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(54) Title: SIGNAL STRUCTURE FOR FULL-DUPLEX CELLULAR SYSTEMS

(57) Abstract: A frame structure and reference signal (RS) structure for full-duplex (FD) cellular systems are described that take into account both conventional co-channel and new interferences introduced by FD. Based on this frame and RS structure, mechanics for channel estimation for demodulation and channel state information measurement and signaling are described.

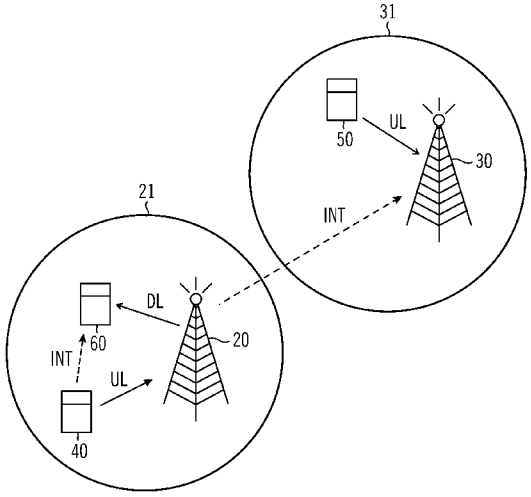

FIG. 1

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SIGNAL STRUCTURE FOR FULL-DUPLEX CELLULAR SYSTEMS

Technical Field

[0001] Embodiments described herein relate generally to wireless networks and communications systems. Some embodiments relate to cellular communication networks including 3GPP (Third Generation Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, and 3GPP LTE-A (LTE Advanced) networks, although the scope of the embodiments is not limited in this respect.

Background

[0002] In Long Term Evolution (LTE) systems, a mobile terminal (referred to as a User Equipment or UE) connects to the cellular network via a base station (referred to as an evolved Node B or eNB). Conventional radio transceivers are generally not capable of receiving and transmitting on the same frequency channel simultaneously because of interference between the transmitter (Tx) and the receiver (Rx). Current LTE systems are half duplex (HD) in each channel with bidirectional transmissions being sent over two orthogonal HD channels. The orthogonality may be provided, for example, by time multiplexing or frequency multiplexing (e.g., time division duplex (TDD) or frequency division duplex (FDD)). Advances in antenna design, circuit design, and digital signal processing have achieved sufficient reduction in the self-interference between the Tx and Rx chains that full duplex (FD) communications systems can now be deployed and are being considered for next generation wireless cellular systems. As compared with a point-to-point FD system, an FD cellular network has additional types of interference, including base station to base station (BS-to-BS) interference in the uplink receiver and UE-to-UE interference in the downlink receiver. Estimation of these interferences to enable appropriate scheduling of FD resources is a concern of the present disclosure.

Brief Description of the Drawings

[0003] Fig. 1 illustrates a BS-to-BS and UE-to-UE interferences in a full-duplex system according to some embodiments.

[0004] Fig. 2 illustrates an example UE and eNB according to some embodiments.

[0005] Fig. 3 illustrates a frame structure and reference signal structure for full-duplex systems according to some embodiments.

[0006] Fig. 4 illustrates an example of a user equipment device according to some embodiments.

[0007] Fig. 5 illustrates an example of a computing machine according to some embodiments.

Detailed Description

[0008] Described herein is a frame structure and reference signal (RS) structure for full-duplex (FD) cellular systems that takes into account both conventional co-channel and new interferences introduced by FD. Based on this frame and RS structure, mechanics for channel estimation for demodulation and channel state information measurement and signaling are described.

[0009] For cellular systems such as LTE, UEs transmitting an UL signal create conventional co-channel interference to other UL signals in other cells. For FD cellular systems, the UL signal may also create interference to a DL signal transmitted to another UE, especially a nearby UE. This is UE-to-UE interference which can corrupt the victim DL signal. From the perspective of user perceived service quality, cell edge UEs in high-density indoor environments are particularly vulnerable to severe performance degradation caused by UE-to-UE interference. This is because stationary UEs in such environments are likely to transmit/receive persistently for long periods of time, resulting in prolonged service disruption due to strong interference. Such service disruption caused by UE-to-UE interference has

to be properly handled to truly utilize the benefits of FD capability. In addition, downlink transmissions from neighboring base stations may greatly impact uplink reception of the serving base station in FD cellular systems, called BS-to-BS interference. Since BS-to-BS channel is closer to line-of-sight with much smaller path loss and the transmit power and antenna gain at BS is much larger than those of a UE, the BS-to-BS interferences easily dominates the desired weaker UL signal from the UE.

[0010] Fig. 1 shows an example of a network that includes a base station or eNB 30 with a coverage zone 31, a base station or eNB 20 with a coverage zone 21, and mobile devices or UEs 40, 50, and 60. Both base stations are operating in full-duplex mode. As shown in the figure, the downlink (DL) transmission from base station 20 to UE 60 is interfered with by the simultaneous uplink (UL) transmission from nearby UE 40 to base station 20 when the time-frequency resources for both transmissions are shared. This is an example of UE-to-UE interference. Also shown in the figure is the UL transmission from UE 50 to base station 30 being interfered with by the DL transmission of base station 20 to UE 60 using the same time-frequency resources. This is an example of BS-to-BS interference.

[0011] Fig. 2 illustrates an example of the components of a UE 400 and a base station or eNB 300. The base station 300 includes processing circuitry 301 connected to a full-duplex transceiver 302 for providing an air interface. The UE 400 includes processing circuitry 401 connected to a radio transceiver 402 for providing an interface. The UE's transceiver 402 may or may not be full-duplex. Each of the transceivers in the devices are connected to antennas 55. .

[0012] Described herein is a frame structure framework and reference signal structure for full-duplex cellular systems. Proper design of such a framework is critical for channel estimation and interference estimation, especially in FD cellular systems, where there is UE-to-UE interference in downlink and BS-to-BS interference in uplink in addition to conventional co-channel interferences. A method to estimate the UE-to-UE interference based on the described frame structure and RS design is also described along with channel state information feedback mechanics for the estimated UE-to-UE interference to be fed back from the UE to the eNB. The

described frame structure covers individual downlink and uplink physical channels with a general criterion of assigning channels requiring better protection to dedicated resource and assigning channels allowing more tolerance of interference to use the resource with full-duplex transmission. The reference signal design allows proper channel estimation for both demodulation and channel state information measurement by considering the four different interference types existing in full-duplex cellular systems: conventional downlink interference from another cell; conventional uplink interference from UEs in another cell; UE-to-UE interference in the downlink; BS-to-BS interference in the uplink. In one embodiment, two sets of RSs are proposed for estimation of conventional interference and that due to full-duplex operation. In one embodiment, existing LTE reference signals are reused for FD cellular system operation.

[0013] Current LTE systems are HD systems that use either FDD or TDD so that uplink and downlink resources are orthogonal. Within one cell for the downlink, the primary synchronization sequence (PSS), the secondary synchronization sequence (SSS), the physical broadcast channel (PBCH), the physical downlink control channel (PDCCH), the physical hybrid-ARQ indicator channel (PHICH), and the physical control format indicator channel (PCFICH) all use dedicated resources that do not overlap with downlink data transmission over the physical downlink shared channel (PDSCH). For the uplink, the physical random access channel (PRACH) and physical uplink control channel (PUCCH) use dedicated resources that do not overlap with uplink data transmission over the physical uplink shared channel (PUSCH). Downlink reference signals include cell specific reference signals (CRS), UE-specific demodulation reference signal (DMRS) and channel state information reference signals (CSI-RS). Uplink reference signals include sounding reference signals (SRS) and demodulation reference signals (DMRS). All of these reference signals use dedicated resources that do not overlap with other channels. Reference signals are used to conduct channel estimation for demodulation and decoding in both uplink and downlink. For the downlink, they are also used to estimate the downlink channel state information (CSI) and then

feedback the CSI to the base station that uses the information for scheduling. For the uplink, they are also used to estimate the uplink CSI for the base station to schedule uplink resources in the next transmission. In addition, downlink CRS can be used for handover triggering (by estimating path losses between the serving cell and a neighbor cell).

[0014] In full-duplex systems, since there can be simultaneous transmissions in the uplink and downlink using the same time/frequency resources, a frame structure is should allow proper assignment of pairs of uplink and downlink channels that can use the same resources. Reference signals that reflect interference scenarios introduced by full-duplex operation are needed in order to be able to demodulate and obtain CSI information for the scheduler. The overall design objective for the frame and reference signal structure described below is to protect channels requiring high reliability from being impacted by new interferences due to full-duplex transmission by not allowing full-duplex transmission in such channel regions. Two sets of reference signals are used for data channels, based on whether reverse direction data transmission is allowed or not in the RS region. The reference signal design enables channel estimation with all interferences involved or only new interferences due to full duplex transmission involved.

[0015] In one embodiment, a frame structure for FD cellular system is described as follows with reference to Fig. 3. The PBCH, PSS/SSS, PRACH continue to use dedicated resources not overlapping with any other channels/signals. A full-duplex data region FDR, where downlink transmissions can take place simultaneously with uplink transmissions is provided. The full-duplex region FDR, depending on scheduler decisions, can be used for downlink/uplink data transmission that may involve opportunistic reverse data transmission, joint transmission of downlink and uplink signals, or special uplink or downlink control signals with allowance of the reverse direction's interference.

[0016] A downlink common control signal region DLctrl is always orthogonal to both uplink data region and downlink data region in the same cell. An uplink control signal region ULctrl is always orthogonal to both

uplink data region and downlink data region in the same cell and also orthogonal to the downlink control region. Downlink reference signals for the downlink control channel DLRSDLctrl are located within the downlink control channel region and do not overlap with downlink control channel. Uplink reference signals for the uplink control channel ULRSULctrl are located within the uplink control channel and do not overlap with uplink control channel.

[0017] A first set of downlink reference signals for the downlink data channel DRSD1 is located within the full-duplex data region. Uplink data transmission is allowed at these resources. A first set of uplink reference signal URSD1 is located within the full-duplex data region, and downlink data transmission is allowed at these resources. A configurable second set of downlink reference signals for the downlink data channel DRSD2 is located within the full-duplex data region, and uplink signal is not allowed at these resources. A configurable second set of uplink reference signals URSD2 is located within the full-duplex data region, and downlink data transmission is not allowed at these resources.

[0018] For the downlink and uplink control regions, control channels are not used for full-duplex so they are immune from additional new interferences and reliable reception of control information is not impacted by FD. For the uplink reference signals for the uplink control channel and downlink reference signals for the downlink control channel, these control channel reference signals do not overlap with reverse direction's transmission. They are thus immune from UE-to-UE interference in the downlink and BS-to-BS interference in the uplink to provide accurate channel estimation and decoding of the control channel signals.

[0019] For the first sets of downlink and uplink reference signals, the reference signals are used for demodulation and decoding of the data channel They therefore should reflect all the interferences the data channel encounters so reverse link traffic is present in these RS resources similar to the data channel. These reference signals can also be used for CSI (e.g., SINR) estimation. In this case, the SINR includes all the interferences the data transmission experiences. Specifically, in downlink, the estimated

SINR includes UE-to-UE interference and other downlink interference (from other eNBs); in the uplink, the estimated SINR includes BS-to-BS interference and other uplink interference (from other cell's UEs, assuming an orthogonal frequency division multiple access (OFDMA) or single carrier frequency division multiple access (SC-FDMA) based system where there are no other intra-cell co-channel interferences).

[0020] The configurable second sets of downlink and uplink reference signals are designed to help with estimation of the new BS-to-BS and UE-to-UE interferences. For second set of uplink reference signals, there is no downlink data transmitted in these resources so there is no conventional downlink interference in these resources. The downlink receiver can then listen to and measure the reference signals from uplink transmissions to focus on estimating interference from uplink UEs (UE-to-UE interference). For the second set of downlink reference signals, there is no uplink data transmitted in these resources. The plink receiver can then use it to listen/measure the reference signals from downlink transmission, and focus on estimating interference from other base station's transmission (BS-to-BS interference). Note that these two second sets reference signals are configurable and can be turned on or off and also they can be configured as periodic or aperiodic. The particular configuration selected would depend on a base station decision as to whether there is a need to retrieve the information and/or how frequently the base station needs such information to help the scheduler. In addition, a base station can specify a subset of UEs to turn on this set of uplink reference signal and also define a subset of coordinating base stations to turn on this set of downlink reference signal.

[0021] In another embodiment, the existing LTE structure and reference signals are adapted for a full-duplex cellular system based upon the frame and reference signal structure described above. In an LTE system, downlink cell-specific reference signals (CRS) exist in symbol indexes 0, 4, 7, and 11 where symbol index 0 is within PDCCH range and the other three are within PDSCH region. For the uplink, DMRS for PUCCH is within the PUCCH region, and DMRS for the PUSCH is within PUSCH region and exist in every transmission time interval (TTI) whenever there is data transmission

at symbol index 6, 10. Another type of uplink reference signal is the sounding reference signal (SRS), which is wideband and not in every TTI andmainly used for frequency selective scheduling. The SRS is optional and based on eNB signaling of its configuration to the UE.

[0022] For the downlink, in one embodiment, the existing CRS structure and reference signals are used in a full-duplex cellular system as follows. CRS for the PDCCH in LTE are used to estimate the conventional interference (SINR) from other cell's downlink signal (IDL_PDCCH): The downlink control region where the control signal CRS is located is not impacted by new UE-to-UE interference so this type of CRS can be used to demodulate PDCCH signal and estimate IDL_PDCCH. The CRS for the PDSCH in LTE is divided into two sets. The first set of CRS are at resources that allow uplink data transmission so it can be used to derive all the interferences that the downlink data traffic experiences. This set of CRS can be used for demodulation of PDSCH and also for obtaining the total downlink interference that includes UE-to-UE interference (IDL + IUE2UE). The second set of CRS for the PDSCH is reserved for downlink reference signals (uplink transmission is prevented). The eNB can then listen to or measure the resources reserved for this set of CRS to estimate the interferences coming from other eNB's downlink transmission (BS-to-BS interference (IB2BS)) since there is no conventional uplink interference from uplink UEs in other cells at these CRS locations.

[0023] For the uplink, in one embodiment the existing DMRS structure and reference signals are used as follows. DMRS for the PUCCH in LTE can be used to estimate the conventional interference (SINR) from other UE's uplink signal (IUL_PUCCH). The uplink control region where the control signal DMRS is located is not impacted by BS-to-BS interference, so this type of DMRS can be used to demodulate PUCCH signal and estimate IUL_PUCCH. The DMRS for PUSCH in LTE can be divided into two sets. The first set of DMRS resources allows downlink data transmission so it can be used to derive all the interferences the uplink data traffic experiences. This set of DMRS can be used for demodulation of PUSCH and also for obtaining the total uplink interference including BS-to-

BS interference (IUL+IBS2BS). The second set of DMRS for the PUSCH is the one reserved for uplink reference signal (downlink data transmission is muted at these resources). The DL UE can then listen to or measure the resource reserved for this set of DMRS to estimate the UE-to-UE interferences coming from other UE's uplink (IUE2UE) since there is no conventional downlink interference from other eNBs at this RS location. The full-duplex system can also use the optional SRS structure in LTE by allowing simultaneous downlink transmissions at the SRS resource. This allows the eNB to estimate the wider band of SINRs of individual uplink UEs to facilitate scheduling.

[0024] For the first and second sets of DMRS in the uplink, one approach is to split the existing LTE UL DMRS into the two sets by turning on or off downlink transmission in each set. Similarly, this can be done for the first and second sets of downlink CRS. The location of the DMRS and CRS sets can reuse what is currently in LTE. In one embodiment, symbol index 4 (first set), 7 (second set), 11, (first set) are for DL FD data CRS. In one embodiment, symbol index 6(second set), 10(first set) are for UL FD data DMRS.

[0025] The benefit of splitting and re-using LTE reference signals is to keep minimal structure change between legacy systems and a new full-duplex system. Additional resources can also be allocated to second set DMRS and second set CRS (e.g., by repeating the first set DMRS, CRS sequences), while using existing LTE DMRS and CRS allocation for conventional first set DMRS and CRS only. The specific choice between these two approaches in deployment depends on the balance between accuracy of channel estimation and additional resource and can be configurable in the network. Also, the reference signals for full-duplex LTE cellular systems as described herein are not limited to existing LTE reference signals. They should, however, have good auto-correlation and cross-correlation properties as well as a sufficient sequence pool to choose from.

[0026] With the frame structure and reference signal design as described above with two uplink DMRS sets, an example mechanism to estimate the

UE-to-UE interference and the signaling for feedback of this information from the UE to the eNB is as follows:

1) For the downlink UE of interest, at the end of each second set DMRS occurrence during N_tti (observation interval), an FFT is performed on the receive signal ri_dmrs(n),

Ri(k)=FFT (ri_dmrs(n)),

where i=1, …, N_dmrs, N_dmrs is the number of symbols containing DRMS set2 signal during N_tti, and k=ki_0, …,ki_0+Ni_prb*Nsc_perPRB, Ni_prb is the number of PRBs allocated for this DL UE at current symbol, Nsc_perPRB is number of subcarriers per PRB, ki_0 is the starting index of the subcarriers for this UE at this symbol.

2) Since the second set DMRS resource does not allow downlink transmission, Ri(k) does not contain downlink interference from other base stations, and only contains information from uplink reference signals of other UEs including inter-cell and intra-cell ones. For a downlink UE at serving cell 0 (j=0), we then have:

$$Ri(k) = \sum_{j}^{Ncell-1} Hj(k)X_{j\_dmrs}(k) + H0\ (k)X_{0\_dmrs}(k)+N(k)$$

So the downlink UE calculate each PRB's average power, P_{i_f} , from Ri(k) and for the f-th PRB, f=1, .., Ni_prb,

$$P_{i\_f} = \sum_{n=0}^{\text{Nsc\_perPRB}} Ri(\text{Nsc\_perPRB} * f + n)^2/\text{Nsc\_perPRB}$$

3) Now UE has interference power information on each PRB at each DMRS Set2 occurrence symbol. The UE maps this information into channel state information (CSI). The CSI_{UE2UE} at f-th PRB and i-th DMRS symbol can be obtained by comparing the P_{i_f} with a threshold $T_{\_intf}$,

CSI_{UE2UE} (f, i) =1, if $P_{i\_f} > T_{\_intf}$; CSI_{UE2UE} (f, i) =0, if $P_{i\_f} \leq T_{\_intf}$;

Depending on the granularity requirement, CSI_{UE2UE} can also be obtained with more quantization levels, for X levels (X>=2), it would require $\lceil log2(X) \rceil$ bits to transmit from UE to eNb for CSI_{UE2UE} at each (f, i) location.

4) The UE feeds back this information periodically or aperiodically based on base station request and configuration. The signaling overhead is then:

$\sum_{i=1}^{N\_dmrs} Ni\_prb * \lceil log2(X) \rceil$ bits in total.

[0027] Note that the method used above for interference power to CSI mapping and feedback can be varied from the one described above (per PRB, per DRMS symbol information). For example, the method can be sub-band based instead of per PRB based; and it can use smoothed values across different DMRS symbols instead of feeding back the values for each DRMS symbol along the time domain. The best implementation involves a tradeoff between accuracy, latency, scheduler requirements, and signaling overhead.

[0028] Similar estimation mechanism can be used to estimate the BS-to-BS interference power at uplink receiver (serving base station side), based on the downlink CRS structure described herein. The result of such estimation could be used to identify if the serving cell is suffering from BS-to-BS interference. Furthermore, specific strong interfering BS's can be also identified by the serving base station via measuring a neighbor cell's reference signal strength (similar to the concept of a UE measuring neighbor cell reference signal received power (RSRP) for handover in LTE systems). The neighbor base stations having large signal strengths for the first set CRSs are the strong interfering BSs.

Example UE Description

[0029] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be

implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[0030] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Fig. 4 illustrates, for one embodiment, example components of a User Equipment (UE) device 100. In some embodiments, the UE device 100 may include application circuitry 102, baseband circuitry 104, Radio Frequency (RF) circuitry 106, front-end module (FEM) circuitry 108 and one or more antennas 110, coupled together at least as shown.

[0031] The application circuitry 102 may include one or more application processors. For example, the application circuitry 102 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0032] The baseband circuitry 104 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 104 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 106 and to generate baseband signals for a transmit signal path of the RF circuitry 106. Baseband processing circuity 104 may interface with the application circuitry 102 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 106. For example, in some embodiments, the baseband circuitry 104 may include a second generation (2G) baseband processor 104a, third generation (3G) baseband processor 104b, fourth generation (4G) baseband processor 104c, and/or other baseband processor(s) 104d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 104 (e.g., one or more of baseband processors 104a-d) may handle various radio control functions that enable communication with one or more

radio networks via the RF circuitry 106. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 104 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 104 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0033] In some embodiments, the baseband circuitry 104 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 104e of the baseband circuitry 104 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 104f. The audio DSP(s) 104f 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 104 and the application circuitry 102 may be implemented together such as, for example, on a system on a chip (SOC).

[0034] In some embodiments, the baseband circuitry 104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 104 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area

network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0035] RF circuitry 106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 108 and provide baseband signals to the baseband circuitry 104. RF circuitry 106 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 104 and provide RF output signals to the FEM circuitry 108 for transmission.

[0036] In some embodiments, the RF circuitry 106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 106 may include mixer circuitry 106a, amplifier circuitry 106b and filter circuitry 106c. The transmit signal path of the RF circuitry 106 may include filter circuitry 106c and mixer circuitry 106a. RF circuitry 106 may also include synthesizer circuitry 106d for synthesizing a frequency for use by the mixer circuitry 106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 108 based on the synthesized frequency provided by synthesizer circuitry 106d. The amplifier circuitry 106b may be configured to amplify the down-converted signals and the filter circuitry 106c 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 104 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 106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0037] In some embodiments, the mixer circuitry 106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 106d to generate RF output signals for the FEM circuitry 108. The baseband signals may be provided by the baseband circuitry 104 and may be filtered by filter circuitry 106c. The filter circuitry 106c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0038] In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a 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 106a of the receive signal path and the mixer circuitry 106a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may be configured for super-heterodyne operation.

[0039] 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 106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 104 may include a digital baseband interface to communicate with the RF circuitry 106.

[0040] 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.

[0041] In some embodiments, the synthesizer circuitry 106d 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 106d may be a

delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0042] The synthesizer circuitry 106d may be configured to synthesize an output frequency for use by the mixer circuitry 106a of the RF circuitry 106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 106d may be a fractional N/N+1 synthesizer.

[0043] 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 104 or the applications processor 102 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 102.

[0044] Synthesizer circuitry 106d of the RF circuitry 106 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.

[0045] In some embodiments, synthesizer circuitry 106d 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 (f_{LO}). In some embodiments, the RF circuitry 106 may include an IQ/polar converter.

[0046] FEM circuitry 108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 110, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 106 for further processing. FEM circuitry 108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 106 for transmission by one or more of the one or more antennas 110.

[0047] In some embodiments, the FEM circuitry 108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 106). The transmit signal path of the FEM circuitry 108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 110.

[0048] In some embodiments, the UE device 100 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

Example Machine Description

[0049] Fig. 5 illustrates a block diagram of an example machine 500 upon which any one or more of the techniques (e.g., methodologies) discussed herein may perform. In alternative embodiments, the machine 500 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 500 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 500 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 500 may be a user equipment (UE), evolved Node B (eNB), Wi-Fi access point (AP), Wi-Fi station (STA), personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a

network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0050] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0051] Accordingly, the term "module" is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0052] Machine (e.g., computer system) 500 may include a hardware processor 502 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 504 and a static memory 506, some or all of which may communicate with each other via an interlink (e.g., bus) 508. The machine 500 may further include a display unit 510, an alphanumeric input device 512 (e.g., a keyboard), and a user interface (UI) navigation device 514 (e.g., a mouse). In an example, the display unit 510, input device 512 and UI navigation device 514 may be a touch screen display. The machine 500 may additionally include a storage device (e.g., drive unit) 516, a signal generation device 518 (e.g., a speaker), a network interface device 520, and one or more sensors 521, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 500 may include an output controller 528, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0053] The storage device 516 may include a machine readable medium 522 on which is stored one or more sets of data structures or instructions 524 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 524 may also reside, completely or at least partially, within the main memory 504, within static memory 506, or within the hardware processor 502 during execution thereof by the machine 500. In an example, one or any combination of the hardware processor 502, the main memory 504, the static memory 506, or the storage device 516 may constitute machine readable media.

[0054] While the machine readable medium 522 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 524.

[0055] The term “machine readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 500 and that cause the machine 500 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or

carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

[0056] The instructions 524 may further be transmitted or received over a communications network 526 using a transmission medium via the network interface device 520 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 520 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 526. In an example, the network interface device 520 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 520 may wirelessly communicate using Multiple User MIMO techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of

storing, encoding or carrying instructions for execution by the machine 500, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

Additional Notes and Examples

[0057] In Example 1, an apparatus for a base station (BS) or evolved Node B (eNB), comprises: a radio transceiver for providing a full-duplex air interface to user equipments (UEs); processing circuitry interfaced to the radio transceiver; wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that comprises: a full-duplex data region having resources that are schedulable for either half-duplex or full-duplex transmissions between the base station and the UE using downlink and uplink data channels, a first set of downlink reference signals located within the full-duplex data region at resources for which uplink transmissions are permitted, and a second set of downlink reference signals located within the full-duplex data region at resources at which no uplink transmissions are permitted and wherein the second set of downlink reference signals are configurable to be either present or not in a particular subframe; transmit the first set of downlink reference signals in subframes containing downlink data to allow a UE to demodulate the downlink data channel and determine interference from sources that include uplink transmissions of other UEs; and, determine interference produced by another base station operating in full-duplex mode by muting the resources of the second set of downlink references in a particular subframe and measuring a signal strength of downlink reference signals transmitted by the other base station in order to determine an amount of BS-to-BS interference.

[0058] In Example 2, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that further comprises: a first set of uplink reference signals located within the full-duplex data region at resources at which downlink transmissions are permitted and a second set of uplink reference signals located within the full-duplex data region at resources at which no downlink transmissions are permitted, wherein the second set of uplink reference signals are configurable to

be either present or not in a particular subframe; in subframes containing upllink data, use the first set of uplink reference signals to demodulate the uplink data channel and determine interference from sources that include downlink transmissions of other base stations; and, configure a UE to mute the resources of the second set of uplink references in a particular subframe to allow the UE to measure a signal strength of uplink reference signals transmitted by the other UEs and determine an amount of UE-to-UE interference.

[0059] In Example 3, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that further comprises: a downlink control region for containing one or more downlink control channels and an uplink control region for containing an uplink control channel, wherein the downlink control region, uplink control region, and full-duplex data region are orthogonal to one another; transmit downlink reference signals for the downlink control channels within the downlink control region and non-overlapping with the downlink control channels to allow a UE to demodulate the downlink control channels and estimate downlink interference; and, receive uplink reference signals for the uplink control channel within the uplink control region and non-overlapping with the uplink control channel in order to demodulate the uplink control channel and estimate uplink interference.

[0060] In Example 4, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to: operate as an evolved Node B (eNB) in a Long Term Evolution (LTE) network; and, wherein the downlink reference signals for the downlink control channels within the downlink control region, the first set of downlink reference signals, and the second set of downlink reference signals are cell-specific reference signals (CRS).

[0061] In Example 5, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to transmit the second set of downlink reference signals as CRS at symbol indexes 4, 7, or 11.

[0062] In Example 6, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to transmit reference signals in addition to CRS that make up the second set of downlink reference signals.

[0063] In Example 7, the subject matter of Example 1 or any of the Examples described herein may further includewherein the processing circuitry is to: operate as an evolved Node B (eNB) in a Long Term Evolution (LTE) network; and, wherein the uplink reference signals for the uplink control channel within the uplink control region, the first set of uplink reference signals, and the second set of uplink reference signals are demodulation reference signals (DMRS).

[0064] In Example 8, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to receive the second set of uplink reference signals as DMRS at symbol indexes 6 or 10.

[0065] In Example 9, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to receive reference signals in addition to DMRS that make up the second set of uplink reference signals.

[0066] In Example 10, the subject matter of Example 1 or any of the Examples described herein may further include wherein the processing circuitry is to: operate with a frame structure in which full-duplex transmissions are allowed at resources used by a sounding reference signal (SRS) received from UEs; and estimate a signal-to-interference plus noise ratio (SINR) for an individual UE during full-duplex operation from the SRS received from that individual UE.

[0067] In Example 11, an apparatus for a user equipment (UE) comprises: a radio transceiver; processing circuitry interfaced to the radio transceiver; wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that comprises: a full-duplex data region having resources that are schedulable for either half-duplex or full-duplex transmissions between the base station and the UE using downlink and uplink data channels, a first set of uplink reference signals located within the

full-duplex data region at resources at which downlink transmissions are permitted and a second set of uplink reference signals located within the full-duplex data region at resources at which no downlink transmissions are permitted, wherein the second set of uplink reference signals are configurable to be either present or not in a particular subframe; in subframes containing upllink data, transmit the first set of uplink reference signals to allow a base station (BS) to demodulate the uplink data channel and determine interference from sources that include downlink transmissions of other base stations; and, mute the resources of the second set of uplink references in a particular subframe in order to measure a signal strength of uplink reference signals transmitted by the other UEs and determine an amount of UE-to-UE interference.

[0068] In Example 12, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that further comprises: a first set of downlink reference signals located within the full-duplex data region at resources for which uplink transmissions are permitted, and a second set of downlink reference signals located within the full-duplex data region at resources at which no uplink transmissions are permitted and wherein the second set of downlink reference signals are configurable to be either present or not in a particular subframe; and, receive the first set of downlink reference signals in subframes containing downlink data in order to demodulate the downlink data channel and determine interference from sources that include uplink transmissions of other UEs.

[0069] In Example 13, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to: configure the transceiver for communication in accordance with a frame structure that further comprises: a downlink control region for containing one or more downlink control channels and an uplink control region for containing an uplink control channel, wherein the downlink control region, uplink control region, and full-duplex data region are orthogonal to one another; receive downlink reference signals for the downlink control channels within the downlink control region and non-overlapping with the downlink control channels in order to demodulate the downlink control channels and estimate

downlink interference; and, transmit uplink reference signals for the uplink control channel within the uplink control region and non-overlapping with the uplink control channel to allow the base station to demodulate the uplink control channel and estimate uplink interference.

[0070] In Example 14, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to: operate in a Long Term Evolution (LTE) network; and, wherein the downlink reference signals for the downlink control channels within the downlink control region, the first set of downlink reference signals, and the second set of downlink reference signals are cell-specific reference signals (CRS).

[0071] In Example 15, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to receive the second set of downlink reference signals as CRS at symbol indexes 4, 7, or 11.

[0072] In Example 16, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to receive reference signals in addition to CRS that make up the second set of downlink reference signals.

[0073] In Example 17, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to: operate in a Long Term Evolution (LTE) network; and, wherein the uplink reference signals for the uplink control channel within the uplink control region, the first set of uplink reference signals, and the second set of uplink reference signals are demodulation reference signals (DMRS).

[0074] In Example 18, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to transmit the second set of uplink reference signals as DMRS at symbol indexes 6 or 10.

[0075] In Example 19, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to transmit reference signals in addition to DMRS that make up the second set of uplink reference signals.

[0076] In Example 20, the subject matter of Example 11 or any of the Examples described herein may further include wherein the processing circuitry is to operate with a frame structure in which full-duplex transmissions are allowed at resources used by a transmitted sounding reference signal (SRS) to allow the base station to estimate a signal-to-interference plus noise ratio (SINR) during full-duplex operation.

[0077] In Example 21, a non-transitory computer-readable medium comprises instructions to cause a user equipment (UE), upon execution of the instructions by processing circuitry of the UE, to perform the functions of the processing circuitry in any of Examples 11 through 20.

[0078] In Example 22, a method for operating user equipment (UE) comprises performing the functions of the processing circuitry in any of Examples 11 through 20.

[0079] In Example 23, a non-transitory computer-readable medium comprises instructions to cause a base station, upon execution of the instructions by processing circuitry of the base station, to perform the functions of the processing circuitry in any of Examples 1 through 10.

[0080] In Example 24, a method for operating a base station comprises steps for performing the functions of the processing circuitry in any of Examples 1 through 10.

[0081] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as "examples." Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described. Moreover, also contemplate are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[0082] Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though

individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) are supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[0083] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to suggest a numerical order for their objects.

[0084] The embodiments as described above may be implemented in various hardware configurations that may include a processor for executing instructions that perform the techniques described. Such instructions may be contained in a machine-readable medium such as a suitable storage medium or a memory or other processor-executable medium.

[0085] The embodiments as described herein may be implemented in a number of environments such as part of a wireless local area network (WLAN), 3rd Generation Partnership Project (3GPP) Universal Terrestrial Radio Access Network (UTRAN), or Long-Term-Evolution (LTE) or a Long-Term-Evolution (LTE) communication system, although the scope of the invention is not limited in this respect. An example LTE system includes a number of mobile stations, defined by the LTE specification as User Equipment (UE), communicating with a base station, defined by the LTE specifications as an eNB.

[0086] Antennas referred to herein may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole

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

[0087] In some embodiments, a receiver as described herein may be configured to receive signals in accordance with specific communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11 standards and/or proposed specifications for WLANs, although the scope of the invention is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some embodiments, the receiver may be configured to receive signals in accordance with the IEEE 802.16-2004, the IEEE 802.16(e) and/or IEEE 802.16(m) standards for wireless metropolitan area networks (WMANs) including variations and evolutions thereof, although the scope of the invention is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some embodiments, the receiver may be configured to receive signals in accordance with the Universal Terrestrial Radio Access Network (UTRAN) LTE communication standards. For more information with respect to the IEEE 802.11 and IEEE 802.16 standards, please refer to "IEEE Standards for Information Technology -- Telecommunications and Information Exchange between Systems" - Local Area Networks - Specific Requirements – Part 11 "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY), ISO/IEC 8802-11: 1999", and Metropolitan Area Networks - Specific Requirements – Part 16: "Air Interface for Fixed Broadband Wireless Access Systems," May 2005 and related amendments/versions. For more information with respect to UTRAN LTE standards, see the 3rd Generation Partnership

Project (3GPP) standards for UTRAN-LTE, including variations and evolutions thereof.

[0088] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with others. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth every feature disclosed herein as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

1. An apparatus of an evolved Node B (eNB), comprising:

a radio transceiver to provide a full-duplex air interface to user equipments (UEs);

processing circuitry interfaced to the radio transceiver, wherein the processing circuitry is to:

configure the transceiver for communication in accordance with a frame structure that comprises: a full-duplex data region having resources that are schedulable for either half-duplex or full-duplex transmissions using downlink and uplink data channels, a first set of downlink reference signals located within the full-duplex data region at resources for which uplink transmissions are permitted, and a second set of downlink reference signals located within the full-duplex data region at resources at which no uplink transmissions are permitted and wherein the second set of downlink reference signals are mutable in a particular subframe; and,

configure the transceiver to transmit the first set of downlink reference signals in subframes containing downlink data to allow a UE to demodulate the downlink data channel and determine interference from sources that include uplink transmissions of other UEs and determine interference produced by another eNB operating in full-duplex mode by muting the resources of the second set of downlink reference signals in a particular subframe and measuring a signal strength of downlink reference signals transmitted by the other eNB.

2. The apparatus of claim 1 wherein the processing circuitry is to:

configure the transceiver for communication in accordance with a frame structure that further comprises: a first set of uplink reference signals located within the full-duplex data region at resources at which downlink transmissions are permitted and a second set of uplink reference signals located within the full-duplex data region at resources at which no downlink transmissions are

permitted, wherein the second set of uplink reference signals are configurable to be either present or not in a particular subframe;

in subframes containing uplink data, use the first set of uplink reference signals to demodulate the uplink data channel and determine interference from sources that include downlink transmissions of other base stations; and,

configure a UE to mute the resources of the second set of uplink references in a particular subframe to allow the UE to measure a signal strength of uplink reference signals transmitted by the other UEs and determine an amount of UE-to-UE interference.

3. The apparatus of claim 2 wherein the processing circuitry is to configure the transceiver to:

operate with the frame structure that further comprises: a downlink control region for containing one or more downlink control channels and an uplink control region for containing an uplink control channel, wherein the downlink control region, uplink control region, and full-duplex data region are orthogonal to one another;

transmit downlink reference signals for the downlink control channels within the downlink control region and non-overlapping with the downlink control channels to allow a UE to demodulate the downlink control channels and estimate downlink interference; and,

receive uplink reference signals for the uplink control channel within the uplink control region and non-overlapping with the uplink control channel in order to demodulate the uplink control channel and estimate uplink interference.

4. The apparatus of claim 3 wherein the downlink reference signals for the downlink control channels within the downlink control region, the first set of downlink reference signals, and the second set of downlink reference signals are cell-specific reference signals (CRS).

5. The apparatus of claim 4 wherein the processing circuitry is to transmit the second set of downlink reference signals as CRS at symbol indexes 4, 7, or 11.

6. The apparatus of claim 4 wherein the processing circuitry is to transmit reference signals in addition to CRS that make up the second set of downlink reference signals.

7. The apparatus of claims 1 through 6 wherein the uplink reference signals for the uplink control channel within the uplink control region, the first set of uplink reference signals, and the second set of uplink reference signals are demodulation reference signals (DMRS).

8. The apparatus of claim 7 wherein the processing circuitry is to receive the second set of uplink reference signals as DMRS at symbol indexes 6 or 10.

9. The apparatus of claim 7 wherein the processing circuitry is to receive reference signals in addition to DMRS that make up the second set of uplink reference signals.

10. The apparatus of any of claims 1 through 9 wherein the processing circuitry is to:

operate with a frame structure in which full-duplex transmissions are allowed at resources used by a sounding reference signal (SRS) received from UEs; and

estimate a signal-to-interference plus noise ratio (SINR) for an individual UE during full-duplex operation from the SRS received from that individual UE.

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

a radio transceiver;

processing circuitry interfaced to the radio transceiver;

wherein the processing circuitry is to:

configure the transceiver for communication in accordance with a frame structure that comprises: a full-duplex data region having resources that are schedulable for either half-duplex or full-duplex transmissions using downlink and uplink data channels, a first set of uplink reference signals located within the full-duplex data region at resources at which downlink transmissions are permitted and a second set of uplink reference signals located within the full-duplex data region at resources at which no downlink transmissions are permitted, wherein the second set of uplink reference signals are configurable to be either present or not in a particular subframe;

in subframes containing uplink data, transmit the first set of uplink reference signals to allow an evolved Node B (eNB) to demodulate the uplink data channel and determine interference from sources that include downlink transmissions of other eNBs; and,

mute the resources of the second set of uplink references in a particular subframe in order to measure a signal strength of uplink reference signals transmitted by the other UEs and determine an amount of UE-to-UE interference.

12. The apparatus of claim 11 wherein the processing circuitry is to:

configure the transceiver for communication in accordance with a frame structure that further comprises: a first set of downlink reference signals located within the full-duplex data region at resources for which uplink transmissions are permitted, and a second set of downlink reference signals located within the full-duplex data region at resources at which no uplink transmissions are permitted

and wherein the second set of downlink reference signals are configurable to be either present or not in a particular subframe; and,

receive the first set of downlink reference signals in subframes containing downlink data in order to demodulate the downlink data channel and determine interference from sources that include uplink transmissions of other UEs.

13. The apparatus of claim 12 wherein the processing circuitry is to:

configure the transceiver for communication in accordance with a frame structure that further comprises: a downlink control region for containing one or more downlink control channels and an uplink control region for containing an uplink control channel, wherein the downlink control region, uplink control region, and full-duplex data region are orthogonal to one another;

receive downlink reference signals for the downlink control channels within the downlink control region and non-overlapping with the downlink control channels in order to demodulate the downlink control channels and estimate downlink interference; and,

transmit uplink reference signals for the uplink control channel within the uplink control region and non-overlapping with the uplink control channel to allow the eNB to demodulate the uplink control channel and estimate uplink interference.

14. The apparatus of claim 13 wherein the downlink reference signals for the downlink control channels within the downlink control region, the first set of downlink reference signals, and the second set of downlink reference signals are cell-specific reference signals (CRS).

15. The apparatus of claim 14 wherein the processing circuitry is to receive the second set of downlink reference signals as CRS at symbol indexes 4, 7, or 11.

16. The apparatus of claim 14 wherein the processing circuitry is to receive reference signals in addition to CRS that make up the second set of downlink reference signals.

17. The apparatus of claim 13 wherein the uplink reference signals for the uplink control channel within the uplink control region, the first set of uplink reference signals, and the second set of uplink reference signals are demodulation reference signals (DMRS).

18. The apparatus of claim 17 wherein the processing circuitry is to transmit the second set of uplink reference signals as DMRS at symbol indexes 6 or 10

19. The apparatus of claim 17 wherein the processing circuitry is to transmit reference signals in addition to DMRS that make up the second set of uplink reference signals.

20. The apparatus of any claims 11 through 19 wherein the processing circuitry is to operate with a frame structure in which full-duplex transmissions are allowed at resources used by a transmitted sounding reference signal (SRS) to allow the base station to estimate a signal-to-interference plus noise ratio (SINR) during full-duplex operation.

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

configure a transceiver for communication in accordance with a frame structure that comprises: a full-duplex data region having resources that are schedulable for either half-duplex or full-duplex transmissions between the base station and the UE using downlink and uplink data channels, a first set of uplink reference signals located within the full-duplex data region at resources at which

downlink transmissions are permitted and a second set of uplink reference signals located within the full-duplex data region at resources at which no downlink transmissions are permitted, wherein the second set of uplink reference signals are configurable to be either present or not in a particular subframe;

in subframes containing uplink data, transmit the first set of uplink reference signals to allow an evolved Node B (eNB) to demodulate the uplink data channel and determine interference from sources that include downlink transmissions of other base stations; and,

mute the resources of the second set of uplink references in a particular subframe in order to measure a signal strength of uplink reference signals transmitted by the other UEs and determine an amount of UE-to-UE interference.

22. The medium of claim 21 further comprising instructions to:

configure the transceiver for communication in accordance with a frame structure that further comprises: a first set of downlink reference signals located within the full-duplex data region at resources for which uplink transmissions are permitted, and a second set of downlink reference signals located within the full-duplex data region at resources at which no uplink transmissions are permitted and wherein the second set of downlink reference signals are configurable to be either present or not in a particular subframe; and,

receive the first set of downlink reference signals in subframes containing downlink data in order to demodulate the downlink data channel and determine interference from sources that include uplink transmissions of other UEs.

23. The medium of claim 22 further comprising instructions to:

configure the transceiver for communication in accordance with a frame structure that further comprises: a downlink control region for containing one or more downlink control channels and an uplink control region for containing an

uplink control channel, wherein the downlink control region, uplink control region, and full-duplex data region are orthogonal to one another;

receive downlink reference signals for the downlink control channels within the downlink control region and non-overlapping with the downlink control channels in order to demodulate the downlink control channels and estimate downlink interference; and,

transmit uplink reference signals for the uplink control channel within the uplink control region and non-overlapping with the uplink control channel to allow the base station to demodulate the uplink control channel and estimate uplink interference.

24. The medium of claim 23 further comprising instructions such that the downlink reference signals for the downlink control channels within the downlink control region, the first set of downlink reference signals, and the second set of downlink reference signals are cell-specific reference signals (CRS).

25. The medium of claim 23 further comprising instructions such that the uplink reference signals for the uplink control channel within the uplink control region, the first set of uplink reference signals, and the second set of uplink reference signals are demodulation reference signals (DMRS).

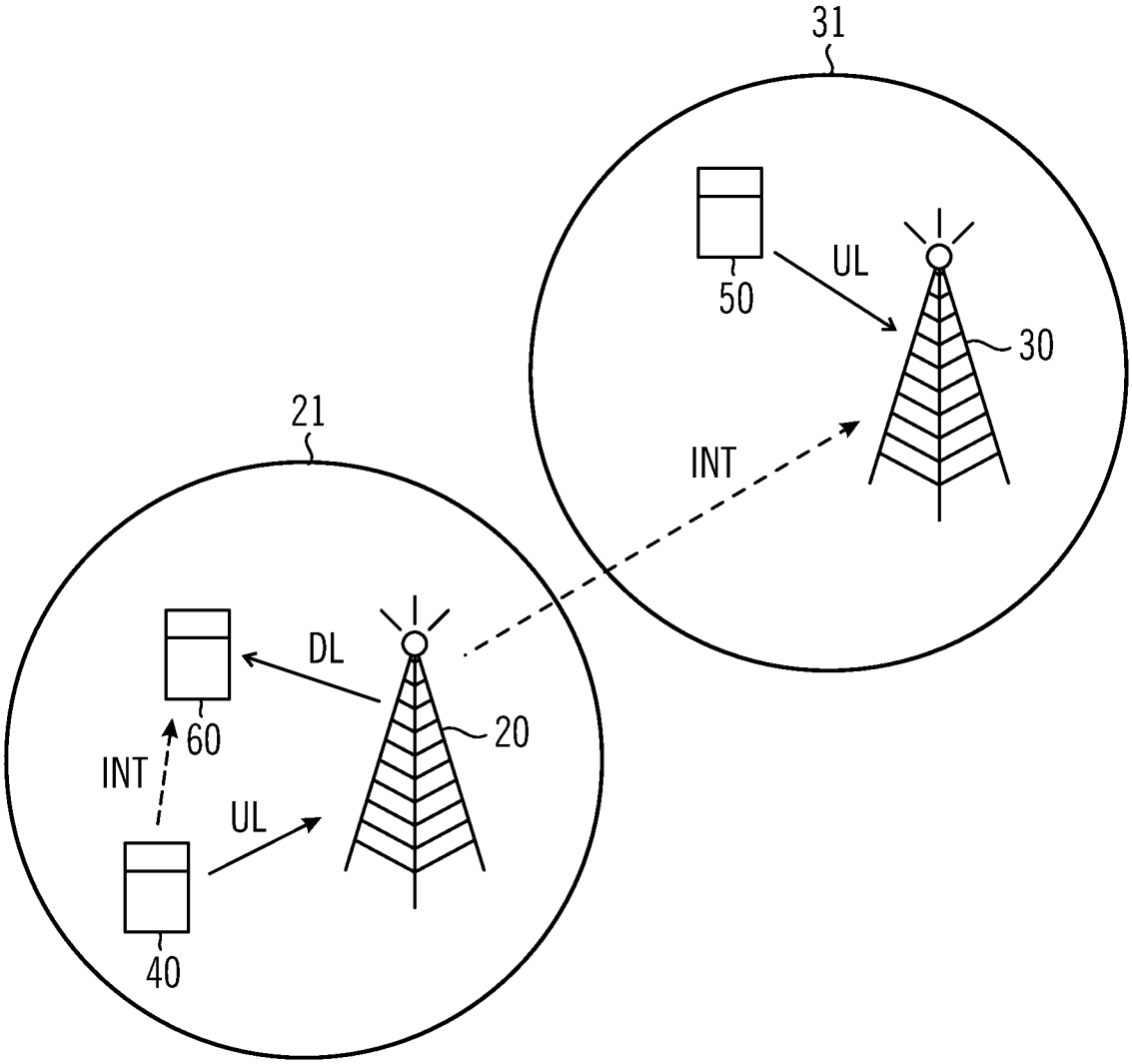
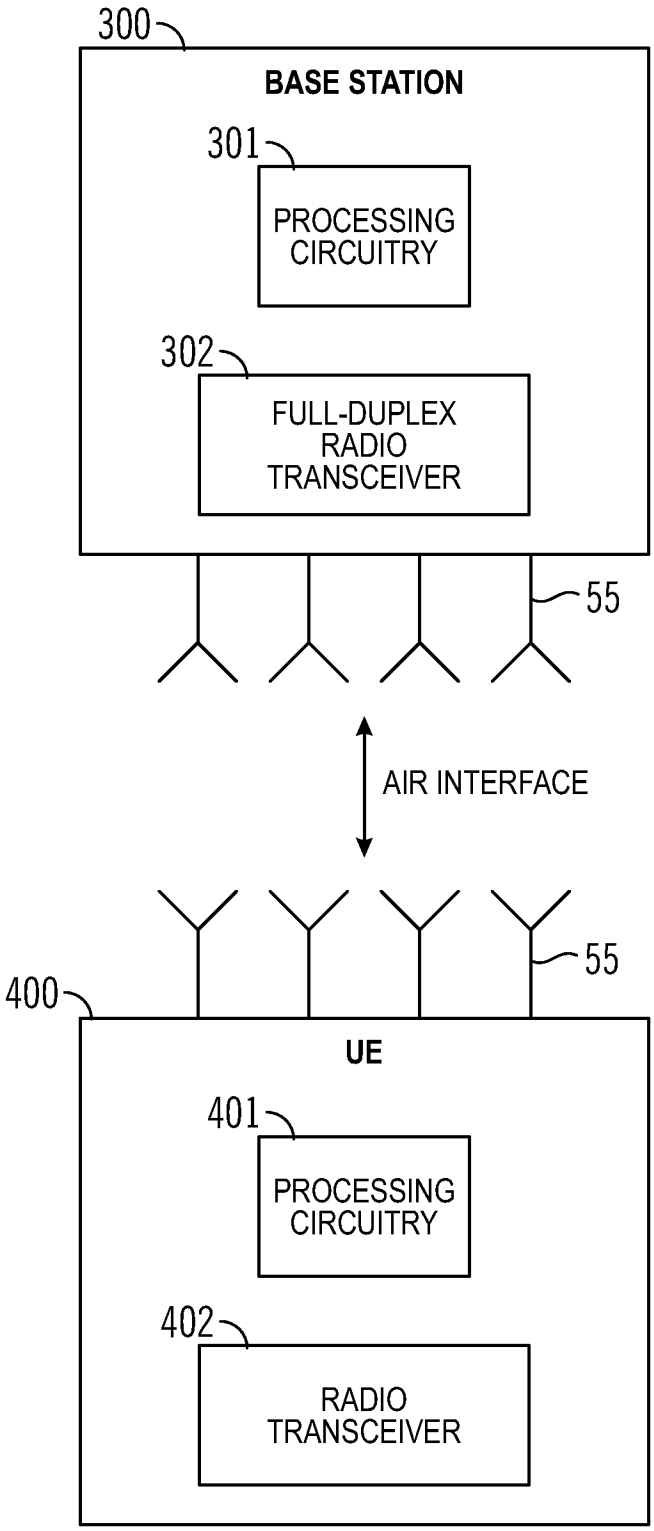


FIG. 1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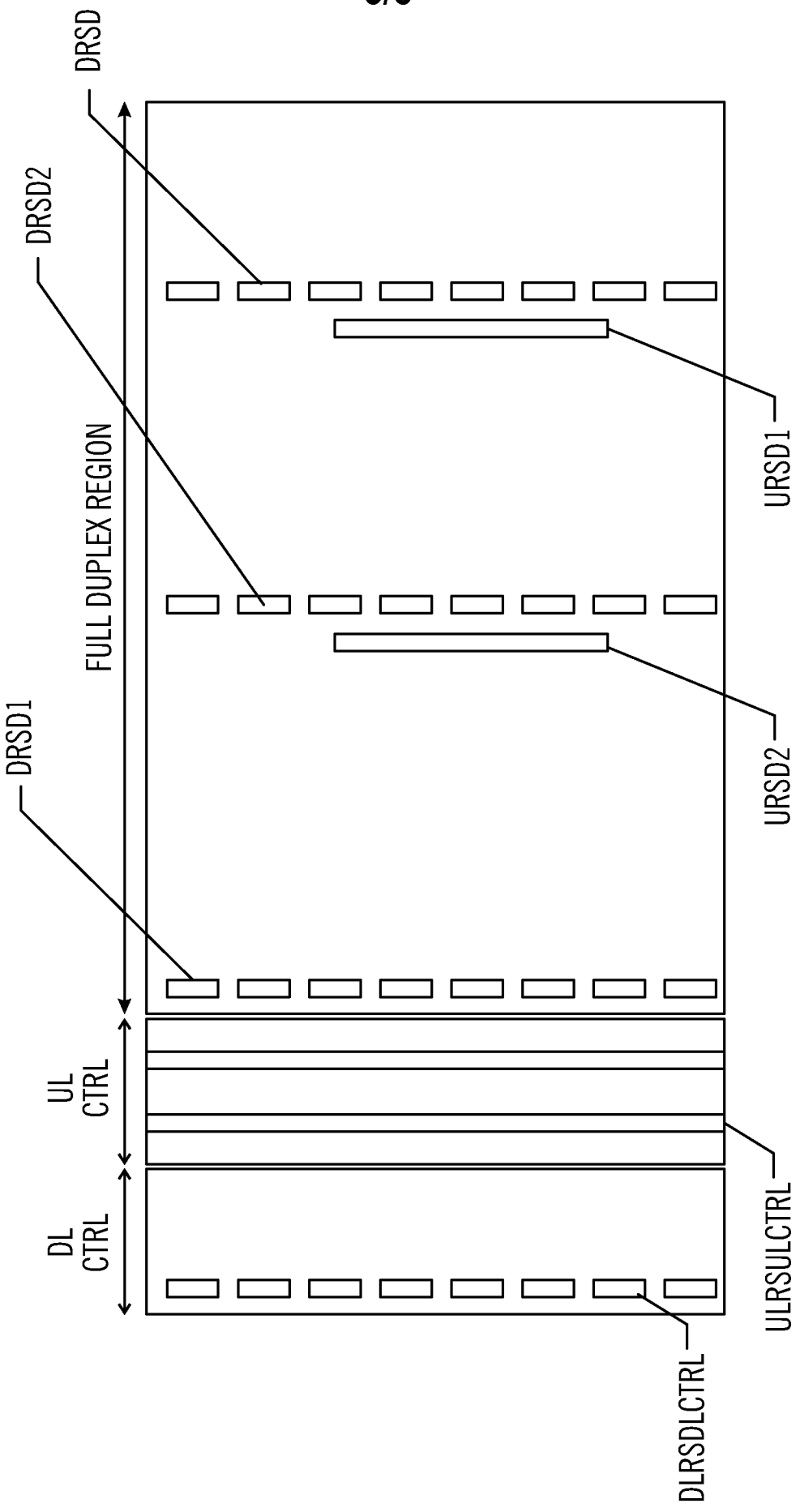
301
PROCESSING CIRCUITRY
302
FULL-DUPLEX RADIO TRANSCEIVER
55
AIR INTERFACE
55
400
UE
401
PROCESSING CIRCUITRY
402
RADIO TRANSCEIVER

FIG. 2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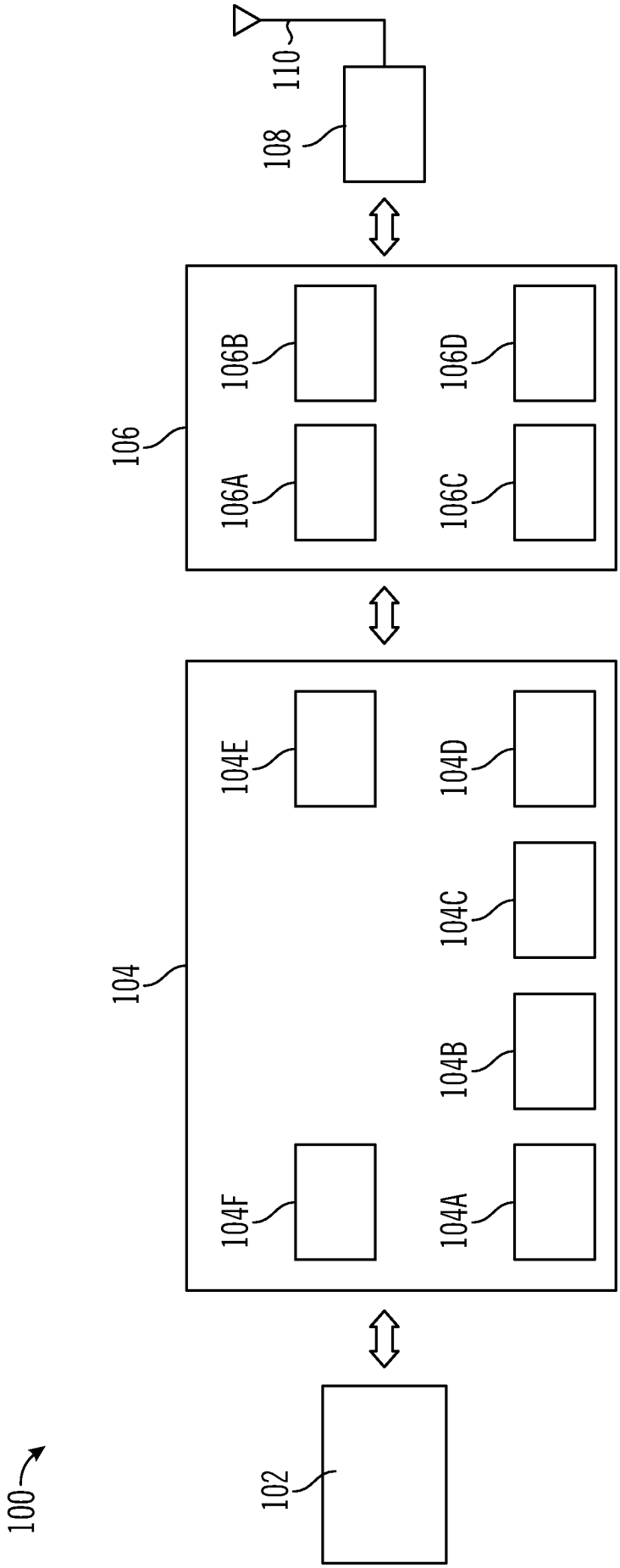
DRSD2
FULL DUPLEX REGION
DRSD1
URSD1
URSD2
UL CTRL
DL CTRL
ULRSULCTRL
DLRSDLCTRL

FIG. 3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102
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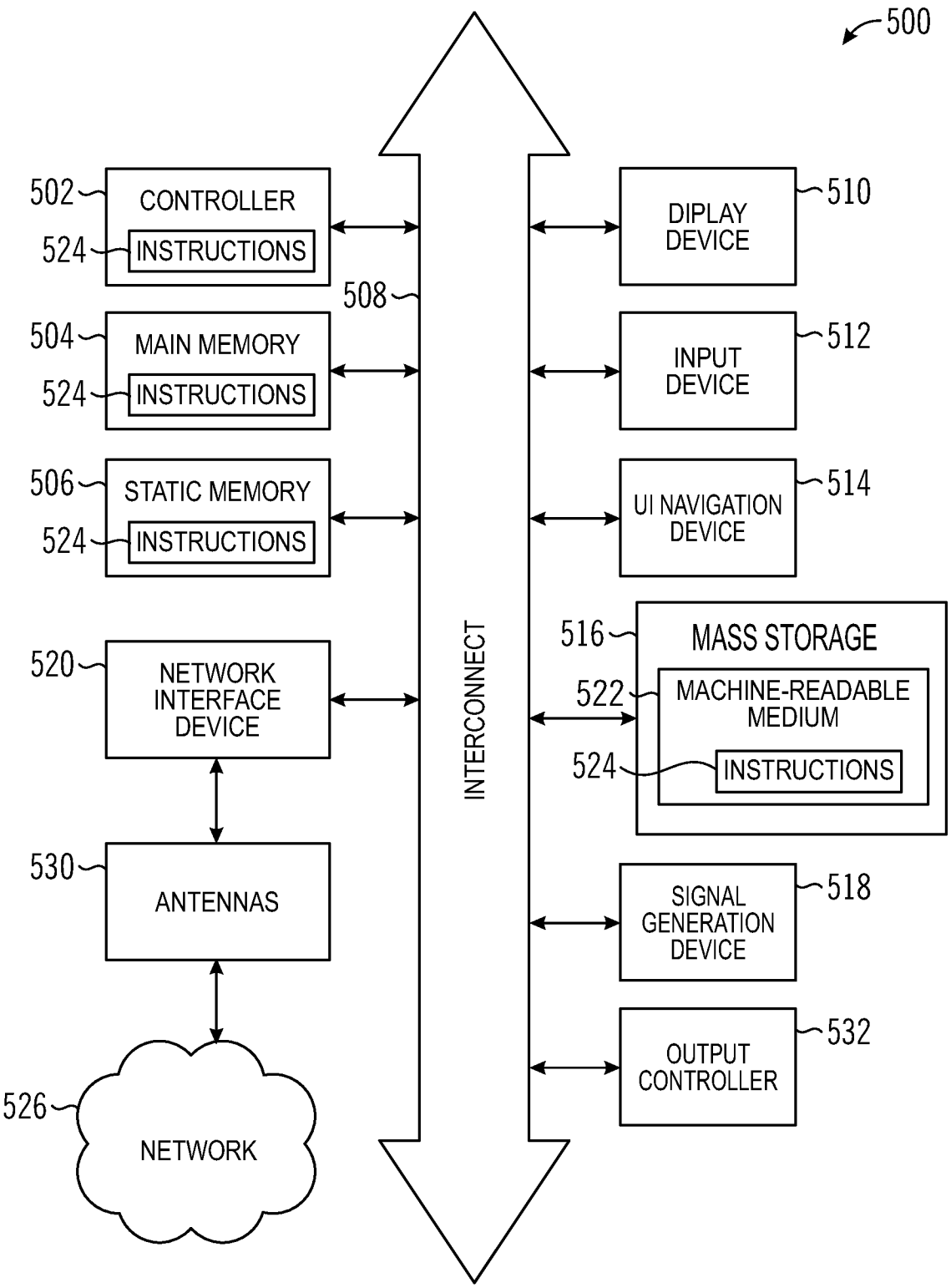
104A
104B
104C
104D
104E
104F
106
106A
106B
106C
106D
108
110

FIG. 4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502
CONTROLLER
524
INSTRUCTIONS
504
MAIN MEMORY
524
INSTRUCTIONS
506
STATIC MEMORY
524
INSTRUCTIONS
520
NETWORK INTERFACE DEVICE
530
ANTENNAS
526
NETWORK
508
INTERCONNECT
510
DIPLAY DEVICE
512
INPUT DEVICE
514
UI NAVIGATION DEVICE
516
MASS STORAGE
522
MACHINE-READABLE MEDIUM
524
INSTRUCTIONS
518
SIGNAL GENERATION DEVICE
532
OUTPUT CONTROLLER

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

H04J 11/00(2006.01)i, H04B 7/26(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J 11/00; H04L 5/00; H04W 24/10; H04W 52/24; H04L 27/26; H04L 5/14; H04B 7/26

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: full duplex, frame structure, reference signal, data region, mute, interference, UE-to-UE, BS-to-BS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015-0078465 A1 (LG ELECTRONICS INC.) 19 March 2015 See paragraphs [0038], [0089], [0203]-[0205]; and figures 5, 21.	1-25
A	WO 2015-039293 A1 (TELEFONAKTIEBOLAGET L M ERICSSON (PUBL)) 26 March 2015 See pages 8-10; figures 1-5; and claims 1, 8.	1-25
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A	US 2014-0078939 A1 (HOOMAN SHIRANI-MEHR et al.) 20 March 2014 See paragraph [0043]; and figure 5.	1-25
A	WO 2015-180773 A1 (NEC EUROPE LTD.) 03 December 2015 See pages 7-12; and figures 1-3.	1-25

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

☒ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
24 August 2016 (24.08.2016)	**24 August 2016 (24.08.2016)**

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