerology may be processed. The transmission may be one of: a transmission bearing RRC signaling, or a transmission bearing DCI.
Returning to Fig. 19, various methods may be in accordance with the various embodiments discussed herein. A method 1900 may comprise a generating 1910 and a generating 1915. In some embodiments, method 1900 may comprise a processing 1920.

In generating 1910, a first set of UL symbols may be generated in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal. In generating 195, a second set of UL symbols may be generated in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel. The first subcarrier spacing may be different from the second subcarrier spacing.

In some embodiments, the first numerology may have a first symbol time, the second numerology may have a second symbol time, and the first symbol time may be less than the second symbol time. For some embodiments, the first set of symbols may carry an additional data channel and/or an additional control channel, and a symbol time of the reference signal and a symbol time of the additional data channel may be in accordance with the first symbol time. In some embodiments, the reference signal may be an SRS.

For some embodiments, the reference signal may be a DM-RS. In some embodiments, multiple DM-RS APs may be multiplexed in the first set of DL symbols in at least one of: a TDM manner, a FDM manner, or a CDM manner. For some embodiments, the data channel may be a PUSCH.

In some embodiments, in processing 1920, a transmission carrying at least one parameter associated with the first numerology may be processed. The transmission may be a transmission bearing RRC signaling and/or a transmission bearing DCI.

Returning to Fig. 20, various methods may be in accordance with the various embodiments discussed herein. A method 2000 may comprise a processing 2010 and a processing 2015. In some embodiments, method 2000 may also comprise a decoding 2020, a decoding 2025, a processing 2030, and/or a processing 2035.

In processing 2010, a first plurality of REs carrying DM-RS for a set of one or more APs may be processed, the first plurality of REs spanning a plurality of OFDM symbols. In processing 2015, a second plurality of REs carrying DM-RS for the set of APs may be processed, the second plurality of REs spanning a plurality of subcarrier frequencies.

In some embodiments, the set of APs may comprise a first AP corresponding with a first OCC and a second AP corresponding with a second OCC. In decoding 2020, the DM-RS carried by the first plurality of REs for the first AP may be decoded using the first
OCC. In decoding 2025, the DM-RS carried by the second plurality of REs for the second AP may be decoded using the second OCC.

[00149] For some embodiments, the first plurality of REs may span a single subcarrier frequency, and the second plurality of REs may span a single OFDM symbol. In some embodiments, a PRB may comprise both the first plurality of REs and the second plurality of REs. For some embodiments, a first PRB may comprise the first plurality of REs, and a second PRB may comprise the second plurality of REs.

[00150] In some embodiments, the set of APs may be a first set of APs, the plurality of OFDM symbols may be a first plurality of OFDM symbols, and the plurality of subcarrier frequencies may be a first plurality of subcarrier frequencies. In processing 2030, a third plurality of REs carrying DM-RS for a second set of one or more APs may be processed, the third plurality of REs spanning a second plurality of OFDM symbols. In processing 2035, a fourth plurality of REs carrying DM-RS for the second set of APs may be processed, the fourth plurality of REs spanning a second plurality of subcarrier frequencies.

[00151] For some embodiments, DM-RS for the first set of APs may be carried by more REs within a resource block than DM-RS for the second set of APs. In some embodiments, the first plurality of REs may be offset by a number of symbols from a first OFDM symbol in a first half of a RB, and the third plurality of REs may be offset by the number of symbols from a first OFDM symbol in a second half of the RB.

[00152] Fig. 21 illustrates example components of a device, in accordance with some embodiments of the disclosure. In some embodiments, the device 2100 may include application circuitry 2102, baseband circuitry 2104, Radio Frequency (RF) circuitry 2106, front-end module (FEM) circuitry 2108, one or more antennas 2110, and power management circuitry (PMC) 2112 coupled together at least as shown. The components of the illustrated device 2100 may be included in a UE or a RAN node. In some embodiments, the device 2100 may include less elements (e.g., a RAN node may not utilize application circuitry 2102, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 2100 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).

[00153] The application circuitry 2102 may include one or more application processors. For example, the application circuitry 2102 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, an so on). 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 2100. In some embodiments, processors of application circuitry 2102 may process IP data packets received from an EPC.

[00154] The baseband circuitry 2104 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 2104 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 2106 and to generate baseband signals for a transmit signal path of the RF circuitry 2106. Baseband processing circuitry 2104 may interface with the application circuitry 2102 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 2106. For example, in some embodiments, the baseband circuitry 2104 may include a third generation (3G) baseband processor 2104A, a fourth generation (4G) baseband processor 2104B, a fifth generation (5G) baseband processor 2104C, or other baseband processor(s) 2104D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), and so on). The baseband circuitry 2104 (e.g., one or more of baseband processors 2104A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 2106. In other embodiments, some or all of the functionality of baseband processors 2104A-D may be included in modules stored in the memory 2104G and executed via a Central Processing Unit (CPU) 2104E. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, and so on. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 2104 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 2104 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.

[00155] In some embodiments, the baseband circuitry 2104 may include one or more audio digital signal processor(s) (DSP) 2104F. The audio DSP(s) 2104F 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 2104 and the application circuitry 2102 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 2104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 2104 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 2104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

RF circuitry 2106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 2106 may include switches, filters, amplifiers, and so on to facilitate the communication with the wireless network. RF circuitry 2106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 2108 and provide baseband signals to the baseband circuitry 2104. RF circuitry 2106 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 2104 and provide RF output signals to the FEM circuitry 2108 for transmission.

In some embodiments, the receive signal path of the RF circuitry 2106 may include mixer circuitry 2106A, amplifier circuitry 2106B and filter circuitry 2106C. In some embodiments, the transmit signal path of the RF circuitry 2106 may include filter circuitry 2106C and mixer circuitry 2106A. RF circuitry 2106 may also include synthesizer circuitry 2106D for synthesizing a frequency for use by the mixer circuitry 2106A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 2106A of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 2108 based on the synthesized frequency provided by synthesizer circuitry 2106D. The amplifier circuitry 2106B may be configured to amplify the down-converted signals and the filter circuitry 2106C 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 2104 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 2106A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00159] In some embodiments, the mixer circuitry 2106A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 2106D to generate RF output signals for the FEM circuitry 2108. The baseband signals may be provided by the baseband circuitry 2104 and may be filtered by filter circuitry 2106C.

[00160] In some embodiments, the mixer circuitry 2106A of the receive signal path and the mixer circuitry 2106A 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 2106A of the receive signal path and the mixer circuitry 2106A 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 2106A of the receive signal path and the mixer circuitry 2106A may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 2106A of the receive signal path and the mixer circuitry 2106A of the transmit signal path may be configured for super-heterodyne operation.

[00161] 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 2106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 2104 may include a digital baseband interface to communicate with the RF circuitry 2106.

[00162] 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.

[00163] In some embodiments, the synthesizer circuitry 2106D 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 2106D may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00164] The synthesizer circuitry 2106D may be configured to synthesize an output frequency for use by the mixer circuitry 2106A of the RF circuitry 2106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 2106D may be a fractional N/N+1 synthesizer.

[00165] 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 2104 or the applications processor 2102 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 2102.

[00166] Synthesizer circuitry 2106D of the RF circuitry 2106 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.

[00167] In some embodiments, synthesizer circuitry 2106D 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 2106 may include an IQ/polar converter.

[00168] FEM circuitry 2108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 2110, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 2106 for further processing. FEM circuitry 2108 may also include a transmit
signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 2106 for transmission by one or more of the one or more antennas 2110. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 2106, solely in the FEM 2108, or in both the RF circuitry 2106 and the FEM 2108.

[00169] In some embodiments, the FEM circuitry 2108 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 2106). The transmit signal path of the FEM circuitry 2108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 2106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 2110).

[00170] In some embodiments, the PMC 2112 may manage power provided to the baseband circuitry 2104. In particular, the PMC 2112 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 2112 may often be included when the device 2100 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 2112 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[00171] While Fig. 21 shows the PMC 2112 coupled only with the baseband circuitry 2104. However, in other embodiments, the PMC 2112 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 2102, RF circuitry 2106, or FEM 2108.

[00172] In some embodiments, the PMC 2112 may control, or otherwise be part of, various power saving mechanisms of the device 2100. For example, if the device 2100 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 2100 may power down for brief intervals of time and thus save power.

[00173] If there is no data traffic activity for an extended period of time, then the device 2100 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, and so on. The device 2100 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 2100
may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00174] 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.

[00175] Processors of the application circuitry 2102 and processors of the baseband circuitry 2104 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 2104, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 2104 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.

[00176] Fig. 22 illustrates example interfaces of baseband circuitry, in accordance with some embodiments of the disclosure. As discussed above, the baseband circuitry 2104 of Fig. 21 may comprise processors 2104A-2104E and a memory 2104G utilized by said processors. Each of the processors 2104A-2104E may include a memory interface, 2204A-2204E, respectively, to send/receive data to/from the memory 2104G.

[00177] The baseband circuitry 2104 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 2212 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 2104), an application circuitry interface 2214 (e.g., an interface to send/receive data to/from the application circuitry 2102 of Fig. 21), an RF circuitry interface 2216 (e.g., an interface to send/receive data to/from RF circuitry 2106 of Fig. 21), a wireless hardware connectivity interface 2218 (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 2220 (e.g., an interface to send/receive power or control signals to/from the PMC 2112.
It is pointed out that elements of any of the Figures herein having the same reference numbers and/or names as elements of any other Figure herein may, in various embodiments, operate or function in a manner similar to those elements of the other Figure (without being limited to operating or functioning in such a manner).

Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually exclusive.

While the disclosure has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. For example, other memory architectures e.g., Dynamic RAM (DRAM) may use the embodiments discussed. The embodiments of the disclosure are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

In addition, well known power/ground connections to integrated circuit (IC) chips and other components may or may not be shown within the presented figures, for simplicity of illustration and discussion, and so as not to obscure the disclosure. Further, arrangements may be shown in block diagram form in order to avoid obscuring the disclosure, and also in view of the fact that specifics with respect to implementation of such block diagram arrangements are highly dependent upon the platform within which the present disclosure is to be implemented (i.e., such specifics should be well within purview of one
skilled in the art). Where specific details (e.g., circuits) are set forth in order to describe example embodiments of the disclosure, it should be apparent to one skilled in the art that the disclosure can be practiced without, or with variation of, these specific details. The description is thus to be regarded as illustrative instead of limiting.

[00183] The following examples pertain to further embodiments. Specifics in the examples may be used anywhere in one or more embodiments. All optional features of the apparatus described herein may also be implemented with respect to a method or process.

[00184] Example 1 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising: one or more processors to: process a first set of Downlink (DL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and process a second set of DL symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing; and an interface for receiving the first set of DL symbols and the second set of DL symbols from a receiving circuitry.

[00185] In example 2, the apparatus of example 1, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

[00186] In example 3, the apparatus of example 2, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

[00187] In example 4, the apparatus of example 3, wherein the reference signal is a Channel State Information Reference Signal (CSI RS).

[00188] In example 5, the apparatus of any of examples 1 through 4, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

[00189] In example 6, the apparatus of example 5, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

[00190] In example 7, the apparatus of any of examples 1 through 6, wherein the data channel is a Physical Downlink Shared Channel (PDSCH).
In example 8, the apparatus of any of examples 1 through 7, wherein the one or more processors are to: process a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

Example 9 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of examples 1 through 8.

Example 10 provides a method comprising: processing a first set of Downlink (DL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and processing a second set of DL symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.

In example 11, the method of example 10, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

In example 12, the method of example 11, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

In example 13, the method of example 12, wherein the reference signal is a Channel State Information Reference Signal (CSI RS).

In example 14, the method of any of examples 10 through 13, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

In example 15, the method of example 14, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

In example 16, the method of any of examples 10 through 15, wherein the data channel is a Physical Downlink Shared Channel (PDSCH).

In example 17, the method of any of examples 10 through 16, comprising: processing a transmission carrying at least one parameter associated with the first
numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

[00201] Example 18 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 10 through 17.

[00202] Example 19 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising: means for processing a first set of Downlink (DL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and means for processing a second set of DL symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.

[00203] In example 20, the apparatus of example 19, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

[00204] In example 21, the apparatus of example 20, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

[00205] In example 22, the apparatus of example 21, wherein the reference signal is a Channel State Information Reference Signal (CSI RS).

[00206] In example 23, the apparatus of any of examples 19 through 22, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

[00207] In example 24, the apparatus of example 23, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

[00208] In example 25, the apparatus of any of examples 19 through 24, wherein the data channel is a Physical Downlink Shared Channel (PDSCH).

[00209] In example 26, the apparatus of any of examples 19 through 25, comprising: means for processing a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).
Example 27 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with a New Radio (NR) Node-B (gNB) on a wireless network to perform an operation comprising: process a first set of Downlink (DL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and process a second set of DL symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.

In example 28, the machine readable storage media of example 27, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

In example 29, the machine readable storage media of example 28, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

In example 30, the machine readable storage media of example 29, wherein the reference signal is a Channel State Information Reference Signal (CSI RS).

In example 31, the machine readable storage media of any of examples 27 through 30, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

In example 32, the machine readable storage media of example 31, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

In example 33, the machine readable storage media of any of examples 27 through 32, wherein the data channel is a Physical Downlink Shared Channel (PDSCH).

In example 34, the machine readable storage media of any of examples 27 through 33, the operation comprising: process a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

Example 35 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising: one or more processors to: generate a first set of Uplink (UL) symbols in accordance with a first
numerology having a first subcarrier spacing, the first set of symbols carrying a reference
signal; and generate a second set of Uplink (UL) symbols in accordance with a first
numerology having a second subcarrier spacing, the second set of symbols carrying a data
channel, wherein the first subcarrier spacing is different from the second subcarrier spacing;
and an interface for transmitting the first set of UL symbols and the second set of UL
symbols to a transmitting circuitry.

[00219] In example 36, the apparatus of example 35, wherein the first numerology has
a first symbol time, the second numerology has a second symbol time, and the first symbol
time is less than the second symbol time.

[00220] In example 37, the apparatus of example 36, wherein the first set of symbols
carries at least one of: an additional data channel, or an additional control channel, and
wherein a symbol time of the reference signal and a symbol time of the additional data
channel are in accordance with the first symbol time.

[00221] In example 38, the apparatus of example 37, wherein the reference signal is a
Sounding Reference Signal (SRS).

[00222] In example 39, the apparatus of any of examples 35 through 38, wherein the
reference signal is a Demodulation Reference Signal (DM-RS).

[00223] In example 40, the apparatus of example 39, wherein multiple DM-RS
Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time
Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or
a Code Division Multiplexing (CDM) manner.

[00224] In example 41, the apparatus of any of examples 35 through 40, wherein the
data channel is a Physical Uplink Shared Channel (PUSCH).

[00225] In example 42, the apparatus of any of examples 35 through 41, wherein the
one or more processors are to: process a transmission carrying at least one parameter
associated with the first numerology; wherein the transmission is one of: a transmission
bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink
Control Information (DCI).

[00226] Example 43 provides a User Equipment (UE) device comprising an
application processor, a memory, one or more antennas, a wireless interface for allowing the
application processor to communicate with another device, and a touch-screen display, the
UE device including the apparatus of any of examples 35 through 42.

[00227] Example 44 provides a method comprising: generating a first set of Uplink
(UL) symbols in accordance with a first numerology having a first subcarrier spacing, the
first set of symbols carrying a reference signal; and generating a second set of Uplink (UL) symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.

[00228] In example 45, the method of example 44, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

[00229] In example 46, the method of example 45, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

[00230] In example 47, the method of example 46, wherein the reference signal is a Sounding Reference Signal (SRS).

[00231] In example 48, the method of any of examples 44 through 47, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

[00232] In example 49, the method of example 48, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

[00233] In example 50, the method of any of examples 44 through 49, wherein the data channel is a Physical Uplink Shared Channel (PUSCH).

[00234] In example 51, the method of any of examples 44 through 50, comprising: processing a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

[00235] Example 52 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 44 through 51.

[00236] Example 53 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising: means for generating a first set of Uplink (UL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and means for generating a second set of Uplink (UL) symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a
data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.

[00237] In example 54, the apparatus of example 53, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

[00238] In example 55, the apparatus of example 54, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

[00239] In example 56, the apparatus of example 55, wherein the reference signal is a Sounding Reference Signal (SRS).

[00240] In example 57, the apparatus of any of examples 53 through 56, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

[00241] In example 58, the apparatus of example 57, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

[00242] In example 59, the apparatus of any of examples 53 through 58, wherein the data channel is a Physical Uplink Shared Channel (PUSCH).

[00243] In example 60, the apparatus of any of examples 53 through 59, comprising: means for processing a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

[00244] Example 61 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with a New Radio (NR) Node-B (gNB) on a wireless network to perform an operation comprising: generate a first set of Uplink (UL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and generate a second set of Uplink (UL) symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel, wherein the first subcarrier spacing is different from the second subcarrier spacing.
In example 62, the machine readable storage media of example 61, wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

In example 63, the machine readable storage media of example 62, wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

In example 64, the machine readable storage media of example 63, wherein the reference signal is a Sounding Reference Signal (SRS).

In example 65, the machine readable storage media of any of examples 61 through 64, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

In example 66, the machine readable storage media of example 65, wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

In example 67, the machine readable storage media of any of examples 61 through 66, wherein the data channel is a Physical Uplink Shared Channel (PUSCH).

In example 68, the machine readable storage media of any of examples 61 through 67, the operation comprising: process a transmission carrying at least one parameter associated with the first numerology; wherein the transmission is one of: a transmission bearing Radio Resource Control (RRC) signaling, or a transmission bearing Downlink Control Information (DCI).

Example 69 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising: one or more processors to: process a first plurality of Resource Elements (REs) carrying DM-RS for a set of one or more Antenna Ports (APs), the first plurality of REs spanning a plurality of Orthogonal Frequency-Division Multiplexing (OFDM) symbols; and process a second plurality of REs carrying DM-RS for the set of APs, the second plurality of REs spanning a plurality of subcarrier frequencies; and an interface for receiving the first plurality of REs and the second plurality of REs from a receiving circuitry.

In example 70, the apparatus of example 69, wherein the set of APs comprises a first AP corresponding with a first Orthogonal Cover Code (OCC) and a second AP corresponding with a second OCC; and wherein the one or more processors are to: decode the
DM-RS carried by the first plurality of REs for the first AP using the first OCC; and decode
the DM-RS carried by the second plurality of REs for the second AP using the second OCC.

[00254] In example 71, the apparatus of either of examples 69 or 70, wherein the first
plurality of REs spans a single subcarrier frequency, and wherein the second plurality of REs
spans a single OFDM symbol.

[00255] In example 72, the apparatus of any of examples 69 through 71, wherein a
Physical Resource Block (PRB) comprises both the first plurality of REs and the second
plurality of REs.

[00256] In example 73, the apparatus of any of examples 69 through 72, wherein a first
Physical Resource Block (PRB) comprises the first plurality of REs, and a second PRB
comprises the second plurality of REs.

[00257] In example 74, the apparatus of any of examples 69 through 73, wherein the
set of APs is a first set of APs, the plurality of OFDM symbols is a first plurality of OFDM
symbols, and the plurality of subcarrier frequencies is a first plurality of subcarrier
frequencies; and wherein the one or more processors are to: process a third plurality of REs
carrying DM-RS for a second set of one or more APs, the third plurality of REs spanning a
second plurality of OFDM symbols; and process a fourth plurality of REs carrying DM-RS
for the second set of APs, the fourth plurality of REs spanning a second plurality of
subcarrier frequencies.

[00258] In example 75, the apparatus of example 74, wherein DM-RS for the first set
of APs is carried by more REs within a resource block than DM-RS for the second set of
APs.

[00259] In example 76, the apparatus of example 74, wherein the first plurality of REs
is offset by a number of symbols from a first OFDM symbol in a first half of a Resource
Block (RB); and wherein the third plurality of REs is offset by the number of symbols from a
first OFDM symbol in a second half of the RB.

[00260] Example 77 provides a User Equipment (UE) device comprising an
application processor, a memory, one or more antennas, a wireless interface for allowing the
application processor to communicate with another device, and a touch-screen display, the
UE device including the apparatus of any of examples 69 through 76.

[00261] Example 78 provides a method comprising: processing a first plurality of
Resource Elements (REs) carrying DM-RS for a set of one or more Antenna Ports (APs), the
first plurality of REs spanning a plurality of Orthogonal Frequency-Division Multiplexing
(OFDM) symbols; and processing a second plurality of REs carrying DM-RS for the set of APs, the second plurality of REs spanning a plurality of subcarrier frequencies.

In example 79, the method of example 78, wherein the set of APs comprises a first AP corresponding with a first Orthogonal Cover Code (OCC) and a second AP corresponding with a second OCC, comprising: decoding the DM-RS carried by the first plurality of REs for the first AP using the first OCC; and decoding the DM-RS carried by the second plurality of REs for the second AP using the second OCC.

In example 80, the method of either of examples 78 or 79, wherein the first plurality of REs spans a single subcarrier frequency, and wherein the second plurality of REs spans a single OFDM symbol.

In example 81, the method of any of examples 78 through 80, wherein a Physical Resource Block (PRB) comprises both the first plurality of REs and the second plurality of REs.

In example 82, the method of any of examples 78 through 81, wherein a first Physical Resource Block (PRB) comprises the first plurality of REs, and a second PRB comprises the second plurality of REs.

In example 83, the method of any of examples 78 through 82, wherein the set of APs is a first set of APs, the plurality of OFDM symbols is a first plurality of OFDM symbols, and the plurality of subcarrier frequencies is a first plurality of subcarrier frequencies, comprising: processing a third plurality of REs carrying DM-RS for a second set of one or more APs, the third plurality of REs spanning a second plurality of OFDM symbols; and processing a fourth plurality of REs carrying DM-RS for the second set of APs, the fourth plurality of REs spanning a second plurality of subcarrier frequencies.

In example 84, the method of example 83, wherein DM-RS for the first set of APs is carried by more REs within a resource block than DM-RS for the second set of APs.

In example 85, the method of example 83, wherein the first plurality of REs is offset by a number of symbols from a first OFDM symbol in a first half of a Resource Block (RB); and wherein the third plurality of REs is offset by the number of symbols from a first OFDM symbol in a second half of the RB.

Example 86 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 78 through 85.

Example 87 provides an apparatus of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network, comprising:
means for processing a first plurality of Resource Elements (REs) carrying DM-RS for a set of one or more Antenna Ports (APs), the first plurality of REs spanning a plurality of Orthogonal Frequency-Division Multiplexing (OFDM) symbols; and means for processing a second plurality of REs carrying DM-RS for the set of APs, the second plurality of REs spanning a plurality of subcarrier frequencies.

[00271] In example 88, the apparatus of example 87, wherein the set of APs comprises a first AP corresponding with a first Orthogonal Cover Code (OCC) and a second AP corresponding with a second OCC, comprising: means for decoding the DM-RS carried by the first plurality of REs for the first AP using the first OCC; and means for decoding the DM-RS carried by the second plurality of REs for the second AP using the second OCC.

[00272] In example 89, the apparatus of either of examples 87 or 88, wherein the first plurality of REs spans a single subcarrier frequency, and wherein the second plurality of REs spans a single OFDM symbol.

[00273] In example 90, the apparatus of any of examples 87 through 89, wherein a Physical Resource Block (PRB) comprises both the first plurality of REs and the second plurality of REs.

[00274] In example 91, the apparatus of any of examples 87 through 90, wherein a first Physical Resource Block (PRB) comprises the first plurality of REs, and a second PRB comprises the second plurality of REs.

[00275] In example 92, the apparatus of any of examples 87 through 91, wherein the set of APs is a first set of APs, the plurality of OFDM symbols is a first plurality of OFDM symbols, and the plurality of subcarrier frequencies is a first plurality of subcarrier frequencies, comprising: means for processing a third plurality of REs carrying DM-RS for a second set of one or more APs, the third plurality of REs spanning a second plurality of OFDM symbols; and means for processing a fourth plurality of REs carrying DM-RS for the second set of APs, the fourth plurality of REs spanning a second plurality of subcarrier frequencies.

[00276] In example 93, the apparatus of example 92, wherein DM-RS for the first set of APs is carried by more REs within a resource block than DM-RS for the second set of APs.

[00277] In example 94, the apparatus of example 92, wherein the first plurality of REs is offset by a number of symbols from a first OFDM symbol in a first half of a Resource Block (RB); and wherein the third plurality of REs is offset by the number of symbols from a first OFDM symbol in a second half of the RB.
Example 95 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with a New Radio (NR) Node B (gNB) on a wireless network to perform an operation comprising: process a first plurality of Resource Elements (REs) carrying DM-RS for a set of one or more Antenna Ports (APs), the first plurality of REs spanning a plurality of Orthogonal Frequency-Division Multiplexing (OFDM) symbols; and process a second plurality of REs carrying DM-RS for the set of APs, the second plurality of REs spanning a plurality of subcarrier frequencies.

In example 96, the machine readable storage media of example 95, wherein the set of APs comprises a first AP corresponding with a first Orthogonal Cover Code (OCC) and a second AP corresponding with a second OCC; and the operation comprising: decode the DM-RS carried by the first plurality of REs for the first AP using the first OCC; and decode the DM-RS carried by the second plurality of REs for the second AP using the second OCC.

In example 97, the machine readable storage media of either of examples 95 or 96, wherein the first plurality of REs spans a single subcarrier frequency, and wherein the second plurality of REs spans a single OFDM symbol.

In example 98, the machine readable storage media of any of examples 95 through 97, wherein a Physical Resource Block (PRB) comprises both the first plurality of REs and the second plurality of REs.

In example 99, the machine readable storage media of any of examples 95 through 98, wherein a first Physical Resource Block (PRB) comprises the first plurality of REs, and a second PRB comprises the second plurality of REs.

Example 100, the provides the machine readable storage media of any of examples 95 through 99, wherein the set of APs is a first set of APs, the plurality of OFDM symbols is a first plurality of OFDM symbols, and the plurality of subcarrier frequencies is a first plurality of subcarrier frequencies; and the operation comprising: process a third plurality of REs carrying DM-RS for a second set of one or more APs, the third plurality of REs spanning a second plurality of OFDM symbols; and process a fourth plurality of REs carrying DM-RS for the second set of APs, the fourth plurality of REs spanning a second plurality of subcarrier frequencies.

In example 101, the machine readable storage media of example 100, wherein DM-RS for the first set of APs is carried by more REs within a resource block than DM-RS for the second set of APs.
In example 102, the machine readable storage media of example 100, wherein the first plurality of REs is offset by a number of symbols from a first OFDM symbol in a first half of a Resource Block (RB); and wherein the third plurality of REs is offset by the number of symbols from a first OFDM symbol in a second half of the RB.

In example 103, the apparatus of any of examples 1 through 8, 35 through 42, and 69 through 76, wherein the one or more processors comprise a baseband processor.

In example 104, the apparatus of any of examples 1 through 8, 35 through 42, and 69 through 76, comprising a memory for storing instructions, the memory being coupled to the one or more processors.

In example 105, the apparatus of any of examples 1 through 8, 35 through 42, and 69 through 76, comprising a transceiver circuitry for at least one of: generating transmissions, encoding transmissions, processing transmissions, or decoding transmissions.

In example 106, the apparatus of any of examples 1 through 8, 35 through 42, and 69 through 76, comprising a transceiver circuitry for generating transmissions and processing transmissions.

An abstract is provided that will allow the reader to ascertain the nature and gist of the technical disclosure. The abstract is submitted with the understanding that it will not be used to limit the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.
CLAIMS

We claim:

1. An apparatus of a User Equipment (UE) operable to communicate with a New Radio
(NR) Node-B (gNB) on a wireless network, comprising:
   one or more processors to:
   process a first set of Downlink (DL) symbols in accordance with a first
   numerology having a first subcarrier spacing, the first set of symbols carrying
   a reference signal; and
   process a second set of DL symbols in accordance with a second numerology
   having a second subcarrier spacing, the second set of symbols carrying a data channel,
   wherein the first subcarrier spacing is different from the second subcarrier
   spacing; and
   an interface for receiving the first set of DL symbols and the second set of DL
   symbols from a receiving circuitry.

2. The apparatus of claim 1,
   wherein the first numerology has a first symbol time, the second numerology has a
   second symbol time, and the first symbol time is less than the second symbol time.

3. The apparatus of claim 2,
   wherein the first set of symbols carries at least one of: an additional data channel, or
   an additional control channel, and
   wherein a symbol time of the reference signal and a symbol time of the additional
   data channel are in accordance with the first symbol time.

4. The apparatus of claim 3,
   wherein the reference signal is a Channel State Information Reference Signal
   (CSI-RS).

5. The apparatus of any of claims 1 through 4,
   wherein the reference signal is a Demodulation Reference Signal (DM-RS).
6. The apparatus of claim 5,
   wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL
   symbols in at least one of: a Time Division Multiplexing (TDM) manner, a
   Frequency Division Multiplexing (FDM) manner, or a Code Division
   Multiplexing (CDM) manner.

7. Machine readable storage media having machine executable instructions that, when
   executed, cause one or more processors of a User Equipment (UE) operable to
   communicate with a New Radio (NR) Node-B (gNB) on a wireless network to perform an
   operation comprising:
   process a first set of Downlink (DL) symbols in accordance with a first numerology
   having a first subcarrier spacing, the first set of symbols carrying a reference
   signal; and
   process a second set of DL symbols in accordance with a second numerology having a
   second subcarrier spacing, the second set of symbols carrying a data channel,
   wherein the first subcarrier spacing is different from the second subcarrier spacing.

8. The machine readable storage media of claim 7,
   wherein the first numerology has a first symbol time, the second numerology has a
   second symbol time, and the first symbol time is less than the second symbol time.

9. The machine readable storage media of claim 8,
   wherein the first set of symbols carries at least one of: an additional data channel, or
   an additional control channel, and
   wherein a symbol time of the reference signal and a symbol time of the additional
   data channel are in accordance with the first symbol time.

10. The machine readable storage media of claim 9,
    wherein the reference signal is a Channel State Information Reference Signal
        (CSI-RS).

11. The machine readable storage media of any of claims 7 through 10,
    wherein the reference signal is a Demodulation Reference Signal (DM-RS).
12. The machine readable storage media of claim 11,
   wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL
   symbols in at least one of: a Time Division Multiplexing (TDM) manner, a
   Frequency Division Multiplexing (FDM) manner, or a Code Division
   Multiplexing (CDM) manner.

13. An apparatus of a User Equipment (UE) operable to communicate with a New Radio
    (NR) Node-B (gNB) on a wireless network, comprising:
        one or more processors to:
        generate a first set of Uplink (UL) symbols in accordance with a first numerology
            having a first subcarrier spacing, the first set of symbols carrying a reference
            signal; and
        generate a second set of Uplink (UL) symbols in accordance with a second
            numerology having a second subcarrier spacing, the second set of symbols
            carrying a data channel,
        wherein the first subcarrier spacing is different from the second subcarrier
            spacing; and
        an interface for transmitting the first set of UL symbols and the second set of UL
        symbols to a transmitting circuitry.

14. The apparatus of claim 13,
    wherein the first numerology has a first symbol time, the second numerology has a
    second symbol time, and the first symbol time is less than the second symbol time.

15. The apparatus of claim 14,
    wherein the first set of symbols carries at least one of: an additional data channel, or
    an additional control channel, and
    wherein a symbol time of the reference signal and a symbol time of the additional
    data channel are in accordance with the first symbol time.

16. The apparatus of claim 15,
    wherein the reference signal is a Sounding Reference Signal (SRS).
17. The apparatus of any of claims 13 through 16, wherein the reference signal is a Demodulation Reference Signal (DM-RS).

18. The apparatus of claim 17,
wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.

19. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with a New Radio (NR) Node-B (gNB) on a wireless network to perform an operation comprising:
generate a first set of Uplink (UL) symbols in accordance with a first numerology having a first subcarrier spacing, the first set of symbols carrying a reference signal; and
generate a second set of Uplink (UL) symbols in accordance with a second numerology having a second subcarrier spacing, the second set of symbols carrying a data channel,
wherein the first subcarrier spacing is different from the second subcarrier spacing.

20. The machine readable storage media of claim 19,
wherein the first numerology has a first symbol time, the second numerology has a second symbol time, and the first symbol time is less than the second symbol time.

21. The machine readable storage media of claim 20,
wherein the first set of symbols carries at least one of: an additional data channel, or an additional control channel, and
wherein a symbol time of the reference signal and a symbol time of the additional data channel are in accordance with the first symbol time.

22. The machine readable storage media of claim 21,
wherein the reference signal is a Sounding Reference Signal (SRS).
23. The machine readable storage media of any of claims 19 through 22,
wherein the reference signal is a Demodulation Reference Signal (DM-RS).

24. The machine readable storage media of claim 23,
wherein multiple DM-RS Antenna Ports (APs) are multiplexed in the first set of DL symbols in at least one of: a Time Division Multiplexing (TDM) manner, a Frequency Division Multiplexing (FDM) manner, or a Code Division Multiplexing (CDM) manner.
Fig. 1
Fig. 2
Fig. 4
Fig. 7
DM-RS (using 30 kHz SCS)
data symbol (initially using 30 kHz SCS, remaining using 15 kHz SCS)

DM-RS (using 60 kHz SCS)
data symbol (initially using 60 kHz SCS, remaining using 15 kHz SCS)

Fig. 8
Fig. 9
Fig. 10
Fig. 11
Fig. 13
1810
PROCESS A 1\textsuperscript{ST} SET OF DL SYMBOLS IN ACCORDANCE WITH A 1\textsuperscript{ST} NUMEROLOGY HAVING A 1\textsuperscript{ST} SUBCARRIER SPACING, THE 1\textsuperscript{ST} SET OF SYMBOLS CARRYING A REFERENCE SIGNAL

1815
PROCESS A 2\textsuperscript{ND} SET OF DL SYMBOLS IN ACCORDANCE WITH A 2\textsuperscript{ND} NUMEROLOGY HAVING A 2\textsuperscript{ND} SUBCARRIER SPACING, THE 2\textsuperscript{ND} SET OF SYMBOLS CARRYING A DATA CHANNEL

1820
PROCESS X\textsuperscript{MISSION} CARRYING AT LEAST ONE PARAMETER ASSOCIATED WITH THE 1\textsuperscript{ST} NUMEROLOGY

1800

Fig. 18
1910

GENERATE A 1\textsuperscript{ST} SET OF UL SYMBOLS IN ACCORDANCE WITH A 1\textsuperscript{ST} NUMEROLOGY HAVING A 1\textsuperscript{ST} SUBCARRIER SPACING, THE 1\textsuperscript{ST} SET OF SYMBOLS CARRYING A REFERENCE SIGNAL

1915

GENERATE A 2\textsuperscript{ND} SET OF UL SYMBOLS IN ACCORDANCE WITH A 2\textsuperscript{ND} NUMEROLOGY HAVING A 2\textsuperscript{ND} SUBCARRIER SPACING, THE 2\textsuperscript{ND} SET OF SYMBOLS CARRYING A DATA CHANNEL

1920

PROCESS X\textasciitildeMISSION CARRYING AT LEAST ONE PARAMETER ASSOCIATED WITH THE 1\textsuperscript{ST} NUMEROLOGY

1900

\textbf{Fig. 19}
2010
PROCESS A 1\textsuperscript{ST} PLURALITY OF REs
CARRYING DMRS FOR A SET OF AP(S),
THE 1\textsuperscript{ST} PLURALITY OF REs
SPANNING A PLURALITY
OF OFDM SYMBOLS

2015
PROCESS A 2\textsuperscript{ND} PLURALITY OF REs
CARRYING DMRS FOR THE SET OF AP(S),
THE 2\textsuperscript{ND} PLURALITY OF REs
SPANNING A PLURALITY
OF SUBCARRIER FREQUENCIES

2020
DECODE THE DMRS CARRIED BY THE 1\textsuperscript{ST}
PLURALITY OF REs FOR THE 1\textsuperscript{ST} AP
USING THE 1\textsuperscript{ST} OCC

2025
DECODE THE DMRS CARRIED BY THE 2\textsuperscript{ND}
PLURALITY OF REs FOR THE 2\textsuperscript{ND} AP
USING THE 2\textsuperscript{ND} OCC

2030
PROCESS A 3\textsuperscript{RD} PLURALITY OF REs
CARRYING DMRS FOR A 2\textsuperscript{ND} SET OF
AP(S), THE 3\textsuperscript{RD} PLURALITY OF REs
SPANNING A 2\textsuperscript{ND} PLURALITY
OF OFDM SYMBOLS

2035
PROCESS A 4\textsuperscript{TH} PLURALITY OF REs
CARRYING DMRS FOR THE 2\textsuperscript{ND} SET OF
AP(S), THE 4\textsuperscript{TH} PLURALITY OF REs
SPANNING A 2\textsuperscript{ND} PLURALITY
OF SUBCARRIER FREQUENCIES

2000
Fig. 20
**INTERNATIONAL SEARCH REPORT**

**International application No**

PCT/US2017/054565

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**A. CLASSIFICATION OF SUBJECT MATTER**

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

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**B. FIELDS SEARCHED**

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

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>OPPO: &quot;Subcarrier spacing design for data and reference signal&quot;, 3GPP DRAFT; RI-166609, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTI POLIS CEDEX ; FRANCE ; vol. RAN W01, no. Gothenburg, Sweden; 21 August 2016 (2016-08-21), XP051140300, Retrived from the Internet: URL: <a href="http://www.3gpp.org/f">http://www.3gpp.org/f</a> tp/Meeiti ngs_3GPP.Sync/RANI/Docs/ [retrieved on 2016-08-21] sections 1-3 figure 3</td>
<td>1-24</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search

13 December 2017

Date of mailing of the international search report

22/12/2017

Name and mailing address of the ISA:

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Roussos, Fragki skos
<table>
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<th>Category</th>
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<td>QUALCOMM INCORPORATED: &quot;Scaled Numerology Control Design for NR&quot;, 3GPP DRAFT; R1-166363_SCALED NUMEROLOGY CONTROL DESIGN FOR NR, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE; 650, ROUTE DES LUCIOLES; F-06921 SOPHIA-ANTI POLIS CEDEX; FRANCE, vol. RAN WG1, no. Gothenburg, Sweden; 20160822 - 20160826 21 August 2016 (2016-08-21), XP051140183, Retrieved from the Internet: URL: <a href="http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/">http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/</a> [retrieved on 2016-08-21] sections 2.2, 3 and 4.2</td>
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