(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 July 2016 (21.07.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/114824 A1

(51) International Patent Classification:
H04L 27/26 (2006.01) *H04L 5/22* (2006.01)

(21) International Application Number:
PCT/US2015/049713

(22) International Filing Date:
11 September 2015 (11.09.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

62/103,708	15 January 2015 (15.01.2015)	US
62/141,011	31 March 2015 (31.03.2015)	US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,

[Continued on next page]

(54) Title: APPARATUS AND METHOD OF PROVIDING A FLEXIBLE GUARD INTERVAL FOR BLOCK SINGLE CARRIER TRANSMISSION

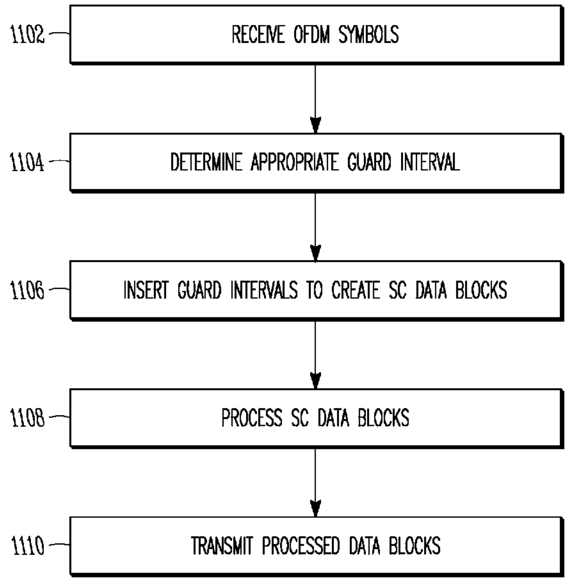


FIG. 11

(57) Abstract: An eNodeB (eNB), user equipment (UE) and method of providing a dynamically determined guard interval (GI) sequence are generally described. Uplink and downlink TDD subframes may each contain a block having a symbol and a GI sequence. The GI sequences may differ or be the same between the different subframes and the GI sequences may depend on an estimation of channel delay spread, a cell identifier (ID) of a cell to which the UE is configured to communicate, and a UE ID. The uplink or downlink subframe may comprise a guard time. A last block of the downlink subframe or first block of the uplink subframe may contain the GI sequence and the guard time and a first block of the uplink subframe or last block of the downlink subframe respectively may contain an additional GI sequence to maintain cyclicity.

WO 2016/114824 A1

DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

APPARATUS AND METHOD OF PROVIDING A FLEXIBLE GUARD INTERVAL FOR BLOCK SINGLE CARRIER TRANSMISSION

PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 62/103,708, filed January 15, 2015, and entitled "FLEXIBLE GUARD INTERVAL FOR BLOCK SINGLE CARRIER TRANSMISSION," and United States Provisional Patent Application Serial No. 62/141,011, filed March 31, 2015, and entitled "GUARD INTERVAL ADAPTATION AND FRAME STRUCTURE FOR 5G," each which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to radio access networks. Some embodiments relate to cyclic prefixes and guard intervals in cellular networks, including Third Generation Partnership Project Long Term Evolution (3GPP LTE) networks and LTE advanced (LTE-A) networks as well as 4th generation (4G) networks and 5th generation (5G) networks.

BACKGROUND

[0003] The use of personal communication devices has increased astronomically over the last two decades. The penetration of cellular telephones and smartphones (the latter now over 50% in the United States and 1.76 billion people worldwide) in modern society has continued to drive demand for a number of types of networked devices in a wide variety of environments. The use of networking using 3GPP LTE systems has increased in all areas of home and work life.

[0004] In many of the diverse locations, notably urban environments, in which communication devices are disposed, multiple different paths between communication endpoints may exist. In this case, the length of the various paths may differ, causing the same signal transmitted from the transmitting communication device to arrive at the receiving communication device at slightly different times and thereby causing spreading of the signal referred to as delay spread. Delay spread may thus be an inherent environmental effect rather than an issue generated by the communication devices, which may lead to different delay spreads in different environments.

[0005] It may be desirable to provide a mechanism to allow communication devices to mitigate for delay spread while minimizing communication inefficiencies involved in compensating for the delay spread.

BRIEF DESCRIPTION OF THE FIGURES

[0006] In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The figures illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0007] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments.

[0008] FIG. 2 is a block diagram of a 3GPP device in accordance with some embodiments.

[0009] FIG. 3 shows a Guard Interval Discrete Fourier transform-Spread-Orthogonal Frequency Division Multiplexing (GI-DFT-s-OFDM) waveform in accordance with some embodiments.

[0010] FIG. 4 illustrates an uplink transmitter implementation in accordance with some embodiments.

[0011] FIG. 5 illustrates downlink transmitter implementation in accordance with some embodiments.

[0012] FIG. 6 illustrates a receiver implementation in accordance with some embodiments.

[0013] FIG. 7 illustrates uplink and downlink Time Division Duplexing (TDD) subframes containing guard intervals in accordance with some embodiments.

[0014] FIGS. 8A and 8B illustrate uplink and downlink TDD subframes containing guard intervals in accordance with other embodiments.

[0015] FIG. 9 illustrates a block diagram of a transmitter in accordance with some embodiments.

[0016] FIG. 10 illustrates a block diagram of a receiver in accordance with some embodiments.

[0017] FIG. 11 illustrates a flowchart of a method of transmitting symbols with a flexible guard interval in accordance with some embodiments.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0019] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments. The network may comprise a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 100 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity sake, only a portion of the core network 120, as well as the RAN 100, is shown.

[0020] The core network 120 includes mobility management entity (MME) 122, serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 100 includes Evolved Node-Bs (eNBs) 104 (which may operate as base stations) for communicating with UE 102. The eNBs 104 may include macro eNBs and low power (LP) eNBs.

[0021] The MME is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME manages mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 terminates the interface toward the RAN 100, and routes traffic packets (such as data packets or voice packets) between the RAN 100 and the core network 120. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates a SGi interface toward the packet data network (PDN). The PDN GW 126 routes traffic packets between the EPC 120 and the external PDN, and may be a key node for policy enforcement and charging data collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in one physical node or separated physical nodes.

[0022] The eNBs 104 (macro and micro) terminate the air interface protocol and may be the first point of contact for a UE 102. The eNBs 104 may communicate both with UEs 102 in a normal coverage mode and UEs 104 in one or more enhanced coverage modes. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 100 including but not limited to RNC (radio network controller functions) such as radio bearer management, uplink and downlink dynamic radio resource management and traffic packet scheduling, and mobility management. In accordance with embodiments, UEs 102 may be configured to communicate OFDM communication signals with an eNB 104 over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM (or SC-FDMA) signals may comprise a plurality of orthogonal subcarriers. Other technologies may also be used, such as Non-Orthogonal Multiple Access (NOMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency-Division Multiple Access (OFDMA).

[0023] The S1 interface 115 is the interface that separates the RAN 100 and the EPC 120. It is split into two parts: the S1-U, which carries traffic packets between the eNBs 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNBs 104 and the MME 122.

[0024] With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise femtocell.

[0025] Communication over an LTE network may be split up into 10ms frames, each of which may contain ten 1ms subframes. Each subframe of the frame, in turn, may contain two slots of 0.5ms. The eNB may schedule uplink and downlink transmissions over a variety of frequency bands. The allocation of resources in subframes used in one frequency band and may differ from those in another frequency band. Each slot of the subframe may contain 6-7 symbols, depending on the system used. In some embodiments, the subframe may contain 12 or 24 subcarriers. A resource grid may be used for downlink and uplink transmissions between an eNB and a UE. The resource grid may be a time-frequency grid, which is the physical resource in each slot. The smallest time-frequency unit in a resource grid may be denoted as a resource element (RE). Each column and each row of the resource grid may correspond to one OFDM symbol and one OFDM subcarrier, respectively. The resource grid may contain resource blocks (RBs) that describe the mapping of physical channels to resource elements and physical RBs (PRBs). A PRB may be the smallest unit of resources that can be allocated to a UE in the current 3GPP standard. A resource block may be 180 kHz wide in frequency and 1 slot long in time. In frequency, resource blocks may be either 12 x 15 kHz subcarriers or 24 x 7.5 kHz subcarriers wide. For most channels and signals, 12 subcarriers may be used per resource block, dependent on the system bandwidth. The duration of the resource grid in the time domain corresponds to one subframe or two resource blocks. Each resource grid may comprise 12 (subcarriers) *14 (symbols) =168 resource elements for normal cyclic prefix (CP) case. Several different physical channels may be conveyed using such resource blocks.

[0026] There may be several different physical downlink channels that are conveyed using such resource blocks, including the physical downlink control channel (PDCCH) and the physical downlink shared channel (PDSCH). Each subframe may be partitioned into the physical downlink control channel (PDCCH) and the PDSCH. The PDCCH may normally occupy the first two symbols of each subframe and carry, among other things, information about the transport format and resource allocations related to the PDSCH channel, as well as H-ARQ information related to the uplink shared channel. The PDSCH may carry user data and higher layer signaling to a UE and occupy the remainder of the subframe. Typically, downlink scheduling (assigning control and shared channel resource blocks to UEs within a cell) may be performed at the eNB based on channel quality information provided from the UEs to the eNB, and then the downlink resource assignment information may be sent to each UE on the PDCCH used for (assigned to) the UE.

[0027] The PDCCH may contain downlink control information (DCI) in one of a number of formats that tells the UE how to find and decode data, transmitted on PDSCH in the same subframe, from the resource grid. The DCI may provide details such as number of resource blocks, resource allocation type, modulation scheme, transport block, redundancy version, coding rate etc. Each DCI format may have a cyclic redundancy code (CRC) and be scrambled with a Radio Network Temporary Identifier (RNTI) that identifies the target UE for which the PDSCH is intended. Use of the RNTI, which may be UE-specific, may limit decoding of the DCI information (and hence the corresponding PDSCH) to only the intended UE. The PDCCH may be located in any of a number of frequency/temporal regions, depending on whether the PDCCH is UE-Specific or common, as well as the aggregation level. The set of possible locations for PDCCH is called the search space. The search space indicates the set of Control Channel Element (CCE) locations where the UE may find its PDCCHs. A common search space may carry DCIs that are common for all UEs; for example, system information (using the SI-RNTI), paging (P-RNTI), PRACH responses (RA-RNTI), or UL TPC commands (TPC-PUCCH/PUSCH-RNTI). A UE-specific search space may carry DCIs for UE-specific allocations using a control RNTI (C-RNTI) assigned to the UE, a semi-persistent scheduling (SPS C-RNTI), or an initial allocation (temporary C-RNTI). As the UE may not know the exact DCI format, nor the location in time and frequency where the PUCCH may be transmitted by the eNB, the UE may thereby rely on blind decoding attempts. In addition to the PDCCH, an enhanced PDCCH (EPDCCH) may be used by the eNB and UE. Different UEs may have different EPDCCH configurations. The EPDCCH may be configured, for example, via Radio Resource Control (RRC) signaling.

[0028] FIG. 2 is a functional diagram of a 3GPP device in accordance with some embodiments. The device may be a UE or eNB, for example. In some embodiments, the eNB may be a stationary non-mobile device. The 3GPP device 200 may include physical layer circuitry 202 for transmitting and receiving signals using one or more antennas 201. The 3GPP device 200 may also include medium access control layer (MAC) circuitry 204 for controlling access to the wireless medium. The 3GPP device 200 may also include processing circuitry 206 and memory 208 arranged to perform the operations described herein.

[0029] In some embodiments, mobile devices or other devices described herein may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the mobile device or other device can be a UE 102 or eNB 104 configured to operate in accordance with 3GPP standards. In some embodiments, the mobile device or other device may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the mobile device or other device may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0030] The antennas 201 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 multiple-input multiple-output (MIMO) embodiments, the antennas 201 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0031] Although the 3GPP device 200 is illustrated 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, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

[0032] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0033] 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 one or more instructions. The term “machine readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the 3GPP device 200 and that cause it 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. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0034] As described above, delay spread is generated by a receiver receiving OFDM symbols from a transmitter via different paths. To combat this, a guard interval (GI) containing a cyclic prefix (CP) may be added before the start of each OFDM symbol to provide protection against multi-path delay spread. The cyclic prefix may typically comprise replication of the last portion of a symbol disposed at the first part of the symbol thereby creating a guard between the symbol and the adjacent symbol. Cyclic prefixes may range in size from 1/4 to 1/32 of a symbol period. A receiver may locate the start of a symbol through a high correlation between the cyclic prefix and the last part of the current symbol, and subsequently start decoding the symbol. The duration of the cyclic prefix may be designed to be greater than the duration of the maximum delay spread in an OFDM system. The cyclic prefix may not carry any useful data and thus represents overhead to be minimized as it takes longer to transfer the same actual information.

[0035] A zero-insertion guard interval or a fixed guard interval may also be used rather than a cyclic prefix. However, the zero-insertion guard interval implementation may have issues related to autocorrelation and may generate abrupt transmission power transitions, causing transient distortion in the transmitter power amplifier. The use of a fixed guard interval may result in tailoring the system to the worst-case delay spread, thereby reducing system efficiency.

[0036] It thus may be desirable to adjust the length of the guard interval to be environmental-specific. In urban environments, the propagation at millimeter frequencies (e.g., 28 GHz, 60 GHz, etc.) may show a higher degree of variability in multipath delay spread as compared with lower frequency communication systems. As the multipath effects (delay spread) may differ between urban (likely smaller path length differences) and rural (likely longer path length differences) environments, it may be desirable to use a different cyclic prefix length. A normal cyclic prefix may have a duration of 4.7 μs (representing a distance of 1.4 km) resulting in 7 (data) symbols per slot, and an extended cyclic prefix may have a duration of 16.67 μs, resulting in 6 symbols per slot. Thus, while LTE-A may be designed to support a few cyclic-prefix lengths, different cyclic prefix configurations (symbol duration, cyclic prefix length and Transmission Time Interval (TTI) length) as yet have not been defined to enable use of a re-configurable cyclic prefix. Moreover, some environments, such as those of small cells with reduced coverage, may see a much smaller delay spread than even urban environments, for which a reduction in the cyclic prefix length may be desirable but the 3GPP standard currently does not support. In some embodiments, it may accordingly be useful to vary the size of the guard interval dependent on the delay spreads.

[0037] In more detail, the delay spread in some embodiments may be dependent on the transmission mechanism. For example, although in microwave systems the delay spread may mainly be determined by the environment itself, mmWave channel delay spreads may also be sensitive to beamforming techniques used in transmission. One example of the delay spread cumulative distribution function for a beamformed channel and pre-beamformed omnidirectional channel indicates that the RMS delay spread decreases by a factor of 3-4 post beamforming. Thus, using a re-configurable guard interval of varying lengths may reduce the overhead and optimize system efficiency as the environmental conditions change.

[0038] Moreover, while a cyclic prefix typically may carry mere replication of the actual data of the symbol, this data may essentially be discarded. Thus, in some embodiments, the guard interval may be designed to carry a guard interval sequence used to fulfill a predetermined set of design criteria, such as time/frequency synchronization/tracking. Consequently, the number of cell-specific reference signals per subframe may be reduced or removed altogether.

[0039] In some embodiments, Discrete Fourier Transformation-Spread-Orthogonal Frequency Division Multiplexing (DFT-s-OFDM) modulation with a flexible, configurable guard interval of variable size (GI-DFT-s-OFDM) may be employed. DFT-S-OFDM is a communication scheme that may be implemented to overcome issues with high peak-to-average power ratio (PAPR), for example, in the OFDM and OFDMA communication schemes. DFT-S-OFDM may spread signals with a DFT in the frequency domain before generating OFDM signals. The signals spread may then be modulated and transmitted using conventional OFDM techniques. GI-DFT-s-OFDM or single carrier block transmission (GI-SCBT) may employ a fixed symbol length regardless of guard interval length, making dynamic adaptation of the guard interval easier.

[0040] The size of the guard interval may be adjusted to accommodate the maximum delay spread in a given scenario, e.g., normal operating environments, a LTE uplink small cell with limited coverage, or a mmWave small cell. In some embodiments, the system design may be based on a GI-SCBT or GI-DFT-s-OFDM scheme that can be applied to a wide variety of systems with different channel delay spread characteristics.

[0041] A transmission format and transceiver structure for DFT-s-OFDM systems (e.g., for uplink LTE, mmWave, etc.) with a variable guard interval may exploit the use of a known variable-length information sequence (hereinafter referred to as a guard interval sequence) to be sent, rather than using a cyclic prefix in the guard interval. The variability of the guard interval may permit automatic adaptation of the guard interval length dependent on the channel delay spread on a per-cell basis (for FDM systems) or on a per-user basis (for TDM systems), for example. In this case, a-priori knowledge of the channel conditions may be avoidable for configuration of a given system, in addition to minimizing cyclic prefix/guard interval-related overheads, as the guard interval length can be determined on the fly using pilot symbols enabling determination of the delay spread. This may also enable a uniform design for a 5G air interface by supporting systems for different application scenarios, Radio Access Technologies, etc.

[0042] The guard interval sequence may also be used for time/frequency tracking and thus may be designed to have good autocorrelation and cross-correlation properties to minimize the effect of inter-cell interference. Various options for the subframe structure of GI-DFT-s-OFDM or GI- SCBT systems may be used, including packing guard interval symbols into one TTI. The TTI may be the smallest unit of time, for example 1ms, in which the eNB is capable of scheduling any UE for uplink or downlink transmission. In SCBT systems for example, the guard interval may be used to separate consecutive blocks, which may then be processed at the receiver, typically in the frequency domain.

[0043] In other embodiments, however, GI-DFT-s-OFDM or GI-SCBT may use a fixed symbol length regardless of guard interval length, simplifying the guard interval adaptation. In such an embodiment, an adaptive or configurable guard interval with fixed DFT size and numerology may be used, as well as using a guard interval sequence that may be optimized for design criteria/target such as time/frequency synchronization/tracking.

[0044] In mmWave small cell design for example, it may be desirable to pack the guard interval symbol of the GI-DFT-s-OFDM into each subframe due to the TDD configuration and TTI while still providing cyclic convolution (guard intervals at the end of each data symbol transmission) to reduce intersymbol interference or provide protection from delay spread. The GI-DFT-s-OFDM waveform and transceiver block is described herein, as are uplink and downlink implementations, subframe configurations, a guard interval sequence design and signaling to determine the guard interval sequence length.

[0045] FIG. 3 shows a GI-DFT-s-OFDM waveform in accordance with some embodiments. In embodiment in which a random guard interval sequence that does not carry symbol data is formed by copying the last few data samples and appending them to the beginning of the symbol, the cyclic prefix may not be considered part of the DFT interval and thus increases the length of the overall symbol from T_{DFT} to T_{DFT} +T_{GI}. Unlike these embodiments, the GI-DFT-s-OFDM waveform 300 shown in FIG. 3, the DFT interval 302 comprises both the data 304 of the symbol 302 and the GI 306 appended at the end of the block 302. In addition, an additional guard interval may be inserted before the initial block of a TTI, thereby reducing the size of the data of the initial block. The total length of the symbol 302, however, may remain constant at T_{DFT}.

[0046] The GI 306 may be a fixed, apriori known sequence. The known GI 306 may be utilized for time/frequency tracking and/or channel estimation. Additionally, as the GI 306 is part of the symbol 302, the length of each of the data 304 and GI 306 may be varied as long as the total length of the symbol 302 remains constant. Following the TDD frame structure, a TTI with 70 blocks (symbols) for OFDM, or GIDFTsOFDM 75 symbols per TTI, is described as part of a 1 ms frame including 10 TTI.

[0047] FIG. 4 illustrates an uplink transmitter implementation in accordance with some embodiments. The embodiment of FIG. 4, which may be disposed in a particular UE, includes an M-point DFT block 402 to which may be supplied data and zeros and provide a discrete Fourier transform. The data may be that of the symbol or symbols to be transmitted. The size of the discrete Fourier transform may be equal to the physical resource block size allocated to the particular UE. Based on configuration signaling, a guard interval length, and thus number of zeros, may be selected that satisfies the maximum delay spread on a per-cell or a per-user/device basis. The data symbols may be Quadrature Amplitude Modulated (QAM) data symbols and may be succeeded by a zero tail, the length of which may be the length of the guard interval times the ratio M/N, where M is the number of points of the DFT and N is the number of points of an inverse Fourier transform (IFFT). The zeros may thus be placeholders for the guard interval sequence to be inserted.

[0048] After performing a discrete Fourier transform on the input, the output of the DFT block 402 may be mapped to particular subcarriers by a subcarrier mapper 404 to provide frequency spreading of the discrete data from the DFT 402 to different subcarriers. Once mapped to the individual subcarriers, the symbols may be subjected to an N-point IFFT at an IFFT block 406. The output from the IFFT block 406 may be provided to a combiner 408, where the guard interval sequence are added to the almost-zero output sequence from the IFFT block 406 replaced prior to amplification by a power amplifier and transmission by an antenna. The DFT block 402, subcarrier mapper 404, IFFT block 406 and combiner 408 may be separate components within a UE shown in FIGS. 1 and 2 or may be implemented by a particular processor within the UE.

[0049] FIG. 5 illustrates downlink transmitter implementation in accordance with some embodiments. The downlink transmitter of FIG. 5, which may be disposed in a particular eNB serving a number of UEs, may comprise a plurality of DFT blocks 502. Each DFT blocks 502 may correspond to a different UE. Similar to the embodiment of FIG. 4, the size of the DFT M_i for the i^{th} UE may be equal to the PRB allocation size of the i^{th} UE. The number of zeros inserted at the tail of the data for a particular UE (the i^{th} UE) before DFT spreading may be equal to the length of the desired guard interval multiplied by the ratio M_i/N, where N is IFFT size and thus number of DFT blocks 502. In various embodiments, the number of zeros (and thus guard interval sequence) may be the same or may differ between UEs.

[0050] After performing a discrete Fourier transform on the input to the DFT blocks 502, the output of the DFT block 502 may be mapped to particular subcarriers by a subcarrier mapper 504. Once mapped to the individual subcarriers, the symbols may be subjected to an N-point IFFT at an IFFT block 506. The output from the IFFT block 506 may be provided to a combiner 508, where the guard interval sequence are added to the almost-zero output sequence from the IFFT block 506 prior to being amplified by a power amplifier and transmission by an antenna. In case of spatially separated UEs, which may be the case for mmWave systems, downlink transmission may be similar to uplink transmission using a DFT block spread in the data symbols over the entire bandwidth of the LTE system (e.g., 20MHz). The DFT block 502, subcarrier mapper 504, IFFT block 506 and combiner 508 may be separate components within an eNB shown in FIGS. 1 and 2 or may be implemented by a particular processor within the eNB.

[0051] FIG. 6 illustrates a receiver implementation in accordance with some embodiments. The receiver structure may be similar to the structural implementations shown in FIGS. 4 and 5. The receiver may processes symbols in blocks of size T_{DFT}, which, as above, comprise data symbols and guard interval. The receiver of FIG. 6 includes an N-point FFT block 602 to which may be supplied an incoming baseband signal, and in response provide a Fast Fourier Transform. The FFT block 602 may provide N discrete individual signals designated for different frequencies.

[0052] After performing the FFT on the baseband input communication signal, the output of the FFT block 602 may be provided to an equalizer 604. The equalizer 604 may provide equalization in the frequency domain to the transformed signal to compensate for the different phases and amplitudes of the symbol as received via different paths.

[0053] The equalizer 604 output may subsequently be supplied to a subtractor 606. The subtractor 606 may subtract the contributions of the guard intervals (i.e., the guard interval sequences) on the data subcarriers. In some embodiments, the eNB may subtract the contribution of all guard intervals for uplink operation. In some embodiments, only one guard interval may be used for all UEs for downlink operation, and thus the UE knowledge may be limited to the guard interval to subtract its contribution to the data subcarriers. This permits guard intervals of different lengths to be used without modifying the DFT size T_{DFT}.

[0054] The output from the subtractor 606 may be provided to an inverse DFT (IDFT) block 608, where the QAM data symbols are extracted through an IDFT operation. The FFT block 602, equalizer 604, subtractor 606 and IDFT block 608 may be separate components within a receiver shown in FIGS. 1 and 2 or may be implemented by a particular processor within the receiver.

[0055] FIG. 7 illustrates uplink and downlink TDD subframes containing guard intervals in accordance with some embodiments. The transmission TDD frame structure 700 shown in FIG. 7 may contain alternating downlink subframes 702 and uplink subframes 704. The placement of the uplink and downlink subframes 702, 704 are merely exemplary. The uplink and downlink subframes 702, 704 may comprise SC data symbols or DFT-s-OFDM data symbols and guard intervals.

[0056] The uplink and downlink TTIs 710, 720, 730, 740 may contain multiple data symbols and guard intervals. Both the FFT window 712, 732, which may be used for demodulation, and the length of the symbol 714, 734, which may be used for counting symbols to be packed into one TTI, may be of the same length. This length may be a symbol duration, which comprises the length of a data symbol 716 and a guard interval 718. However, in the first set of uplink and downlink TTIs 710, 720, the FFT window 712 for demodulation and symbol duration 714 may not entirely overlap. Typical values for the various elements of FIG. 7 include a TTI of 0.1ms, a subcarrier spacing of 750KHz, a symbol duration of 1.33μs and 75 symbols per TTI. Other subcarrier spacings, such as 480KHz, may be used, with the corresponding values adjusted accordingly. For the TDD frame structure shown, the guard time may include the round trip delay (twice the propagation delay) and twice the Tx/Rx switching delay and power amplifier settling time (for the transmitter and receiver). In one example, for a 100m cell, the round trip delay may be 666.67ns, the Tx/Rx switching delay may be 10-20 ns, and the power amplifier setting time may be around 100ns. Overall, the guard time (GT) may thus be at least about 800-900ns.

[0057] In the first set of uplink and downlink TTIs 710, 720 of FIG. 7, the guard time 722 may be disposed within the downlink TTI 710. In the second set of uplink and downlink TTIs 730, 740 of FIG. 7, the guard time 742 may be disposed within the uplink TTI 740.

[0058] In the first set of uplink and downlink TTIs 710, 720, the last symbol of the downlink TTI 710 may be a special symbol, which contains a normal sized guard interval and a guard time 722. The guard time 722 may provide a buffer for switching of the UE between transmitter mode and receiver mode, as well as providing a buffer to prevent corruption of the first symbol of the uplink TTI 720. Using the example above, the guard interval and guard time may be 1.33μs, where the guard time duration is determined by the length of the guard interval used in the subframe. When adapting the guard interval, all the guard intervals in the subframe may be adapted. In one example, assuming a guard time of 1μs, the maximum guard interval length that can be supported in the downlink may thus be 0.33 μs.

[0059] In addition, the last symbol 726 of the uplink TTI 720 may also be a special symbol, but not a guard time symbol. In particular, the data duration of the last symbol 726 of the uplink TTI 720 may be less than the data duration in the first symbols (symbols 1-74 per the above example of 75 symbols in each TTI) of the uplink TTI 720 to fit in an extra guard interval 724 before the initial symbol of the uplink TTI 720 to maintain cyclicity. In GI-DFT-s-OFDM, this can be accomplished, in one embodiment, by mapping data to selective subcarriers, for alternative subcarriers to obtain half of the symbol duration. In another embodiment, a greater number of zeros may be inserted before the DFT spreading. In GI-SCBT, partial data blocks may be transmitted when the same sized DFT and IFFT are used, or, in another embodiment similar to the above, a greater number of zeros may be used when the DFT and IFFT size are different. In some embodiments, the guard time and/or subframe of shorter data duration may be in a subframe other than the last subframe of the TTI.

[0060] In the second set of uplink and downlink TTIs 730, 740, the guard time 742 may be disposed in the uplink TTI 740. Unlike the first set of uplink and downlink TTIs 710, 720, in which the guard time 722 may be disposed in the downlink TTI 710, the guard time 742 may be disposed in the first symbol of the uplink TTI 740. Similar to the previous embodiment, the first symbol 732 of the downlink TTI 730 may again be a special symbol that contains an additional guard interval 734 and a shortened data symbol 736 compared with the data duration in the remaining downlink symbols. Thus, in the downlink TTI 730, the first symbol may be generated by shortened data transmission with a guard interval in the beginning as well as at the end of the symbol. In some embodiments, the data in the first symbol may be training sequence for beam tracking, channel estimation or other functionality. In some embodiments, the guard intervals (and guard times) may have different durations between the uplink and downlink TTIs while in other embodiments the guard intervals may be the same duration.

[0061] FIGS. 8A and 8B illustrate uplink and downlink TDD subframes containing guard intervals in accordance with other embodiments. The transmissions in FIGS. 8A and 8B may have similar characteristics as the transmissions in FIGS. 7A and 7B. A transmission TDD frame structure 800 shown in FIG. 8A may contain a first set of consecutive downlink subframes 810, 820 and a second set of uplink subframes 830 in which a guard time is disposed in one of the downlink subframes 820. The placement of the uplink and downlink subframes 810, 820, 830 as above, is merely exemplary. In some embodiments, the sets may have a fewer number of subframes or a greater number of subframes than the number of subframes shown. In some embodiments, the number of subframes in each set may be the same or may differ between uplink and downlink subframes. The downlink 810, 820 and uplink 830 subframes may each comprise SC data symbols or DFT-s-OFDM data symbols 816 and guard intervals 818.

[0062] As above, the uplink and downlink TTIs 812, 832 may contain multiple data symbols 816 and guard intervals 818. The FFT window 814, which may be used for demodulation, may have a length of a symbol duration, which comprises the length of a data symbol 816 and a guard interval 818. The guard time 822 may be disposed within the downlink TTI 812 of the final downlink subframe 820 of the set of downlink subframes 820 adjacent to the initial uplink subframe 830 in the set of uplink subframes 830. In the downlink TTI 812 of the final downlink subframe 820 of the set of downlink subframes, the last symbol of the downlink TTI 820 (the last symbol prior to the uplink subframe 830 may be a special symbol that contains a guard time 822. As above, when adapting the guard interval 818, all the guard intervals in each downlink and uplink subframe 810, 820, 830 may be adapted.

[0063] Similarly, a transmission TDD frame structure 850 shown in FIG. 8B may contain a first set of consecutive downlink subframes 860 and a second set of uplink subframes 870, 880 in which a guard time is disposed in one of the uplink subframes 870. The placement of the downlink and uplink subframes 860, 870, 880 as above, is merely exemplary. In some embodiments, the sets may have a fewer number of subframes or a greater number of subframes than the number of subframes shown. In some embodiments, the number of subframes in each set may be the same or may differ between uplink and downlink subframes. The downlink 860 and uplink 870, 880 subframes may each comprise SC data symbols or DFT-s-OFDM data symbols and guard intervals.

[0064] As above, the uplink and downlink TTIs may contain multiple data symbols and guard intervals. The FFT window 868 may be a symbol duration, which comprises the length of a data symbol and a guard interval. The length of the symbol 866 may be of the same length as the FFT window 868. The guard time 872 may be disposed within the uplink TTI 812 of the initial uplink subframe 870 adjacent to the final downlink subframe 860 in the set of downlink subframes 860. In particular, the first symbol of the uplink TTI (the first symbol after the downlink subframe 860) may be a special symbol that contains a guard time 822. As above, when adapting the guard interval, all the guard intervals in each downlink and uplink subframe 860, 870, 880 may be adapted. Moreover, the longest the guard interval duration may be limited by the duration of the guard time 872. In either transmission TDD frame structure shown in FIG. 8A or 8B, each TTI may be scheduled to different users. Each TTI may thus begin and end with a guard interval to ensure cyclicity and hence no ISI in the first and last data block for demodulation.

[0065] In some embodiments, the guard interval may be designed to have good time domain autocorrelation for time/frequency tracking and good cross-correlation properties between different guard intervals to reduce interference from the guard intervals transmitted on the same resources in other cells (and for FDM multiplexed UEs in uplink the same cells). In some embodiments, Zadoff-Chu (ZC) sequences as described in equation (1) below are used for the guard intervals:

$$a_{q(n)} = exp\left[-\frac{j2\pi q\, n(n+1)/2}{N_{ZC}}\right], q = 1, \ldots, N_{ZC} - 1 \; and \; n = 0, \ldots, N_{ZC} - 1 \qquad (1)$$

[0066] Guard intervals formed using ZC sequences may have the auto and cross-correlation properties of the guard intervals exhibiting ideal cyclic correlation and optimal cross-correlation.

[0067] To maintain good out-of-band emission properties, a guard interval sequence may be generated in the frequency domain and upsampled using an IDFT of size equal to the delay spread the system desires to account for, say N_{GI}. Some embodiments may use an upsampling rate of 2. In some embodiments, the length of the ZC sequence N_{ZC} may be selected to be the largest prime number smaller than or equal to $N_{GI}/2$. The ZC sequence may also be cyclically extended to desired length $N_{GI}/2$ as provided in equation (2).

$$r_q(n) = a_q(n \bmod N_{ZC}), n = 0,1,\ldots,N_{GI}/2-1 \qquad (2)$$

[0068] The cyclic extension may preserve a constant amplitude property of ZC sequences.

[0069] For uplink communications, in order for a cell to support different guard interval lengths, each cell may be assigned one base ZC sequence for each possible guard interval length. Different cells may be assigned different base sequences. Different base sequences can be obtained from (1) by using different values of q. A guard interval sequence of a particular length can be derived from the base sequence by a cyclic extension, as indicated in equation (2). Different UEs may be assigned cyclically shifted versions of the cyclically extended base sequences, with the length of the sequence assigned being long enough to handle the corresponding delay spread. As the correlation of a ZC sequence with cyclically shifted versions of itself is zero, ZC sequences are good choices for providing a guard interval sequence. Use of different base sequences for different UEs in the same cell may not be desirable because of non-zero cross-correlation between base sequences that can degrade the performance of time/frequency tracking.

[0070] For downlink communications, only one guard interval sequence may be used for transmission of symbols within a subframe because the guard interval is attached after the IFFT. Each cell may be assigned one base sequence for each possible guard interval length. Different cells may be assigned different base sequences. Cross-correlation between the base sequences may be low due to inherent properties of the ZC sequences, thus leading to low inter-cell interference.

[0071] To decide the guard interval sequence, the transmitter and receiver (e.g., UE and eNB) may agree on the choice of the flexible guard interval. The eNB may estimate the desired guard interval length based on an estimation of channel delay spread as determined using pilot symbols on the uplink transmission from the UE. The guard interval sequence may also be specific to the eNB or cell and/or UE. The eNB may subsequently signal to the UE a guard interval index to be used for both uplink and downlink communications. The guard interval sequence may thus be based on an estimation of channel delay spread, as well as cell ID or UE ID. If a cell-specific guard interval set is established, it may also be possible to obtain the cell-specific guard interval set by processing a universal guard interval set in a fashion dependent on the cell identifier, known both to eNB and attached UE. This option may reduce the amount of signaling between UE and eNB to determine the cell-specific guard interval set. The guard interval sequence may be chosen statically or semi-statically as the variation of delay spread in a wireless channel tends to be much slower than that of the received signal strength.

[0072] Several signaling schemes may be used to provide a guard interval index to the UE. This signaling may include higher layer control signaling, such as RRC signaling, or active signaling, such as via the PDCCH or PUCCH. For example, a new PDCCH field may be used to provide the guard interval index or an existing PDCCH field may be used to provide the guard interval index. Similarly, a new or existing RRC signal may be used to provide the guard interval index. The RRC signal may be periodic or aperiodic, and may be exchanged through by means of a predefined RRC field. In PDCCH/PUCCH signaling, a portion of the PDCCH/PUCCH may be reserved to signal the guard interval index. The signaling may be periodic (e.g., every subframe or predetermined number of subframes) or aperiodic, when a change in the guard interval index occurs.

[0073] Other embodiments of the transmitter and receiver of FIGS. 4-6 are shown in FIGS. 9 and 10. In particular, FIG. 9 illustrates a block diagram of a transmitter in accordance with some embodiments. The transmitter 900, which may be the UE or eNB shown in FIGS. 1 and 2, contains control circuitry and other circuitry not shown, for example one or more: power amplifiers, filters such as bandpass filters, mixers that may upconvert/downconvert received signals between baseband and RF, and antennas that may receive the configuration signaling and transmit the symbols (including the cyclic prefix), among others. At least some of the modules described below may be implemented by a processor or may be implemented by dedicated circuitry.

[0074] In FIG. 9, configuration signaling is received either externally, e.g., from the eNB, or from a memory in the transmitter 900 based on a previous network communication. Based on configuration signaling, a GI selector 902 may determine the number of symbols per block for transmission. The GI selector 902 may also determine the appropriate guard interval sequence and duration, obtained from a sequence generator 920 connected with the GI selector 902. The sequence generator 920 may generate a number of different GI sequences based on the Zadoff-Chu sequences as described above for use by the transmitter 900. The combined length of the single carrier block, which contains the data and guard interval, may be constant for different guard interval choices, equaling the DFT size, T_{DFT}. The combined length may be used at both the transmitter 900 and receiver (described below) for frequency domain pre-processing and post-processing, respectively.

[0075] The transmitter 900 may also contain one or more scramblers 904 that may scramble the symbols in a particular symbol stream. In some embodiments, each symbol stream may be scrambled by the scrambler 904. Each symbol stream may then be provided to an encoder 906 in which the data bits of the symbol stream may be encoded using a particular scheme known to both the transmitter 900 and receiver to enable forward error correction. Each encoded symbol stream may then be provided to a modulator 908 in which the data bits of the encoded symbol stream may be modulated using a particular modulation scheme (e.g., QAM, DSB) known to both the transmitter 900 and receiver. Each modulated symbol stream may then be provided to a symbol blocker 910 that may be triggered by the GI selector 902 and may be used in conjunction with a GI inserter 912 to insert the appropriate guard interval (and cyclic prefix) in the symbol stream at the appropriate locations of each single carrier block.

[0076] After the guard interval has been inserted into the symbol stream by the GI inserter 912, the transmitter 900 may perform frequency domain post-processing. In particular, each symbol stream containing the guard intervals (i.e., each single carrier block) may be Fourier transformed using an FFT module 914 to compute the DFT of the symbol stream, allowing the transmitter 900 to process the single carrier block in the frequency domain and then convert the single carrier block back to the time domain. The digitized results produced by the FFT module 914 may then be beamformed by a digital precoder 916 using the appropriate phase and gain weighting for the desired transmission (e.g., SIMO or MIMO). The precoded information, containing the weighted data and cyclic prefix, may subsequently be provided to an IFFT module 918. The IFFT module 918 re-transforms the precoded information via an inverse Fourier transform to ready the information for transmission.

[0077] FIG. 10 illustrates a block diagram of a receiver in accordance with some embodiments. The receiver 1000, similar to the transmitter, contains control circuitry and other circuitry not shown, for example one or more: power amplifiers, filters such as bandpass filters, mixers that may upconvert/downconvert received signals between baseband and RF, and antennas that may receive the configuration signaling and transmit the symbols (including the cyclic prefix), among others. As above, at least some of the modules described below may be implemented by a processor or may be implemented by dedicated circuitry. The receiver 1000 may process symbols in blocks of size T_{DFT}, which each include the single carrier block of data symbols and following guard interval.

[0078] After being received, each symbol stream containing guard intervals may be frequency domain processed, specifically by being Fourier transformed using an FFT module 1002 to compute the DFT of the symbol stream and permit the receiver 1000 to process the single carrier blocks in the frequency domain before converting the blocks back to the time domain. The digitized results produced by the FFT module 1002 may then be de-weighted by a digital beamformer 1004 to obtain the original symbol weighting before beamforming by the transmitter. The de-weighted blocks may subsequently be provided to a frequency domain equalizer 1006 and then an IFFT module 1008, where they may be transformed back via an inverse Fourier transform to ready the information for removal of the guard interval.

[0079] The single carrier blocks from the IFFT module 1008 may next be supplied to a guard interval remover 1010. The guard interval remover 1010 may be supplied with the correct guard interval length as determined by a guard interval length selector 1014. The guard interval length selector 1014 may be provided configuration signaling received either externally, e.g., from the eNB, or from a memory in the receiver 1000. The guard interval length selector 1014 may determine the appropriate guard interval length from a plurality of potential guard interval lengths (and sequences) based on the configuration signaling. This permits guard intervals of different lengths to be used without modifying the DFT size T_{DFT}.

[0080] The guard interval remover 1010, upon receiving the guard interval length information from the guard interval length selector 1014, may subsequently remove the guard interval from each single carrier block. The first guard interval block of the frame may be discarded. As the first guard interval block of the frame may be used substantially only to ensure that, for the first block of the frame, the channel convolution appears cyclic at the receiver 1000. This permits the single carrier blocks to be able to be processed with frequency domain equalization (FDE) by the frequency domain equalizer 1006 to mitigate frequency-selective fading and phase distortion. At that point, based on configuration signaling, the particular guard interval is removed.

[0081] The symbol stream obtained when the guard intervals are removed by the guard interval remover 1010 may subsequently be provided to a demapper 1016, where the data bits of the symbol stream may be demodulated using the modulation scheme employed by the transmitter to modulate the symbol. The demodulated symbols, however, may remain encoded until being supplied to a decoder 1018. The decoder 1018 may employ the encryption scheme to decrypt the symbols of the single carrier blocks. The decrypted symbols may subsequently be provided to a descrambler 1020 that may descramble the symbols in a particular symbol stream that were originally scrambled by the transmitter.

[0082] FIG. 11 illustrates a flowchart of a method of transmitting symbols with a flexible guard interval in accordance with some embodiments. The method may begin at operation 1102 when OFDM symbols are received by the UE for transmission. The OFDM symbols may be generated by any type of communication to be transmitted by the transmitter, e.g., voice data of a cellular telephone call, image data of an image, textual data of a text message, or biometric data or other sensor from a sensor, among others.

[0083] The UE may provide certain types of processing, such as scrambling, encryption and modulation to the OFDM symbols before inserting, at operation 1104, guard intervals containing cyclic prefixes to provide protection against multi-path delay spread. The length of the guard interval may be variable and have a length that varies dependent on, for example, the operating environment (e.g., cell, urban or rural) and processing techniques (e.g., modulation scheme, beamforming) used. The cyclic prefix used in the guard interval may carry a sequence used for time/frequency synchronization and/or tracking. The size of the guard interval may be adjusted to accommodate the maximum delay spread, which may be estimated using environmental and operating conditions or known from previous uses. If known, the guard interval length may be stored in local memory. The guard interval length may also be determined contemporaneously using pilot symbols and provided to the UE by the network, for example in a PDCCH, RRC signaling or system information blocks. The guard interval length may be automatically adapted by the UE or signaled by the network dependent on the channel delay spread on a per-cell basis (for FDM systems) or on a per-user basis (for TDM systems).

[0084] Once the size of the guard interval is determined, the guard intervals may be inserted into a single carrier block at operation 1106. All of the guard intervals in a particular subframe may be adjusted to be the same variable length. The guard interval length may vary between subframes or frames. In some embodiments, the last symbol of a downlink transmission time interval or the first symbol of an uplink transmission time interval may contain a predetermined symbol that contains a normal sized guard interval and a guard time, while, correspondingly, the last symbol of the uplink transmission time interval or the first symbol of the downlink transmission time interval may have a smaller data duration than the data duration of the remaining to fit in an extra guard interval.

[0085] The guard interval may be designed to have good autocorrelation properties, so that the performance of time and frequency tracking algorithms is able to be maximized. The guard interval may be UE-specific (specific to the transmitter and/or receiver). Moreover, it may also be desirable that different cells use different guard intervals with low cross-correlation, so that the impact of inter-cell/inter-user interference is minimized.

[0086] The guard interval selected may be communicated and agreed between the transmitter and receiver. At an initial stage of the communication, a conservative choice of the guard interval may be used to ensure proper detection during a coarse beam search procedure. Afterwards, during fine beam search and tracking, the guard interval may be further adjusted. The eNB may estimate the required guard interval length based on the uplink transmission, exploiting channel reciprocity in the suggested uplink/downlink TDD configuration. The eNB may then signal to the UE a guard interval index to be used for both uplink and downlink transmissions. If a cell-specific guard interval set is used, it may also be possible to obtain the guard interval by processing a universal guard interval set in a manner that is dependent on the cell identifier, known both to eNB and attached UE. This may reduce the amount of signaling between UE and eNB. The guard interval sequence may be dynamically determined by the eNB or static. For example, a portion of PDCCH may be reserved to signal the guard interval index. Signaling can be periodic (every subframe, or every certain number of subframes) or aperiodic, when a change in guard interval index occurs.

[0087] After the guard interval has been inserted, in operation 1108, the UE may provide further processing of the single carrier blocks. In particular, the UE may transform each single carrier block into the frequency domain using an FFT transformation. The UE may then precode the resulting signal before transforming the signal back to the time domain using an IFFT transformation.

[0088] The UE, having inserted the variable guard intervals into the TTI and further processed the resulting combination, the UE may later transmit the data at operation 1110. The UE may transmit the data via, for example, SIMO or MIMO. The UE further may use 4G or 5G LTE transmissions, for example, or other communication protocols.

[0089] Example 1 can include a User equipment (UE) comprising: processing circuitry configured to: generate a Time Division Duplex (TDD) frame comprising multiple blocks, each block comprising one of a single carrier (SC) and Guard Interval Discrete Fourier transform-Spread-Orthogonal

Frequency Division Multiplexing (GI-DFT-s-OFDM) symbols and a dynamically determined guard interval (GI) sequence; and configure a transceiver to transmit the TDD frame to an enhanced NodeB (eNB).

[0090] Example 2 can include the subject matter of Example 1 and optionally include that the GI sequence is dependent on at least one of a cell identifier (ID) of a cell to which the UE is configured to communicate and a UE ID.

[0091] Example 3 can include the subject matter of one or any combination of Examples 1-2 and optionally include that the frame comprises at least one of an uplink and downlink subframe, the at least one of an uplink and downlink subframe comprises a guard time, and a duration of the guard time is dependent on a length of the GI sequence in the at least one of an uplink and downlink subframe.

[0092] Example 4 can include the subject matter of one or any combination of Examples 1-3 and optionally include that a last block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time while at least some of remaining blocks of the downlink subframe of the at least one of an uplink and downlink subframe and blocks of an uplink subframe of the at least one of an uplink and downlink subframe comprise the GI sequence and the one of SC and GI-DFT-s-OFDM symbol, or a first block of an uplink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time while at least some of remaining blocks of the uplink subframe of the at least one of an uplink and downlink subframe and blocks of a downlink subframe of the at least one of an uplink and downlink subframe comprise the GI sequence and the one of SC and GI-DFT-s-OFDM symbol.

[0093] Example 5 can include the subject matter of one or any combination of Examples 1-4 and optionally include that a length of each block, which contains a combination of the GI sequence and the one of the SC and GI-DFT-s-OFDM symbols, is constant throughout the frame, and one of the blocks of the frame comprises an additional GI sequence, the one of the blocks comprising a SC and GI-DFT-s-OFDM symbol of reduced size.

[0094] Example 6 can include the subject matter of one or any combination of Examples 1-5 and optionally include that the one of the blocks comprises one of: a block of a downlink subframe of the at least one of an uplink and downlink subframe when a block of an uplink subframe of the at least one of an uplink and downlink subframe comprises a guard time, or a block of an uplink subframe of the at least one of an uplink and downlink subframe when a block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the guard time.

[0095] Example 7 can include the subject matter of one or any combination of Examples 1-6 and optionally include that the GI sequence originates from at least one of: a frequency domain generated Zadoff-Chu (ZC) sequence upsampled by a factor of 2 using an Inverse Fast Fourier Transform (IFFT) of size two times a length of the ZC sequence, a ZC sequence whose base sequence of each possible GI length for both uplink and downlink communications is dependent on the eNB to which the UE is attached, and a ZC sequence whose base sequence for uplink communications is a cyclically shifted and cyclically extended version of a common base sequence that is dependent on the UE.

[0096] Example 8 can include the subject matter of one or any combination of Examples 1-7 and optionally include that the transceiver is configured to receive the GI sequence in one of a physical downlink control channel (PDCCH) transmission and a radio resource control (RRC) transmission indicating a GI sequence index to be used for both uplink and downlink communication.

[0097] Example 9 can include the subject matter of one or any combination of Examples 1-8 and optionally include transmit control circuitry comprising at least one of a scrambler configured to scramble first SC or GI-DFT-s-OFDM symbols, a channel encoder configured to enable forward error correction for the first SC or GI-DFT-s-OFDM symbols, and a modulator configured to modulate the first SC or GI-DFT-s-OFDM symbols, and receive control circuitry comprising a GI remover configured to remove GI sequences from received blocks to provide second SC or GI-DFT-s-OFDM symbols, a demapper configured to demodulate the second SC or GI-DFT-s-OFDM symbols, a channel decoder configured to provide forward error correction for the second SC or GI-DFT-s-OFDM symbols, and a descrambler configured to descramble the second SC or GI-DFT-s-OFDM symbols.

[0098] Example 10 can include the subject matter of one or any combination of Examples 1-9 and optionally include control circuitry configured to provide frequency domain post-processing of the block prior to transmitting the block, the control circuitry comprising a Discrete Fourier Transform (DFT) configured to map the block into the frequency domain, a digital receive beamformer configured to provide phase and gain weighting to the mapped block, a frequency domain equalizer configured to provide equalization to the block, and an Inverse DFT (IDFT) configured to map the equalized block back to the time domain.

[0099] Example 11 can include the subject matter of one or any combination of Examples 1-10 and optionally include that the GI sequence comprises autocorrelation and cross-correlation properties sufficient to be used for at least one of time and frequency tracking while minimizing inter-cell interference.

[00100] Example 12 can include the subject matter of one or any combination of Examples 1-11 and optionally include that at least one of transmitting and receiving GI-DFT-s-OFDM symbols for respectively uplink and downlink communications in at least one of a Long Term Evolution (LTE) small cell and a mmWave system.

[00101] Example 13 can include the subject matter of one or any combination of Examples 1-12 and optionally include that the processing circuitry is configured to: receive a TDD second frame from the eNB, the second TDD frame comprising multiple blocks, each block comprising one of a second SC and GI-DFT-s-OFDM symbol and a second GI sequence having a length different than a length of the GI sequence in the TDD frame.

[00102] Example 14 can include the subject matter of one or any combination of Examples 1-13 and optionally include that the processing circuitry is further configured to: identify the second GI sequence, remove the second GI sequence from at least one of the blocks in the second TDD frame, and identify the second SC and GI-DFT-s-OFDM symbol in the at least one of the blocks in the second TDD frame.

[00103] Example 15 can include the subject matter of one or any combination of Examples 1-14 and optionally include that an antenna configured to transmit and receive communications between the transceiver and the eNB.

[00104] Example 16 can include an apparatus of an eNode B (eNB) comprising: processing circuitry configured to: dynamically determine a first guard interval (GI) sequence associated with a first Time Division Duplex (TDD) frame, a length of the first GI sequence different than a length of a second GI sequence associated with a second TDD frame; configure a transceiver to transmit an indication of each of the first and second GI sequence to user equipment (UE); generate the first TDD frame, the first TDD frame comprising multiple blocks, at least one of which comprises one of a single carrier (SC) and Guard Interval Discrete Fourier transform-Spread-Orthogonal Frequency Division Multiplexing (GI-DFT-s-OFDM) and the first GI sequence, a length of the one of the SC and GI-DFT-s-OFDM symbol dependent on a length of the first GI sequence and a length of a period (T_{DFT}) of a Discrete Fourier Transform (DFT) function; and configure a transceiver to transmit the first TDD frame to the UE.

[00105] Example 17 can include the subject matter of Example 16 and optionally include that the processing circuitry is further configured to: configure a transceiver to receive the second TDD frame from the UE; remove the second GI sequence from the second TDD frame; and determine one or more of SC and GI-DFT-s-OFDM symbols of the second TDD frame after removing the second GI sequence.

[00106] Example 18 can include the subject matter of one or any combination of Examples 16-17 and optionally include that the processing circuitry is further configured to: transmit the indication of at least one of the first and second GI sequence dependent in one of a physical downlink control channel (PDCCH) and radio resource control (RRC) transmission.

[00107] Example 19 can include the subject matter of one or any combination of Examples 16-18 and optionally include that the processing circuitry is further configured to: at least one of the first and second GI sequence is dependent on at least one of a cell identifier (ID) of a cell of the eNB and a UE ID.

[00108] Example 20 can include the subject matter of one or any combination of Examples 16-19 and optionally include that the processing circuitry is further configured to: implement digital precoding of at least one of the blocks in a frequency domain based on frequency domain precoding that uses the DFT function and an inverse DFT (IDFT) function, the frequency domain precoding includes digital transmit beamforming.

[00109] Example 21 may comprise a non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to configure the UE to communicate with an enhanced Node B (eNB), the one or more processors to configure the UE to: generate a frame comprising multiple blocks, each block comprising a symbol and a dynamically determined guard interval (GI) sequence, a length of the GI sequence dependent on at least one of an estimation of channel delay spread, a cell identifier (ID) of a cell to which the UE is configured to communicate, and a UE ID; and configure a transceiver to transmit the frame to an enhanced NodeB (eNB).

[00110] Example 21 may include the subject matter of claim 21 and further and optionally include that the frame comprises at least one of an uplink and downlink subframe, the and one of: a last block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and a guard time and a block of an uplink subframe of the at least one of an uplink and downlink subframe comprises an additional GI sequence, or a first block of an uplink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time and a block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the additional GI sequence.

[00111] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00112] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[00113] 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 this document, 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, UE, article, composition, formulation, 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 impose numerical requirements on their objects.

[00114] The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b), requiring an abstract that will 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. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. User equipment (UE) comprising:

processing circuitry configured to:

generate a Time Division Duplex (TDD) frame comprising multiple blocks, each block comprising one of a single carrier (SC) and Guard Interval Discrete Fourier transform-Spread-Orthogonal Frequency Division Multiplexing (GI-DFT-s-OFDM) symbols and a dynamically determined guard interval (GI) sequence; and

configure a transceiver to transmit the TDD frame to an enhanced NodeB (eNB).

2. The UE of claim 1, wherein:

the GI sequence is dependent on at least one of a cell identifier (ID) of a cell to which the UE is configured to communicate and a UE ID.

3. The UE of claim 1, wherein:

the frame comprises at least one of an uplink and downlink subframe,

the at least one of an uplink and downlink subframe comprises a guard time, and

a duration of the guard time is dependent on a length of the GI sequence in the at least one of an uplink and downlink subframe.

4. The UE of claim 3, wherein one of:

a last block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time while at least some of remaining blocks of the downlink subframe of the at least one of an uplink and downlink subframe and blocks of an uplink subframe of the at least one of an uplink and downlink subframe comprise the GI sequence and the one of SC and GI-DFT-s-OFDM symbol, or

a first block of an uplink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time while at least some of remaining blocks of the uplink subframe of the at least one of an uplink and downlink subframe and blocks of a downlink subframe of the at least one of an uplink and downlink subframe comprise the GI sequence and the one of SC and GI-DFT-s-OFDM symbol.

5. The UE of claim 1, wherein:

a length of each block, which contains a combination of the GI sequence and the one of the SC and GI-DFT-s-OFDM symbols, is constant throughout the frame, and

one of the blocks of the frame comprises an additional GI sequence, the one of the blocks comprising a SC and GI-DFT-s-OFDM symbol of reduced size.

6. The UE of claim 5, wherein the one of the blocks comprises one of:

a block of a downlink subframe of the at least one of an uplink and downlink subframe when a block of an uplink subframe of the at least one of an uplink and downlink subframe comprises a guard time, or

a block of an uplink subframe of the at least one of an uplink and downlink subframe when a block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the guard time.

7. The UE of claim 1, wherein:

the GI sequence originates from at least one of:

a frequency domain generated Zadoff-Chu (ZC) sequence upsampled by a factor of 2 using an Inverse Fast Fourier Transform (IFFT) of size two times a length of the ZC sequence,

a ZC sequence whose base sequence of each possible GI length for both uplink and downlink communications is dependent on the eNB to which the UE is attached, and

a ZC sequence whose base sequence for uplink communications is a cyclically shifted and cyclically extended version of a common base sequence that is dependent on the UE.

8. The UE of claim 1, wherein:

the transceiver is configured to receive the GI sequence in one of a physical downlink control channel (PDCCH) transmission and a radio resource control (RRC) transmission indicating a GI sequence index to be used for both uplink and downlink communication.

9. The UE of claim 1, further comprising:

transmit control circuitry comprising at least one of a scrambler configured to scramble first SC or GI-DFT-s-OFDM symbols, a channel encoder configured to enable forward error correction for the first SC or GI-DFT-s-OFDM symbols, and a modulator configured to modulate the first SC or GI-DFT-s-OFDM symbols, and

receive control circuitry comprising a GI remover configured to remove GI sequences from received blocks to provide second SC or GI-DFT-s-OFDM symbols, a demapper configured to demodulate the second SC or GI-DFT-s-OFDM symbols, a channel decoder configured to provide forward error correction for the second SC or GI-DFT-s-OFDM symbols, and a descrambler configured to descramble the second SC or GI-DFT-s-OFDM symbols.

10. The UE of claim 1, further comprising:

control circuitry configured to provide frequency domain post-processing of the block prior to transmitting the block, the control circuitry comprising a Discrete Fourier Transform (DFT) configured to map the block into the frequency domain, a digital receive beamformer configured to provide phase and gain weighting to the mapped block, a frequency domain equalizer configured to provide equalization to the block, and an Inverse DFT (IDFT) configured to map the equalized block back to the time domain.

11. The UE of claim 1, wherein:

the GI sequence comprises autocorrelation and cross-correlation properties sufficient to be used for at least one of time and frequency tracking while minimizing inter-cell interference.

12. The UE of claim 1, further comprising:

at least one of transmitting and receiving GI-DFT-s-OFDM symbols for respectively uplink and downlink communications in at least one of a Long Term Evolution (LTE) small cell and a mmWave system.

13. The UE of claim 1, wherein the processing circuitry is configured to:

receive a TDD second frame from the eNB, the second TDD frame comprising multiple blocks, each block comprising one of a second SC and GI-DFT-s-OFDM symbol and a second GI sequence having a length different than a length of the GI sequence in the TDD frame.

14. The UE of claim 13, wherein the processing circuitry is further configured to:

identify the second GI sequence,

remove the second GI sequence from at least one of the blocks in the second TDD frame, and

identify the second SC and GI-DFT-s-OFDM symbol in the at least one of the blocks in the second TDD frame.

15. The UE of claim 1, further comprising an antenna configured to transmit and receive communications between the transceiver and the eNB.

16. An apparatus of an eNode B (eNB) comprising:

processing circuitry configured to:

dynamically determine a first guard interval (GI) sequence associated with a first Time Division Duplex (TDD) frame, a length of the first GI sequence different than a length of a second GI sequence associated with a second TDD frame;

configure a transceiver to transmit an indication of each of the first and second GI sequence to user equipment (UE);

generate the first TDD frame, the first TDD frame comprising multiple blocks, at least one of which comprises one of a single carrier (SC) and Guard Interval Discrete Fourier transform-Spread-Orthogonal

Frequency Division Multiplexing (GI-DFT-s-OFDM) and the first GI sequence, a length of the one of the SC and GI-DFT-s-OFDM symbol dependent on a length of the first GI sequence and a length of a period (T_{DFT}) of a Discrete Fourier Transform (DFT) function; and

configure a transceiver to transmit the first TDD frame to the UE.

17. The eNB of claim 16, wherein the processing circuitry is further configured to:

configure a transceiver to receive the second TDD frame from the UE;

remove the second GI sequence from the second TDD frame; and

determine one or more of SC and GI-DFT-s-OFDM symbols of the second TDD frame after removing the second GI sequence.

18. The eNB of claim 16, wherein the processing circuitry is further configured to:

transmit the indication of at least one of the first and second GI sequence dependent in one of a physical downlink control channel (PDCCH) and radio resource control (RRC) transmission.

19. The eNB of claim 16, wherein the processing circuitry is further configured to:

at least one of the first and second GI sequence is dependent on at least one of a cell identifier (ID) of a cell of the eNB and a UE ID.

20. The eNB of claim 16, wherein the processing circuitry is further configured to:

implement digital precoding of at least one of the blocks in a frequency domain based on frequency domain precoding that uses the DFT function and an inverse DFT (IDFT) function, the frequency domain precoding includes digital transmit beamforming.

21. A non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to

configure the UE to communicate with an enhanced Node B (eNB), the one or more processors to configure the UE to:

generate a frame comprising multiple blocks, each block comprising a symbol and a dynamically determined guard interval (GI) sequence, a length of the GI sequence dependent on at least one of an estimation of channel delay spread, a cell identifier (ID) of a cell to which the UE is configured to communicate, and a UE ID; and

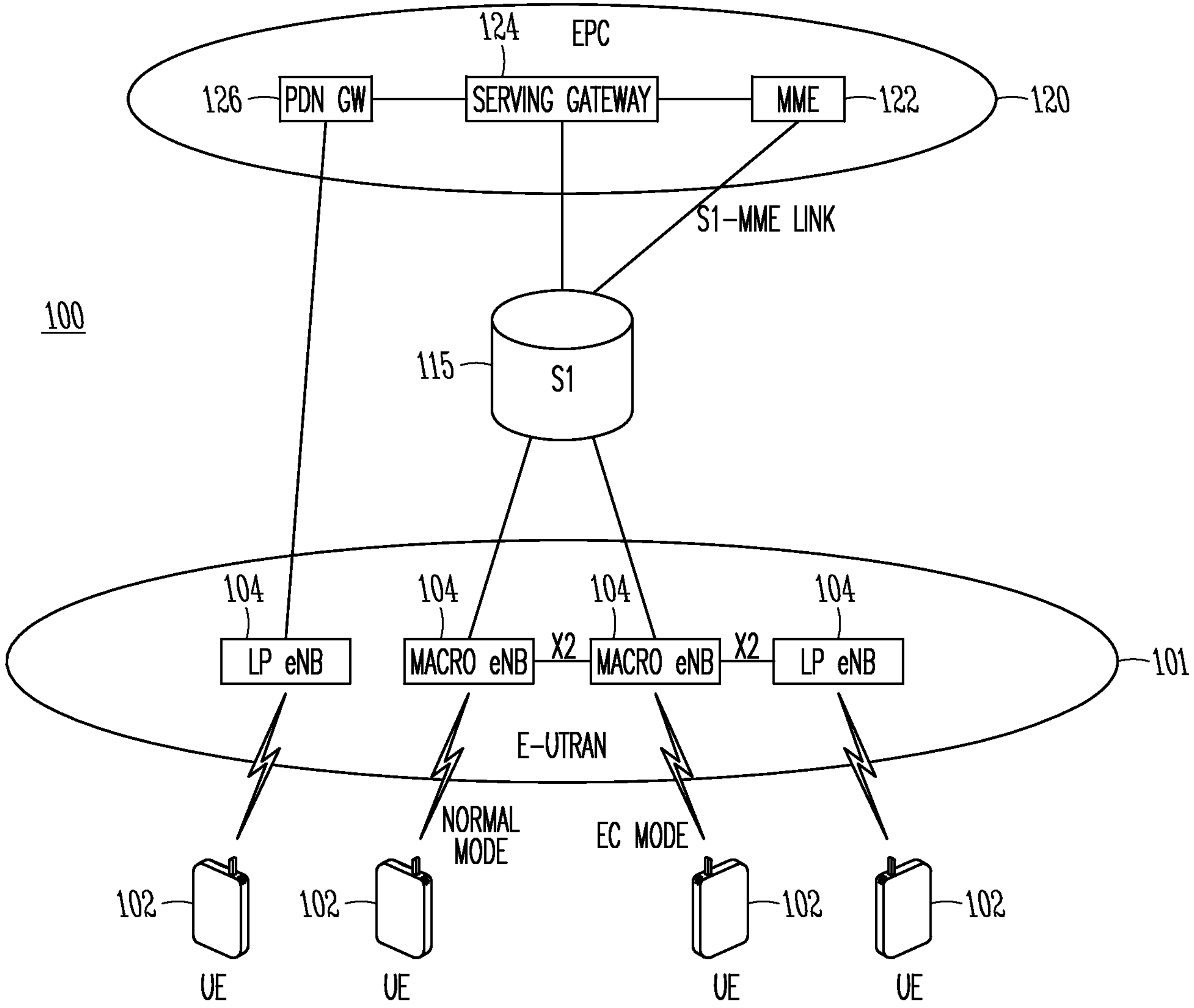
configure a transceiver to transmit the frame to an enhanced NodeB (eNB).

22. The medium of claim 21, wherein:

the frame comprises at least one of an uplink and downlink subframe, the and one of:

a last block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and a guard time and a block of an uplink subframe of the at least one of an uplink and downlink subframe comprises an additional GI sequence, or

a first block of an uplink subframe of the at least one of an uplink and downlink subframe comprises the GI sequence and the guard time and a block of a downlink subframe of the at least one of an uplink and downlink subframe comprises the additional GI sequence.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PDN GW
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S1
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104
104
LP eNB
MACRO eNB
X2
MACRO eNB
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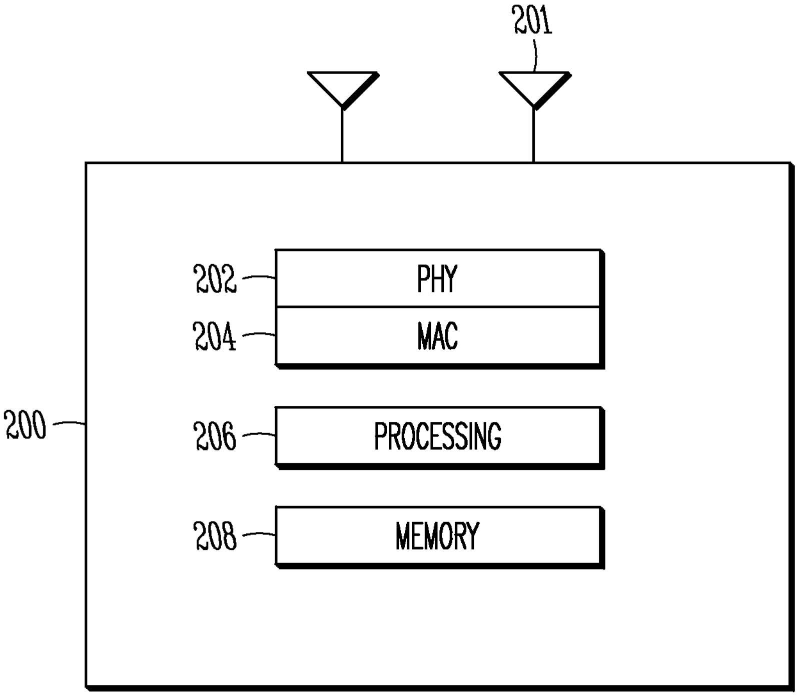
E-UTRAN
NORMAL MODE
EC MODE
102
102
102
102
UE
UE
UE
UE

FIG. 1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202
PHY
204
MAC
200
206
PROCESSING
208
MEMORY

FIG. 2

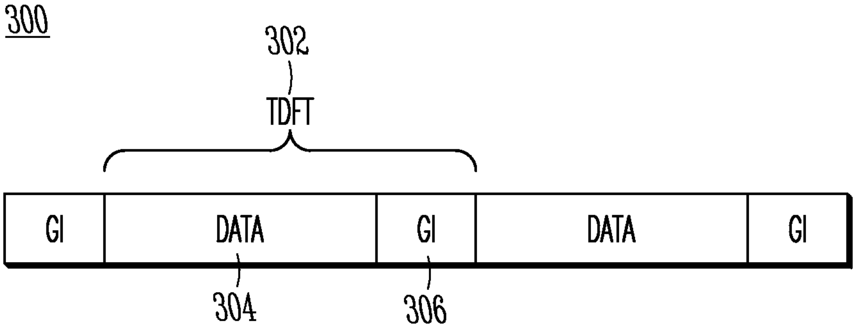
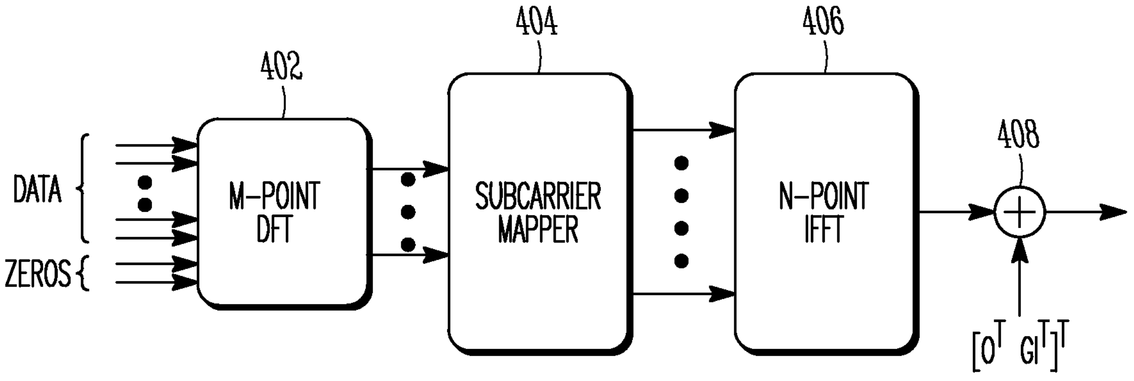
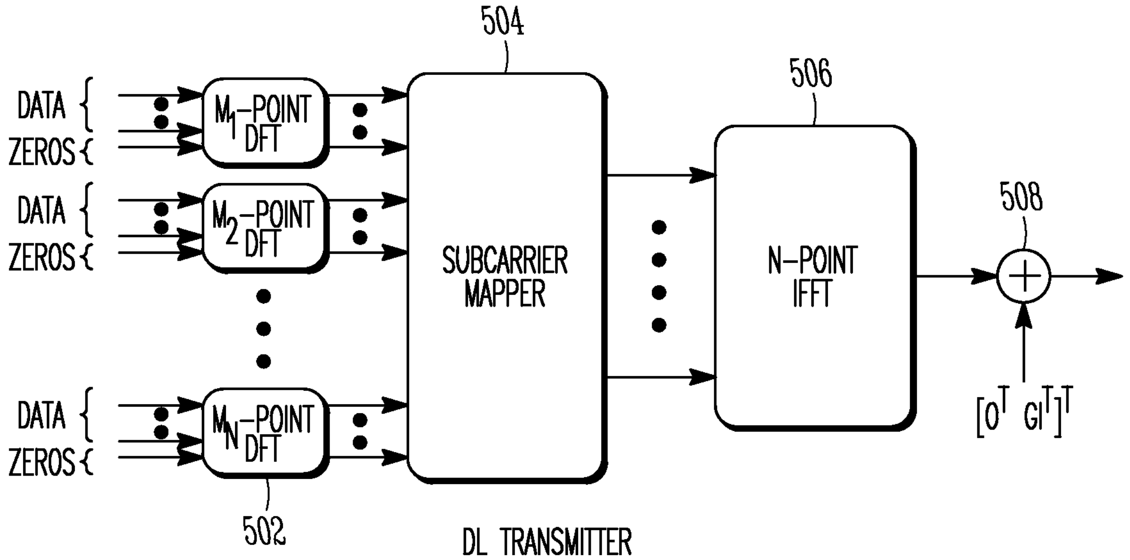

300
302
TDFT
GI
DATA
GI
DATA
GI
304
306

FIG. 3



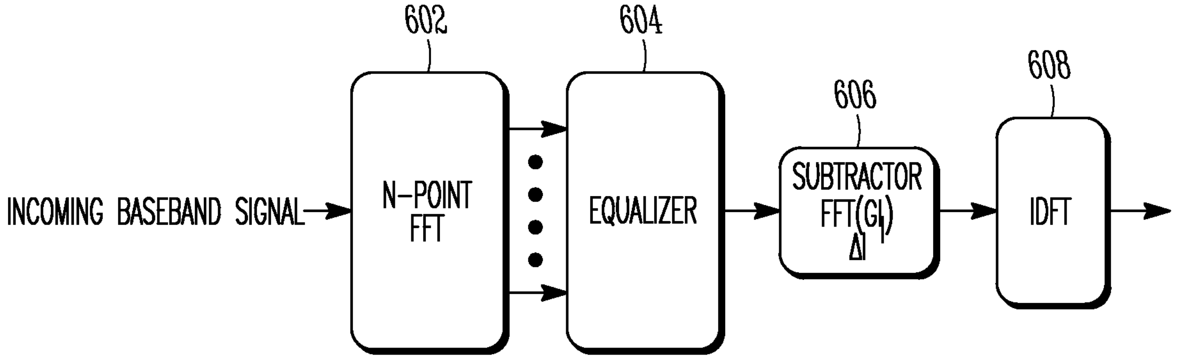
UL TRANSMITTER

FIG. 4



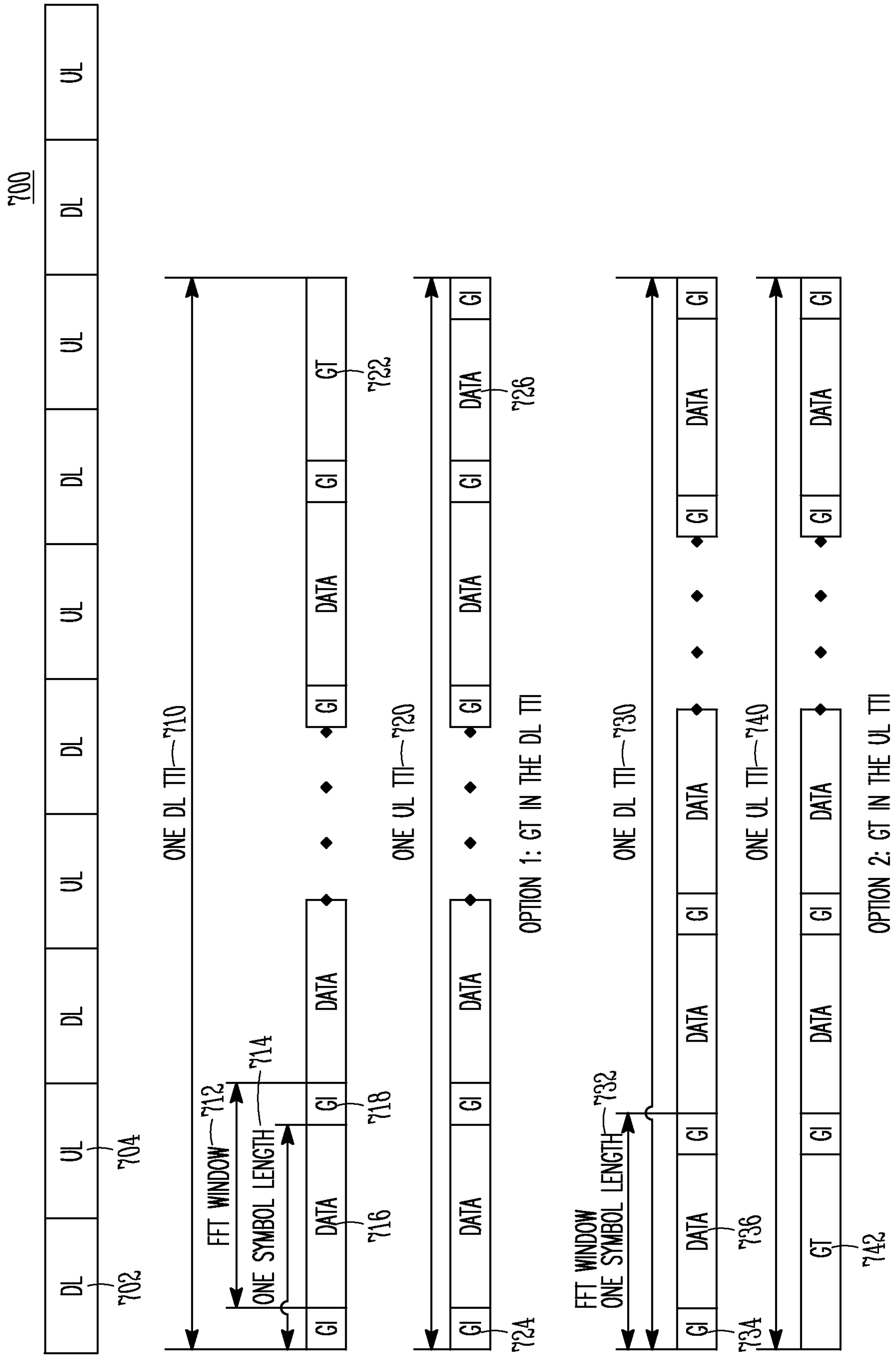
DL TRANSMITTER

FIG. 5



RECEIVER

FIG. 6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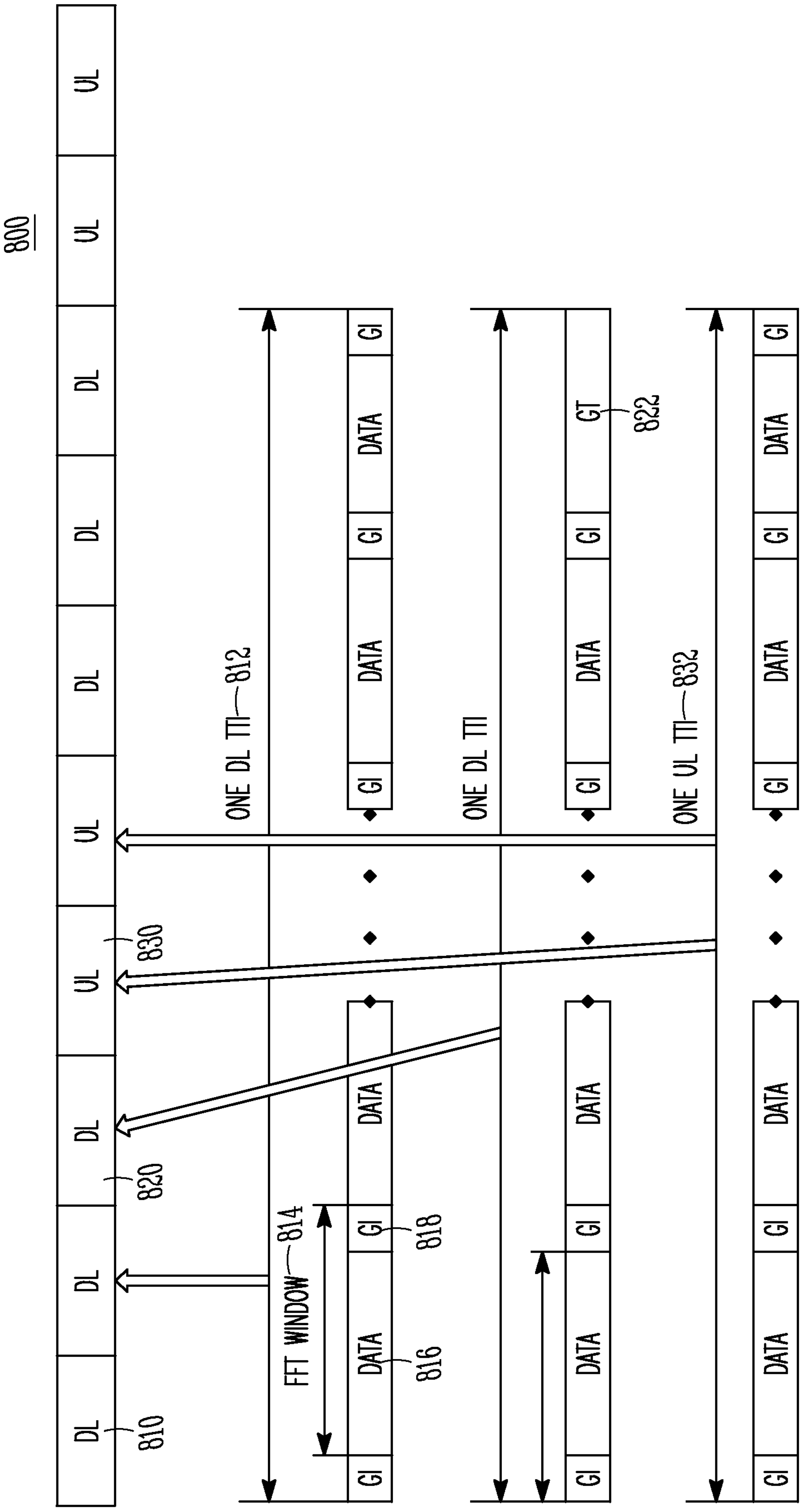
DL
UL
702
704
ONE DL TTI
710
FFT WINDOW
712
ONE SYMBOL LENGTH
714
GI
DATA
716
GI
718
DATA
GI
DATA
GI
GT
722
ONE UL TTI
720
GI
724
DATA
GI
DATA
GI
DATA
GI
DATA
726
GI
OPTION 1: GT IN THE DL TTI
ONE DL TTI
730
FFT WINDOW
ONE SYMBOL LENGTH
732
GI
734
DATA
736
GI
DATA
GI
DATA
GI
DATA
GI
ONE UL TTI
740
GT
742
GI
DATA
GI
DATA
GI
DATA
GI
OPTION 2: GT IN THE UL TTI

FIG. 7


800
DL
810
DL
DL
820
UL
830
UL
DL
DL
DL
UL
UL
ONE DL TTI
812
FFT WINDOW
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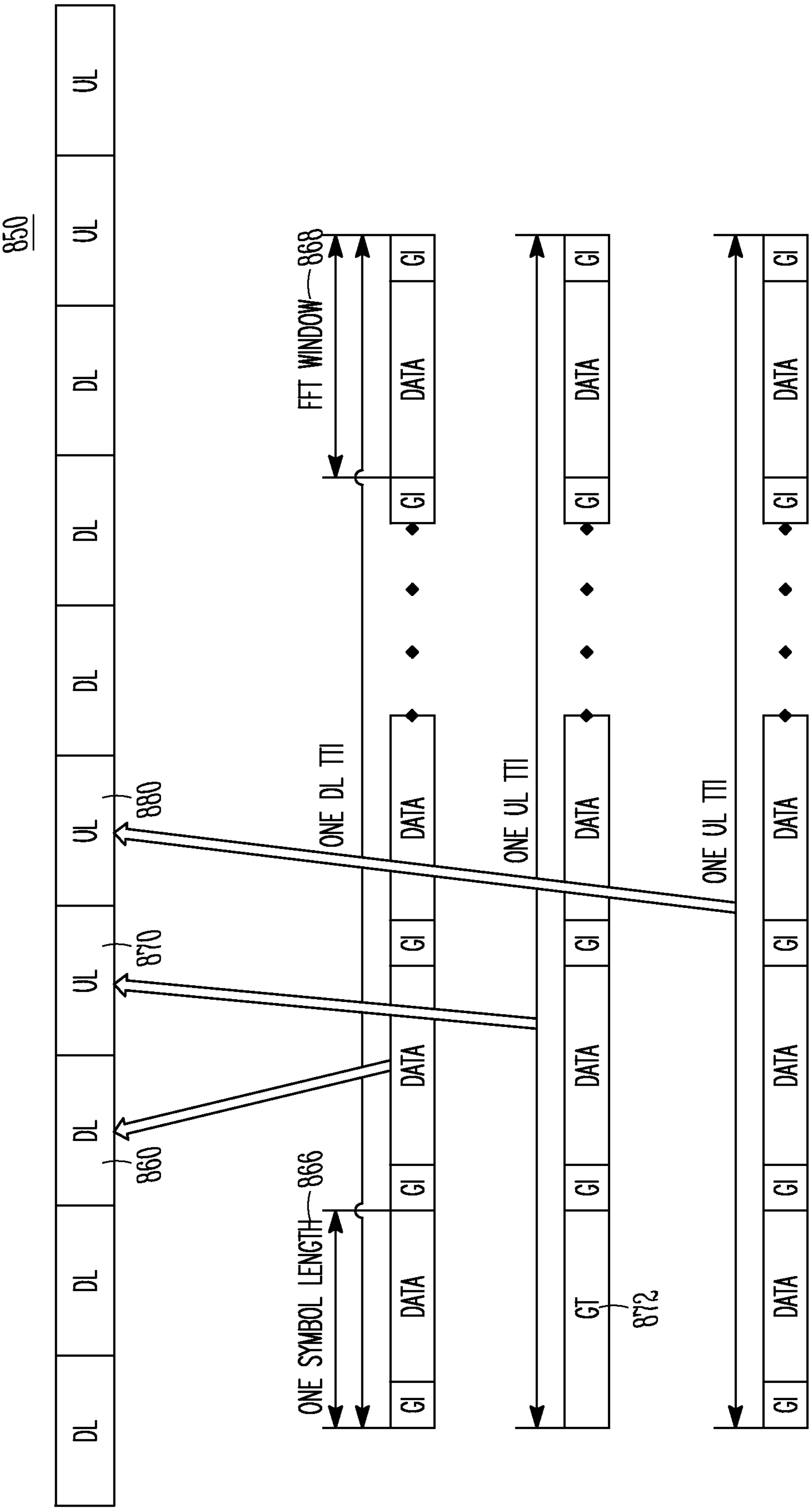
GI
DATA
816
GI
818
DATA
GI
DATA
GI
DATA
GI
ONE DL TTI
GI
DATA
GI
DATA
GI
DATA
GI
GT
822
ONE UL TTI
832
GI
DATA
GI
DATA
GI
DATA
GI
DATA
GI

FIG. 8A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DL
DL
DL
UL
UL
860
870
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ONE UL TTI
ONE UL TTI
GI
DATA
GT
872

FIG. 8B

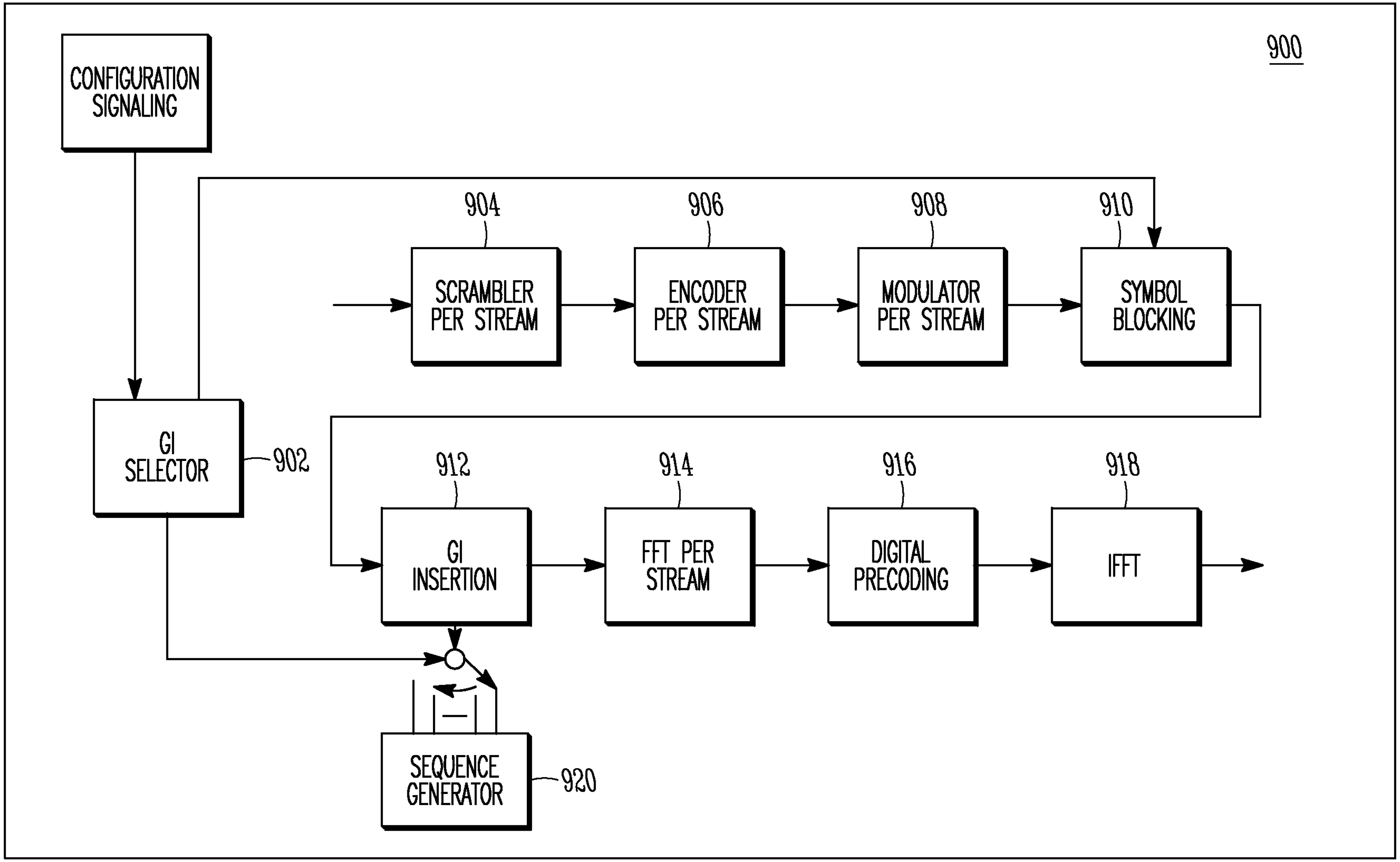
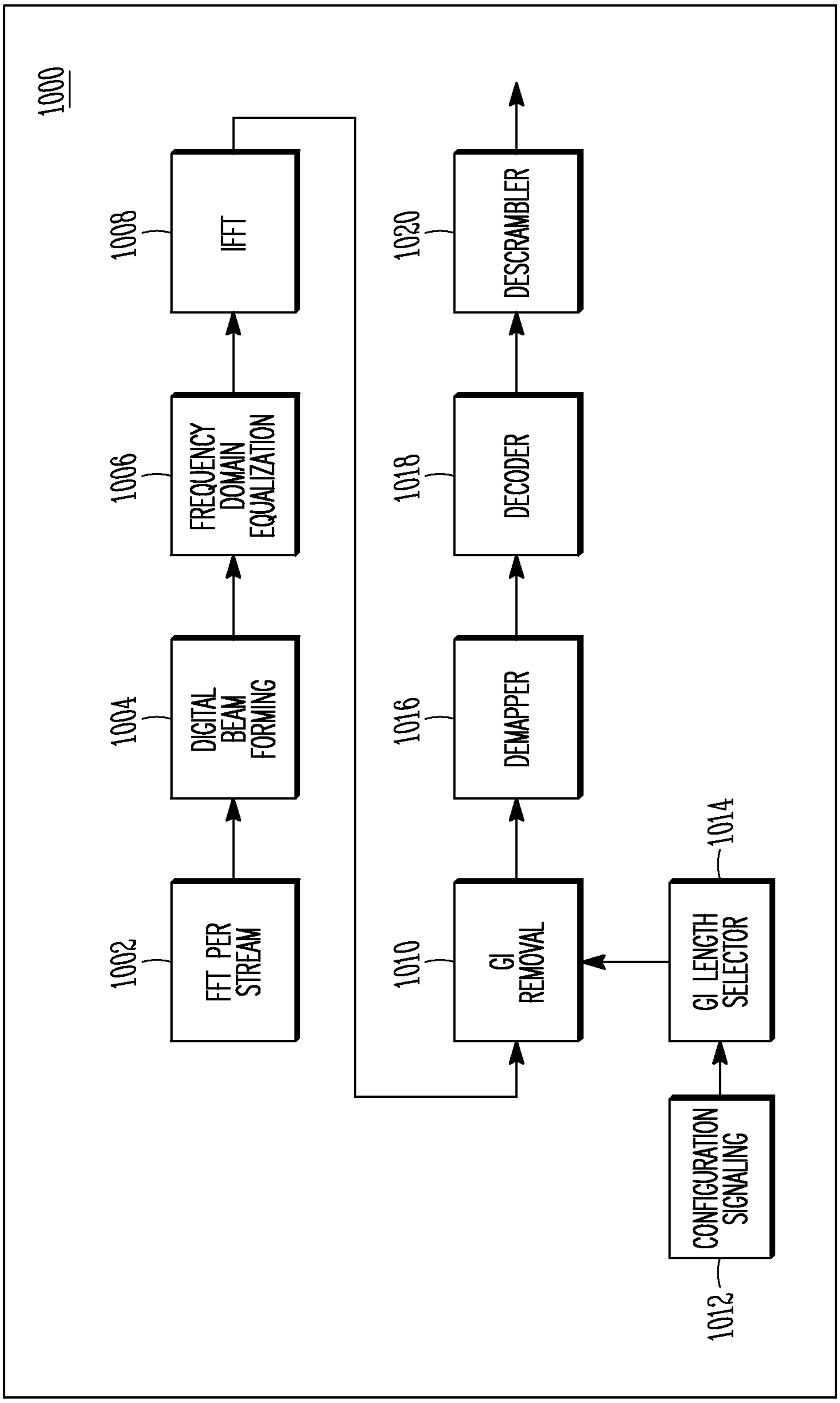

900
CONFIGURATION SIGNALING
GI SELECTOR
902
904
SCRAMBLER PER STREAM
906
ENCODER PER STREAM
908
MODULATOR PER STREAM
910
SYMBOL BLOCKING
912
GI INSERTION
914
FFT PER STREAM
916
DIGITAL PRECODING
918
IFFT
SEQUENCE GENERATOR
920

FIG. 9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1002
FFT PER STREAM
1004
DIGITAL BEAM FORMING
1006
FREQUENCY DOMAIN EQUALIZATION
1008
IFFT
1010
GI REMOVAL
1016
DEMAPPER
1018
DECODER
1020
DESCRAMBLER
1012
CONFIGURATION SIGNALING
1014
GI LENGTH SELECTOR

FIG. 10

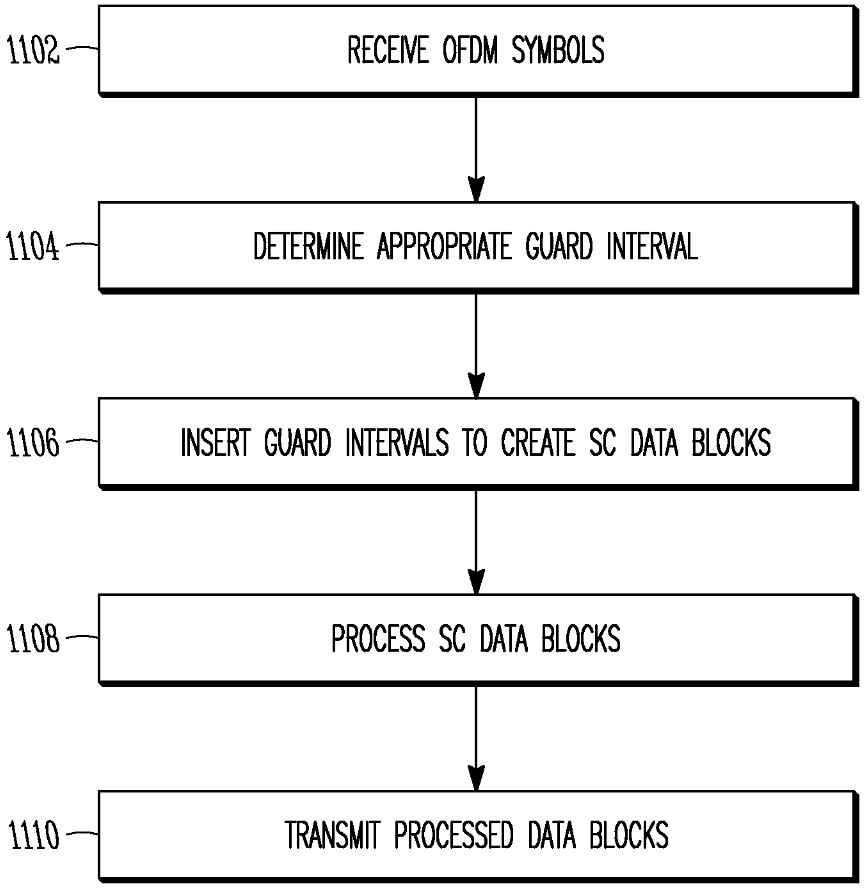
1102
RECEIVE OFDM SYMBOLS
1104
DETERMINE APPROPRIATE GUARD INTERVAL
1106
INSERT GUARD INTERVALS TO CREATE SC DATA BLOCKS
1108
PROCESS SC DATA BLOCKS
1110
TRANSMIT PROCESSED DATA BLOCKS

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/049713

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/26(2006.01)i, H04L 5/22(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)
H04L 27/26; H04W 88/02; H04B 7/212; H04W 72/04; H04L 5/22

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: user equipment, eNodeB, TDD (Time Division Duplex) frame, single carrier, Guard Interval Discrete Fourier transform-Spread-OFDM symbol, Guard Interval sequence

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1014639 A2 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 28 June 2000 See paragraphs [0072], [0141]; claims 2, 13, 26; and figure 20.	21-22
A		1-20
A	US 2011-0261730 A1 (SUNG HO MOON et al.) 27 October 2011 See paragraph [0058]; claims 16, 22; and figure 3.	1-22
A	WO 2006-105005 A2 (MOTOROLA, INC.) 05 October 2006 See page 5, line 3 - page 7, line 34; and figure 1.	1-22
A	FRANCE TELECOM et al., `OFDM/OQAM technical overview', R1-050922, 3GPP TSG RAN WG1#42, London, UK, 29 August - 2 September 2005. [retrieved on 24 August 2005]. See section 2.	1-22
A	US 2009-0257366 A1 (KEVIN POWER et al.) 15 October 2009 See paragraphs [0067]-[0079]; and figure 3.	1-22

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

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

Date of the actual completion of the international search 22 February 2016 (22.02.2016)	Date of mailing of the international search report **23 February 2016 (23.02.2016)**
Name and mailing address of the ISA/KR International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea Facsimile No. +82-42-472-7140	Authorized officer COMMISSIONER Telephone No. +82-42-481-8112

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/049713

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CN 1525675 C	30/04/2008
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		DE 69936832 T2	06/12/2007
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