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(54) Title: ORTHOGONAL TIME FREQUENCY MULTIPLEXING BASED COMMUNICATION FOR FUTURE WIRELESS SYSTEMS

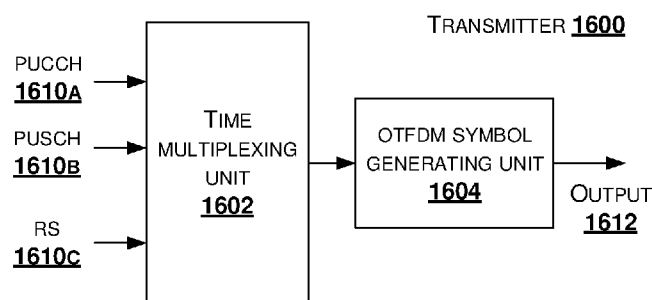


Figure 16A

(57) Abstract: Embodiments of the present disclosure relate to a transmission method performed by a communication system or a transmitter. The method comprising initiating at least one of a synchronous signal (SS) burst carrying at least one of a PSS sequence, a SSS sequence, a PBCH sequence, a PDCCH with control information, a PDSCH with traffic data, a physical downlink CSI-RS. The at least one of the SS Burst, the PDCCH, the PDSCH, the CSI-RS are transmitted using OTFDM symbols in a half frame or a full frame. Also, the method comprises a PRACH transmitted traffic data of in uplink; a PUCCH transmission carrying control data of users in uplink; a PUSCH transmission carrying traffic data of users in uplink; and an SRS transmission. The at least one of the PRACH, the PUCCH, the PUSCH and the SRS are transmitted using OTFDM symbols in a half frame or a full frame.

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**TITLE: “ORTHOGONAL TIME FREQUENCY MULTIPLEXING BASED
COMMUNICATION FOR FUTURE WIRELESS SYSTEMS”**

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from the Indian Provisional Patent Application Number 202341019892, filed on 22 March, 2023, the entirety of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] Embodiments of the present disclosure are related, in general to communication, but exclusively relate to communication system and method for generating, transmitting and receiving an Orthogonal time frequency-division multiplexing (OTFDM) symbol.

BACKGROUND

[0003] 3GPP (3rd Generation Partnership Project) has developed 5G-NR standards to support use cases like eMBB, URLLC, MMTTC. To support multiple access OFDMA has been agreed to use in current 5G-NR. However, in previous standards different Multiple access techniques have been studied and used, like in 2G TDMA, 3G is based on CDMA and relied on OFDMA. OFDM, in spite of many of its attractive properties, has a critical drawback i.e., low power-amplifier efficiency (low energy efficiency).

[0004] The communications latency is fundamentally limited by the delay before a transfer of data begins following an instruction for its transfer. This delay is equal to the duration of a “slot” which is a basic unit of information transmission that comprises of data/control and reference signals. A slot in OFDM systems comprises of multiple data symbols and one or more reference symbols. 4G uses 0.5ms slot and 5G NR specifications allow URLLC using 0.125ms. In order to achieve low latency 5G NR uses mini slots where the duration of the slot is two OFDM symbols. To achieve Extremely Low Latency Communication (ELLC) it is preferable to use a single OFDM symbol to transmit the information. Basic OFDM allows frequency multiplexing of reference signal and data/control within one OFDM symbol. Our chief aim is to use high energy efficiency waveform such as DFT-S-OFDM (it is a variant of OFDM with low-PAPR and is used in both 4G and 5G); this waveform requires a dedicated OFDM symbol for the transmission of RS and an additional symbol for data, thus resulting in two symbols duration (In conventional DFT-S-OFDM, RS is not

time multiplexed with data in one OFDM symbol since this multiplexed RS does not offer reliable estimation of the channel impulse response). The RS is required for the purpose of estimating the channel state information (CSI) and subsequent equalization of data symbol. This two-symbol structure not only doubles the latency (compared to single symbol case), but also has a higher RS overhead i.e., 50%. There is a need for a new type of waveform that allows one shot transmission with flexible RS overhead and high-power efficiency. 6G Mobile Communication System requires a method of information transmission and that offers extremely low latency, very high data rate, and very high-power efficiency.

[0005] In an illustration of a wireless communication network, a base station (BS) is in communication with multiple users, also referred as user equipment's (UEs) or user device or mobile or mobile device. The BS is also referred to as cell or gNB. The Figure 0 further shows an uplink and downlink i.e. two-way communication links between the BS and UEs. These measure the bandwidth and signal strength of data transmission between a user device and a base station or access point. The uplink is the transmission of data from a user device to a base station. Downlink is the transmission of data from a base station to a user device. For example, when a mobile device initiates a call, it establishes a wireless connection on an uplink frequency to a cell tower or base station. The base station then amplifies the signal and sends it on a downlink frequency to the intended recipient.

[0006] A cell ID number is a unique identifier assigned to each cell tower by a cellular network. This identifier is used to distinguish one cell tower from another and is crucial for routing calls and text messages to the correct tower. In wireless communication networks, cells are divided into different sectors, and each sector is assigned a unique Physical Cell ID.

[0007] There is a need for a waveform technology that not only addresses this critical issue of improving energy efficiency but also achieves extremely low latency. Current 5G standards uses slot structure, where user data is transmitted in series of OFDM symbols. A typical slot structure comprises of one or more data symbols and one or more reference symbols.

SUMMARY

[0008] The shortcomings of the prior art are overcome and additional advantages are provided through the provision of method of the present disclosure.

[0009] Additional features and advantages are realized through the techniques of the present disclosure. Other embodiments and aspects of the disclosure are described in detail herein and are considered a part of the claimed disclosure.

[0010] In one aspect of the present disclosure a method for transmitting one or more PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) symbols is disclosed. The method comprising time-multiplexing, by one or more transmitters, at least one of a physical uplink control channel (PUCCH) sequence, a Physical Uplink Shared Channel (PUSCH) sequence, a reference sequence (RS), and a portion of at least one of the PUCCH sequence, the PUSCH sequence and the RS to generate a multiplexed sequence. Also, the method comprises generating, by the one or more transmitters, one or more PUCCH-PUSCH OTFDM symbols by processing the multiplexed sequence.

[0011] In another aspect of the present disclosure a method for transmitting a PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) slot is provided. The method comprising time-multiplexing, by one or more transmitters, at least one of one or more PUCCH-PUSCH OTFDM symbols, one or more PUCCH OTFDM symbols and one or more PUSCH OTFDM symbols to generate an Orthogonal time frequency-division multiplexing (OTFDM) slot.

[0012] In yet another aspect of the present disclosure a method for transmitting one or more a physical random-access channel (PRACH) Orthogonal time frequency-division multiplexing (OTFDM) symbols is provided. The method comprises transforming, by one or more transmitters, at least one PRACH sequence and a portion of the PRACH sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence. Also, the method comprises performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed sequence. Further, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed sequence, and shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed sequence. Furthermore, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence

and processing the time domain sequence to generate the one or more PRACH OTFDM symbols.

[0013] In yet another aspect of the present disclosure a method for transmitting an uplink frame is provided. The method comprising multiplexing, by one or more transmitters, at least one of: one or more PRACH OTFDM symbols/ slot and one or more PUCCH-PUSCH OTFDM slots to generate at least one uplink signal associated with a beam.

[0014] In yet another aspect of the present disclosure a downlink transmission method performed by a communication system is provided. The method comprising initiating, by the communication system, at least one of a synchronous signal (SS) burst carrying at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence; a physical downlink control channel (PDCCH) carrying control information of one or more users; a physical downlink shared channel (PDSCH) carrying traffic data of one or more users. The at least one of the SS Burst, the PDCCH and the PDSCH are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

[0015] In yet another aspect of the present disclosure a method of uplink transmission in a communication network, said communication network comprises a communication system configured with one or more user equipment's (UEs) for performing an uplink transmission is provided. The method comprising performing, by at least one UE, at least one of a cell search, a physical random-access channel (PRACH) transmission, a physical uplink control channel (PUCCH) transmission, a physical uplink shared channel (PUSCH) transmission and a sounding reference signal (SRS) transmission. The at least one of the PRACH, the PUCCH, the PUSCH and SRS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

[0016] In yet another aspect of the present disclosure a transmission method performed by a communication system is provided. The method comprising initiating, by the communication system, at least one of a synchronous signal (SS) burst carrying at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence; a physical downlink control channel (PDCCH) carrying control information of one or more users; a physical

downlink shared channel (PDSCH) carrying traffic data of one or more users; a physical downlink channel state information reference signals (CSI-RS) carrying data, paging, and signaling messages. The at least one of the SS Burst, the PDCCH, the PDSCH, the CSI-RS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame. Also, the method comprises a physical random-access channel (PRACH) transmitted traffic data of one or more users in uplink; a physical uplink control channel (PUCCH) transmission carrying control data of users in uplink; a physical uplink shared channel (PUSCH) transmission carrying traffic data of users in uplink; and a sounding reference signal (SRS) transmission. The at least one of the PRACH, the PUCCH, the PUSCH and the SRS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

[0017] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

[0018] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The same numbers are used throughout the figures to reference like features and components. Some embodiments of device or system and/or methods in accordance with embodiments of the present subject matter are now described, by way of example only, and with reference to the accompanying figures, in which:

[0019] Figure 1A shows a block diagram of an orthogonal time frequency division multiplexing (OTFDM) transmitter, in accordance with an embodiment of the present disclosure;

[0020] Figure 1B shows a block diagram of an OTFDM symbol generating unit, in accordance with an embodiment of the present disclosure;

- [0021] Figure 1C shows a block diagram of a processing unit of the OTFDM symbol generating unit as shown in Figure 1B, in accordance with an embodiment of the present disclosure;
- [0022] Figure 1D shows a block diagram of a processing unit of the OTFDM symbol generating unit as shown in Figure 1B, in accordance with another embodiment of the present disclosure
- [0023] Figure 1E shows a block diagram illustration of an OTFDM transmitter for generating an OTFDM waveform, in accordance with an alternate embodiment of the present disclosure;
- [0024] Figures 2A-2B shows symbol structure or block of primary synchronization signal (PSS) sequence;
- [0025] Figures 2C-2D shows symbol structure or block of secondary synchronization signal (SSS) sequence;
- [0026] Figures 2E-2H shows various symbol structure with PBCH data and optional PTRS;
- [0027] Figure 2I shows an illustration of different OTFDM Symbol carrying SSB, in accordance with an embodiment of the present disclosure;
- [0028] Figure 2J shows an example illustration of a PSS sequence;
- [0029] Figure 2L shows an illustration of a SS Block, in accordance with an embodiment of the present disclosure;
- [0030] Figure 2M shows an illustration of a SS Block, in accordance with another embodiment of the present disclosure;
- [0031] Figure 2N shows an illustration of a SS Block, in accordance with another embodiment of the present disclosure;
- [0032] Figure 3A shows an illustration of PSS, SSS, PBCH carried in one OTFDM SSB symbol, in accordance with an embodiment of the present disclosure;
- [0033] Figure 3B shows an illustration of multiple SS block OTFDM symbols in a slot;
- [0034] Figure 3C shows an illustration of multiple SS block OTFDM symbols in a slot associated with different beams;
- [0035] Figure 3D shows a beam sweeping over successive OTFDM symbols, in a downlink transmitter;
- [0036] Figure 3E shows a beam sweeping in a single OTFDM symbol, in a downlink transmitter;
- [0037] Figure 3F shows an illustration of generation of an OTFDM symbol where two SS blocks are time multiplexed and each SS block is associated with a different beam;

- [0038] Figure 4A shown an illustration of generation of PSS OTFDM symbol, SSS OTFDM symbol and PBCH OTFDM symbol;
- [0039] Figure 4B shows an illustration of an SS block consisting of 3 OTFDM symbols in time;
- [0040] Figure 4C shows an illustration SS block consisting of 2 OTFDM symbols in time;
- [0041] Figure 4D illustrates the transmission of SS burst, where multiple SS blocks are transmitted in a half frame;
- [0042] Figure 4E shows an illustration of PSS symbol;
- [0043] Figure 4F shows an illustration of SSS symbol;
- [0044] Figure 4G shows a beam sweeping over successive OTFDM symbols;
- [0045] Figure 4H shows a synchronization channel structure in a beam sweeping systems;
- [0046] Figure 5A shows a block diagram of an OTFDM transmitter, in accordance with another embodiment of the present disclosure;
- [0047] Figure 5B shows an illustration of different OTFDM Symbol carrying downlink channels;
- [0048] Figure 6A shows various symbol structure with PDCCH data and optional PTRS with RS;
- [0049] Figure 6B shows a symbol structure of PDCCH data, in accordance with an embodiment;
- [0050] Figure 6C shows a symbol structure with PDCCH data and optional PTRS, in accordance with an embodiment of the present disclosure;
- [0051] Figure 6D shows a symbol structure with PDCCH data and optional PTRS, in accordance with an embodiment of the present disclosure;
- [0052] Figures 6E-6H shows various symbol structure with PDSCH data and optional PTRS;
- [0053] Figures 7A-7D shows various symbol structure with PDCCH plus PDSCH data and optional PTRS;
- [0054] Figures 7E-7H shows various symbol structure of PSS, SSS, PBCH, PDCCH and PDSCH data;
- [0055] Figures 7J-7L shows various symbol structure of SSB, PDCCH and PDSCH, PSS and SSS channel data;
- [0056] Figures 8A-8C shows various symbol structure of RS, PDCCH, PDSCH channel data, in accordance with some embodiments of the present disclosure;
- [0057] Figures 8D-8E shows various symbol structure of SSB, PDCCH and PDSCH, PSS and SSS channel data, in accordance with another embodiment of the present disclosure

- [0058] Figure 9 shows a block diagram of an OTFDM transmitter, in accordance with an exemplary embodiment of the present disclosure;
- [0059] Figure 10 shows the generation of a single OTFDM symbol;
- [0060] Figure 11 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a slot with their associated beam, where a slot has N symbols;
- [0061] Figure 12 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a frame with their associated beam, where a slot consisting of 1 OTFDM symbol;
- [0062] Figure 13A shows a block diagram representation of a receiver, in accordance with an embodiment of the present disclosure;
- [0063] Figure 13B shows the receiver block diagram for SSS receiver;
- [0064] Figure 13C shows a block diagram representation of a PSS receiver, in accordance with yet another embodiment of the present disclosure;
- [0065] Figure 14 illustrates the sequence of messages exchanged between a UE and a gNB till RRC connection is established;
- [0066] Figure 15A shows a block diagram of a PRACH receiver;
- [0067] Figure 15B shows an illustration of contiguous repetitions PRACH symbols;
- [0068] Figure 16A shows a block diagram of an Orthogonal time frequency-division multiplexing (OTFDM) communication system, in accordance with an embodiment of the present disclosure;
- [0069] Figure 16B shows a block diagram of an OTFDM symbol generating unit, in accordance with an embodiment of the present disclosure;
- [0070] Figure 16C shows a block diagram of a processing unit of Figure 16B;
- [0071] Figures 17A-17M show an illustration of multiplexed symbol structures, in accordance with an embodiment of the present disclosure;
- [0072] Figure 18A shows a block diagram of a receiver, in accordance with an embodiment of the present disclosure;
- [0073] Figure 18B shows a block diagram of a receiver, in accordance with another embodiment of the present disclosure;
- [0074] Figure 19A shows an illustration of a symbol structure comprising a PRACH, a PUSCH RS CP, a PUSCH CP, PUSCH and a portion of at least one of the PRACH, the PUSCH RS CP, the PUSCH RS and the PUSCH;
- [0075] Figure 19B shows an illustration of a symbol structure comprising a PRACH, a PUCCH RS CP, a PUCCH CP, PUCCH and a portion of at least one of the PRACH, the PUCCH RS CP, the PUCCH RS and the PUCCH;

- [0076] Figure 20A shows an illustration of an OTFDM symbol comprising a PUSCH RS CP, a PUSCH RS, a PUSCH, a PUCCH, and a portion of at least one of the PUSCH RS CP, the PUSCH RS, the PUSCH and the PUCCH;
- [0077] Figure 20B shows an illustration of an OTFDM symbol comprising a PUSCH RS CP, a PUSCH RS, a PUSCH RS CS, a PUSCH, a PUCCH, and a portion of at least one of the PUSCH RS CP, the PUSCH RS, the PUSCH RS CS, the PUSCH and the PUCCH;
- [0078] Figure 20C shows an illustration of an OTFDM symbol comprising a PUCCH RS, a PUCCH, a PUSCH RS, a PUSCH, and a portion of at least one of the PUCCH RS, the PUCCH, the PUSCH RS and the PUSCH;
- [0079] Figure 20D shows an illustration of an OTFDM symbol comprising a PUCCH RS CP, a PUCCH, a PUSCH RS CP, a PUSCH, and a portion of at least one of the PUCCH RS CP, the PUCCH, the PUSCH RS CP and the PUSCH;
- [0080] Figure 21A shows an illustration of three OTFDM symbols comprising a PRACH OTFDM symbol, 2nd symbol is PUCCH OTFDM symbol and the 3rd symbol is PUSCH OTFDM symbol;
- [0081] Figure 21B shows an illustration of two OTFDM symbols comprising a PRACH OTFDM symbol, and the 2nd symbol is PUCCH plus PUSCH OTFDM symbol;
- [0082] Figure 21C shows an illustration of two OTFDM symbols comprising a PRACH + PUSCH OTFDM symbol, and the 2nd symbol is PUCCH OTFDM symbol;
- [0083] Figure 21D shows an illustration of two OTFDM symbols comprising a PRACH + PUCCH OTFDM symbol, and the 2nd symbol is PUSCH OTFDM symbol;
- [0084] Figure 22 shows an illustration of Msg2 and Msg4 between the US and the gNB;
- [0085] Figure 23A shows a symbol with two RS blocks at the symbol boundaries and data in the middle of OFDM symbol. Figure 23B shows a Symbol with RS with pre-fix and post-fix at 1/4th and 3/4th positions of OFDM symbol. Figure 23C shows a Symbol with RS with pre-fix and post-fix starting at 0th and 1/2th positions of OFDM symbol. Figure 23D shows a Symbol with two RS blocks at the symbol boundaries, one in the middle for channel estimation;
- [0086] Figures 24A-24B shows a various block diagram of PRACH transmitter;
- [0087] Figure 25 shows a block diagram of an OTFDM transmitter, in accordance with an embodiment of the present disclosure;
- [0088] Figures 26A, 26B, 26C shows an illustration of downlink slot structure; and
- [0089] Figures 26D, 26E, 26F show the illustration of uplink slot structure.

[0090] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative systems embodying the principles of the present subject matter. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and executed by a computer or processor, whether or not such computer or processor is explicitly shown.

DETAILED DESCRIPTION

[0091] In the present document, the word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment or implementation of the present subject matter described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[0092] While the disclosure is susceptible to various modifications and alternative forms, specific embodiment thereof has been shown by way of example in the drawings and will be described in detail below. It should be understood, however that it is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the disclosure is to cover all modifications, equivalents, and alternative falling within the spirit and the scope of the disclosure.

[0093] The terms "comprises", "comprising", or any other variations thereof, are intended to cover a non-exclusive inclusion, such that a setup, device or method that comprises a list of components or steps does not include only those components or steps but may include other components or steps not expressly listed or inherent to such setup or device or method. In other words, one or more elements in a device or system or apparatus preceded by "comprises... a" does not, without more constraints, preclude the existence of other elements or additional elements in the device or system or apparatus.

[0094] The terms "an embodiment", "embodiment", "embodiments", "the embodiment", "the embodiments", "one or more embodiments", "some embodiments", and "one embodiment" mean "one or more (but not all) embodiments of the invention(s)" unless expressly specified otherwise. The terms "including", "comprising", "having" and variations thereof mean "including but not limited to", unless expressly specified otherwise. The enumerated listing of items does not imply that any or all of the items are mutually exclusive, unless

expressly specified otherwise. The terms "a", "an" and "the" mean "one or more", unless expressly specified otherwise.

[0095] The present disclosure provides a waveform technology that not only addresses this critical issue of improving energy efficiency but also achieves one of the major goals of future wireless communication systems i.e., extremely low latency. Current 5G standards uses slot structure, where user data is transmitted in series of OFDM symbols. A typical slot structure comprises of one or more data symbols and one or more reference symbols.

[0096] Embodiments of the present disclosure provides a new waveform that is an orthogonal time frequency division multiplexing (OTFDM) waveform which allows synchronization channels such as PSS, SSS and PBCH and control channels PDCCH, data channel PDSCH to be transmitted with low PAPR, high PA efficiency, low latency using multiple antenna ports or beams. The embodiments illustrate how low latency is obtained from entire system operation point of view.

[0097] Also, embodiments of the present disclosure provides new waveform which allows uplink channels PRACH, PUCCH, PUSCH to be transmitted with low PAPR, high PA efficiency, low latency using multiple antenna ports or beams. The embodiments illustrate how low latency is obtained from entire system operation point of view.

[0098] Embodiments of the present disclosure provides a new type of waveform that allows time division multiplexing of data, control and RS within a single OTFDM symbol (TDM within a OTFDM Symbol). The generated symbol is referred to as orthogonal time frequency division multiplexing (OTFDM) symbol, which is designed for information exchange taking place in one shot transmission. The duration of the OTFDM symbol (or subcarrier width) is to meet the overall latency requirement.

[0099] In a downlink (DL) transmission, a communication system or transmitter uses a method of TDM of user data/control/RS and also common channels such as PSS, SSS, PBCH, CSI-RS using OTFDM waveform. However, multiple services and multiple numerologies can be frequency multiplexed using FDM based on the BWP concept that uses WOLA/filtering for frequency multiplexing of these services.

[00100] In an uplink (UL) transmission, a communication system or transmitter uses a method of TDM of user data/control/RS and also common channels such as PRACH, PUCCH, PUSCH, and RS using OTFDM waveform. However, multiple services and multiple numerologies can be frequency multiplexed using FDM based on the BWP concept that uses WOLA/filtering for frequency multiplexing of these services.

[00101] In an exemplary embodiment of the present disclosure, when a device is switched on, depending on the device capability and stored information, the device will attempt to select a suitable network. The device is also referred to as a user equipment (UE), a mobile device or a terminal. The initial stage involves the device performing a public land mobile network (PLMN) and access technology selection. This will utilize information on a universal subscriber identity module (USIM), as well as information on the device.

[00102] In order to determine the PLMN identity the device needs to obtain SI (System Information) from a cell. This will involve obtaining the SSB (Synchronization Signal Block) which will be transmitted from the cell, based on a Global Synchronization Channel Number (GSCN) raster. Depending on the deployment, the cell will be broadcasting between 1 and 64 Synchronization Signal Block (SSB), each identifiable by an SSB Index. Each SSB contains a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and a Physical Broadcast Channel (PBCH) carried.

[00103] Figure 1A shows a block diagram of an OTFDM transmitter, in accordance with an exemplary embodiment of the present disclosure. The OTFDM transmitter is referred to as a transmitter or a communication system.

[00104] As shown in the Figure 1A, the transmitter 100 comprises a time multiplexing unit 102 and an OTFDM symbol generating unit 104. The time multiplexing unit 102 is also referred as a time multiplexer or multiplexer or time division multiplexer or TDM. Also, the transmitter 100 comprises a plurality of antennas. The OTFDM symbol generating unit 104 is also referred as OTFDM symbol generator or symbol generator.

[00105] In an embodiment, the time multiplexer 102 multiplexes a PSS sequence 110A, an SSS sequence 110B, a PBCH sequence 110C, and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence 110D to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in the below Figures are the multiplexed sequences obtained using time multiplexer 102.

[00106] The OTFDM symbol generating unit 104 generates an output 134 called as OTFDM symbol using the multiplexed sequences. The multiplexed sequence is obtained by time multiplexing the PSS sequence, the SSS sequence, PBCH sequence and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence. The generated symbol is referred as synchronization signal (SS) Block Orthogonal time frequency-division multiplexing (OTFDM) symbol or SS Block OTFDM symbol.

[00107] In an embodiment, the multiplexed sequence is fed to the filter or OTFDM symbol generating unit 104, to generate a OTFDM symbols specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00108] In another embodiment, the generated OTFDM waveform undergoes a procedure known as Antenna precoding, where the purpose of precoding is to map the generated OTFDM symbols to a set of antenna ports using a precoder matrix. The generated OTFDM signal is multiplied using antenna port specific phase weights and each weighted signal is transmitted using an antenna port. Each complex weighted baseband OTFDM signal is converted to analog waveform using digital to analog converter (DAC). The analog OTFDM waveform undergoes power amplification to boost the signal strength to a level capable of transmission across the air interface. Since, OTFDM signal has low PAPR, the PA requires low back off, thereby resulting in energy efficient transmission. For $\pi/2$ BPSK OTFDM the back off may be 0 dB or very low value so that signal can be transmitted close to power amplifier (PA) saturation power. Digital pre distortion operation may be used before PA when higher order modulation is used. Further the OTFDM waveform undergoes radio frequency (RF) filtering subsequently transmitted through the antenna array.

[00109] In an embodiment, the generated OTFDM symbol is a SS Block OTFDM symbol. The SS Block OTFDM symbol is one of a PSS OTFDM symbol comprising of only PSS sequence, a SSS OTFDM symbol comprising of only SSS sequence, a PBCH OTFDM symbol comprising of only PBCH sequence; and an OTFDM symbol comprising of the PSS sequence, the SSS sequence, the PBCH sequence and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence.

[00110] The PSS sequence includes one of a PSS cyclic prefix (CP), and a PSS CP along with a PSS cyclic suffix (CS). The SSS sequence includes one of a SSS CP and a SSS CP along with a SSS CS. The PBCH sequence includes one of a PBCH CP, and a PBCH CP along with PBCH CS. In an embodiment, the PBCH sequence includes a PBCH DMRS, said PBCH DMRS includes at least one of a PBCH DMRS CP and a PBCH DMRS CS. The PBCH DMRS is one of a $\pi/2$ BPSK, a QPSK, and a ZC, wherein the PBCH data is one of a $\pi/2$ BPSK and a QPSK.

[00111] The PSS sequence is a function of sector id or Base station id, wherein the PSS sequence is one sequence for all sectors or one of N possible sequences, wherein N is an integer. The PSS sequence is one of $\pi/2$ BPSK and ZC; wherein the SSS sequence is one of $\pi/2$ BPSK and ZC. In an embodiment, the PSS sequence comprise a base sequence repeated for a predefined number of times, wherein each of the repeated based sequence is multiplied with an element of a code cover sequence. The SSS sequence comprises of a base sequence repeated for a predefined number of times, wherein each of the repeated based sequence is multiplied with an element of a code cover sequence. The predefined number is one of 1, 2, 4 or more.

[00112] Figure 1B shows a block diagram of an OTFDM symbol generating unit or filter 104, in accordance with an embodiment of the present disclosure. As shown in the figure 1B, the OTFDM symbol generating unit 104 comprises a Discrete Fourier Transform (DFT) unit 122, an excess BW addition unit 124, a spectrum shaping unit 126, a sub-carrier mapping unit 128, an inverse Fast Fourier transform (FFT) unit 130 and a processing unit 132.

[00113] The DFT unit 122 transforms an input 120 i.e. multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. The input 120 is time multiplexed sequence of a PSS sequence 110A, an SSS sequence 110B,

a PBCH sequence 110C, and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence 110D. In an embodiment, the input is time multiplexed sequence of a PSS sequence 110A, an SSS sequence 110B and a PBCH sequence 110C.

[00114] The excess BW addition unit 124 performs padding operation on the transformed multiplexed sequence i.e. prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero. The values of N1 and N2 may be same or different. The value of N1 and N2 may depend on the excess power that is sent by the transmitter.

[00115] The spectrum shaping unit 126, also referred as a shaping unit or a filter, performs shaping of the extended bandwidth transformed multiplexed sequence to obtain a shaped extended bandwidth transformed multiplexed sequence or shaped sequence. The filter used for the shaping operation on the extended bandwidth transformed multiplexed sequence is one of a Nyquist filter, square root raised cosine filter, a raised cosine filter, a hamming filter, a Hanning filter, a Kaiser filter, an oversampled GMSK filter and any filter that satisfies predefined spectrum characteristics. In an embodiment, the filter is one of the filters derived from the above-mentioned filters by applying additional filtering or sampling.

[00116] The sub carrier mapping unit 128, also referred as a mapper or a sub carrier mapper or a mapping unit, performs subcarrier mapping on the shaped extended bandwidth transformed multiplexed sequence or shaped sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. In an embodiment, the distributed subcarrier mapping includes insertion of zeros in to the extended bandwidth transformed multiplexed sequence.

[00117] The IFFT unit 130 performs inverse IFFT on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The time domain sequence is processed by the processing unit 132 to generate an OTFDM symbol.

[00118] The input to the Filter 120 is a time multiplexed sequence, which is one of the symbol structures as shown in the Figures 2A-2D, 2F, 2G, 2I. The generated output 134 is fed to the processing unit as shown in Figure 1C.

[00119] Figure 1C shows a block diagram of a processing unit of the OTFDM symbol generating unit as shown in Figure 1B, in accordance with an embodiment of the present disclosure. As shown in Figure 1C, the processing unit 132 comprises a cyclic prefix (CP) addition unit 142, a weighted with overlap and add operation (WOLA) unit 146, a bandwidth parts (BWP) specific rotation unit 148, a RF up-conversion unit 150, and a digital to analog converter (DAC).

[00120] The processing unit 132 processes an input 140 i.e. the time domain sequence to generate an OTFDM symbol. The processing comprises performing at least one of a symbol specific phase compensation, an addition of symbol cyclic prefix using the CP addition unit 142, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit 146, bandwidth parts (BWP) rotation using BWP specific rotation unit 148, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit 150 and converting the same into analog using the DAC 152, to generate the output OTFDM symbol 154. The generated OTFDM symbol offers low PAPR.

[00121] One embodiment of the present disclosure is a method for transmitting synchronization signal (SS) Block Orthogonal time frequency-division multiplexing (OTFDM) symbol. The order in which the method steps is described is not intended to be construed as a limitation, and any number of the described method steps can be combined in any order to implement the method. Additionally, individual method steps may be deleted from the methods without departing from the scope of the subject matter described herein. Furthermore, the method can be implemented in any suitable hardware, software, firmware, or combination thereof.

[00122] The method comprising time-multiplexing, by the transmitter, at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence to generate a multiplexed sequence.

Thereafter, filtering is performed on the multiplexed sequence to generate a synchronization signal (SS) Block OTFDM symbol.

[00123] The method of filtering the multiplexed sequence to generate the SS Block OTFDM symbol comprising transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. The method comprises performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero.

[00124] Also, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. A shaping is performed on the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence.

[00125] Further, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. Thereafter, the method comprises processing the time domain sequence to generate the OTFDM symbol. This processing of the time domain sequence to generate a OTFDM symbol comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, phase compensation for each symbol by multiplying with a symbol specific exponential value, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate up-conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the OTFDM symbol.

[00126] In another embodiment, the transmitter 100 comprises the filter or OTFDM symbol generating unit 104 which generates an output OTFDM symbol without CP addition. The OTFDM symbol generating unit 104 comprising Discrete Fourier Transform (DFT) unit 122, an excess BW addition unit 124, a spectrum shaping unit 126, a sub-carrier mapping unit 128, an inverse Fast Fourier transform (FFT) unit 130 and a processing unit

132. The processing unit is as shown in Figure 1D which processes the time domain sequence with no CP addition.

[00127] In another embodiment, the input 120 to the Filter 120 is a time multiplexed sequence, which is one of the symbol structures as shown in the Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N. These time multiplexed symbol structures are circular or cyclic in nature. The generated output 134 is fed to the processing unit as shown in Figure 1D.

[00128] Figure 1D shows a block diagram of a processing unit of the OTFDM symbol generating unit as shown in Figure 1B, in accordance with another embodiment of the present disclosure. As shown in Figure 1D, the processing unit 132A comprises a weighted with overlap and add operation (WOLA) unit 146, a bandwidth parts (BWP) specific rotation unit 148, a RF up-conversion unit 150, and a digital to analog converter (DAC).

[00129] The processing unit 132A processes the input 140A time domain sequence to generate an OTFDM symbol. The processing comprises performing at least one of a symbol specific phase compensation, up sampling using the up-sampling unit 144, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit 146, bandwidth parts (BWP) rotation using BWP specific rotation unit 148, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit 150 and converting the same into analog using the DAC 152, to generate the output OTFDM symbol 154A. The generated OTFDM symbol offers low PAPR.

[00130] Figure 1E shows a block diagram illustration of an OTFDM transmitter for generating an OTFDM waveform, in accordance with an alternate embodiment of the present disclosure.

[00131] As shown in the Figure 1E, the transmitter also referred to as a communication system 160 comprises a circular pulse shaping filter with excess bandwidth 162, WOLA unit 164 and a digital to analog converter (DAC) 166. The transmitter 160 also includes a processing unit to process the generated waveform. The transmitter 160 is also referred to as an OTFDM transmitter or an OTFDM symbol generator. In an embodiment, the transmitter 160 also includes a plurality of antennas for transmission of the generated waveforms.

[00132] The circular pulse shaping filtering 162 also referred to as pulse shaping filter or circular pulse shaping filtering with excess bandwidth or a shaping filter. The circular pulse shaping filter with excess bandwidth 162 is circular pulse shaping filter is obtained through circular convolution. A linear pulse shaping is obtained through a linear convolution. An OTFDM symbol may be oversampled to a higher rate and convolved with a linear or circular pulse shaping filter. When linear or circular pulse shaping is used, the signal is confined to OTFDM symbol interval. Alternatively, when linear pulse shaping is used, the signal is convolved continuously with a succession of OTFDM symbols, however, the transmitted signal is limited to the duration of the OTFDM symbols.

[00133] In an embodiment, the multiplexed symbol (or an input 168 to the transmitter 160) after oversampling is represented by $x'(n)$, where $n = 0, 1, \dots, qM - 1$, where q is the oversampling factor. The oversampling sequence comprises of $q-1$ zeros inserted after each input sample of the time multiplexed RS and Data sequence. The multiplexed symbol $x'(n)$ or the input 168 may be filtered with circular pulse shaping filter 162 of M .

$$x_{ps}(n) = x'(n) \odot w(n)$$

[00134] The shaping filter 162 is a poly-phase filter using circular convolution operations. The filter $w(n)$ is one of a square root raise cosine, a raised cosine, square root raised cosine, a Hanning, a Blackman, a Hamming window, an oversampled Linearized Gaussian Minimal Shifting Keying (LGMSK) pulse. In an embodiment, the filter 162 $w(n)$ is a square root of the frequency response of the above-mentioned filters. The spectrum shaping filter is either specified by a base station (BS) or unknown at the BS. The spectrum shaping filter may be specified in the standard or specification transparent. The spectrum shaping filter may or may not have zeros at the end, if it has zeros, it may be at the beginning, or at the end, or at the edges. The filtered symbol $x'_{ps}(n)$ is fed to the WOLA unit 164 followed by the DAC 166 to generate an output 170 before transmission. The transmitter 160 excludes either CP addition or CP removal which is performed after IFFT in traditional transmit methods.

[00135] In an embodiment, the transmitter 160 performs multiplexing of the data and the RS in one OTFDM symbol, with excess bandwidth and spectrum shaping. The spectrum shaped data is mapped on to the subcarriers allocated to the user, followed by an IFFT of size N to generate an OTFDM waveform. The RS is one of a $\pi/2$ -BPSK, a QPSK, a ZC

sequences, and an M-PSK sequences. The QPSK, pi/2-BPSK sequences are generated using the binary sequences from Walsh codes, or, m-sequences, Kasami sequences, gold sequences, or may be obtained from the pre-defined sequences, in an embodiment. The generation of said sequences for RS may depend on the cell/sector/Base station ID, scrambling ID, symbol number, sub frame number corresponding to the frame and the numerology. The ZC sequences generation is defined as

$$r(n) = e^{\frac{j\pi n(n+1+2q)}{N_{zc}}}; n = \{0, 1, 2, \dots, N_{zc} - 1\}$$

N_{zc} is the length of the sequence that needs to be generated.

[00136] The RS sequence obtained using ZC is a plain ZC sequence or cyclically extended ZC sequence. The frequency spectrum of RS could be flat to ensure unbiased channel estimation. RS and CP for RS can occupy a portion of resources allocated to the user, which may depend on properties of channel conditions, excess bandwidth, user allocation size, modulation order, coding rate, and other parameters like impulse response of spectrum shaping filter.

[00137] In an embodiment of the present disclosure, a method for transmitting SS block is provided. The method comprises time-multiplexing, by the transmitter, a PSS OTFDM symbol, a SSS OTFDM symbol and a PBCH OTFDM symbol to generate a multiplexed sequence. Also, the method comprises processing the at least one multiplexed sequence to generate a SS Block. The processing of the at least one multiplexed sequence is performed by the OTFDM generating unit 104 as described and shown in Figure 1B.

[00138] In another embodiment of the present disclosure, a method transmitting OTFDM SS burst is disclosed. The method comprising time-multiplexing a plurality of OTFDM SS Blocks to generate multiplexed OTFDM SS blocks, wherein each of the plurality of OTFDM SS Blocks is associated with a different beam. The multiplexed OTFDM SS blocks are processed by the OTFDM generating unit 104, as described and shown in Figure 1B, to generate a plurality of OTFDM SS blocks or OTFDM SS Burst. The OTFDM SS burst is transmitted through a predefined number of beams, wherein the multiplexed SS blocks are transmitted in succession one for each beam, said predefined number is one of 1, 8, 16, 32, 64, and 128. The method for transmitting a plurality of OTFDM SS bursts is performed such that two successive OTFDM SS Bursts are time separated by a half frame.

[00139] In another embodiment of the present disclosure, a method for transmitting an OTFDM SS burst is provided. The method comprising time-multiplexing a plurality of pre-DFT SS Blocks and guard blocks to generate a time multiplexed block, wherein each of the plurality of pre-DFT SS Blocks comprises a PSS, a SSS and a PBCH, said each of the plurality of pre-DFT SS block is associated with a beam. Each of the guard blocks is a sequence. Thereafter, processing the multiplexed block using OTFDM generation unit to generate OTFDM SS burst. The processing of the at least one multiplexed sequence is performed by the OTFDM generating unit 104 as described and shown in Figure 1B.

[00140] Figures 2A-2B shows symbol structure or block of primary synchronization signal (PSS) sequence. As shown in Figure 2A, the symbol structure comprises a cyclic prefix (CP) and a PSS. The added CP provides circularity to the symbol as shown in Figure 2A.

[00141] Figure 2B shows the symbol structure which is a PSS sequence. The PSS is made up of a Sequence which includes selection of sequence from a group of predefined sequences. The number of predefined sequences is at least one, and the generation of these sequences depends on base station ID or sector ID. The PSS sequences are at least one of ZC, $\pi/2$ BPSK, QPSK, and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. The PSS sequence is a function of sector ID or Base station ID. The PSS sequence is one sequence for all sectors or one of N possible sequences, wherein N is an integer. The PSS sequence comprises a base sequence repeated for a predefined number of times, wherein each of the repeated based sequence is multiplied with an element of a code cover sequence. The predefined number is one of 1, 2, 4 or more.

[00142] Figures 2C-2D shows symbol structure or block of secondary synchronization signal (SSS) sequence. As shown in Figure 2C, the symbol structure comprises a cyclic prefix (CP) and an SSS. The added CP provides circularity to the symbol as shown in Figure 2C. Figure 2D a symbol structure which is an SSS sequence. Similar to PSS, the SSS is also a Sequence, which can be on the same OTFDM symbol that is carrying PSS, or on a different OTFDM symbol. The SSS sequence is one of ZC, $\pi/2$ BPSK, QPSK and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. A gNB/Base station ID or sector ID is a function of the SSS sequence number along and the PSS ID. In an embodiment, the SSS sequence comprises of a base sequence repeated

for a predefined number of times, wherein each of the repeated based sequence is multiplied with an element of a code cover sequence. The predefined number is one of 1, 2, 4 or more.

[00143] On successful decoding of PSS and SSS, the user equipment obtains the cell ID, which is used to obtain the system level information further. System level information includes one of Bandwidth used, system frame number, Cell identity, Cell status.

[00144] A part of system information, which may be common with the cell, may be transmitted using a broadcast channel PBCH which uses a coherent demodulation procedure, i.e., PBCH contains data that carries the system information, and to decode this data, PBCH-RS may also be transmitted.

[00145] Figures 2E-2H shows various symbol structure with PBCH data and optional PTRS. As shown in Figure 2E, the symbol is an OFDM symbol of length M, comprising of PBCH data and RS. The PBCH data may optionally include PT-RS for phase compensation at the receiver. This symbol is circular or cyclic in nature. Figure 2F shows an OFDM symbol comprising of data CP, PBCH data plus optional PT-RS, RS CP of length L, RS, PBCH data plus optional PT-RS and data. This RS is also referred to as PBCH-RS. The PT-RS for the phase compensation at the receiver.

[00146] The PBCH data is modulated to at least one of $\pi/2$ BPSK, QPSK and M-ary modulation. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. The PBCH-RS is at least one of $\pi/2$ BPSK, ZC sequence, QPSK and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. The PT-RS is at least one of $\pi/2$ BPSK, QPSK and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. In an embodiment, the PBCH sequence comprises one of a PBCH CP and a PBCH CP along with PBCH CS.

[00147] The PBCH-RS sequence comprises a base sequence repeated for a predefined number of times, wherein each of the repeated based sequence is multiplied with an element of a code cover sequence. The predefined number is one of 1, 2, 4 or more. The PBCH-RS is a function of at least one of a cell ID or physical cell ID, a sector ID, a Base station ID, a half frame index and a SSB index.

[00148] Figure 2G shows an OFDM symbol comprising of RS cyclic prefix (CP) of length L, PBCH data and optional PT-RS and RS. The optionally include PT-RS is for the

phase compensation at the receiver. As shown in Figure 2H, the symbol is a cyclic OTFDM symbol comprising of PBCH data, RS CP, RS, and PBCH data. The PBCH data may optionally include PT-RS for phase compensation at the receiver

[00149] Figure 2I shows an illustration of different OTFDM Symbol carrying SSB, in accordance with an embodiment of the present disclosure.

[00150] The SS Block OTFDM symbol is one of a PSS OTFDM symbol comprising of only PSS sequence, a SSS OTFDM symbol comprising of only SSS sequence, a PBCH OTFDM symbol comprising of only PBCH, and OTFDM symbol comprising of PSS sequence, SSS sequence, PBCH. In an embodiment, length of the PSS sequence, the SSS sequence and the PBCH are same or different.

[00151] The PSS sequence includes one of a PSS cyclic prefix (CP), and a PSS CP along with a PSS cyclic suffix (CS). The SSS sequence includes one of a SSS CP and a SSS CP along with a SSS CS. The PBCH comprises at least one of a PBCH data and a PBCH data CP. In an embodiment, the PSS sequence and SSS sequence may not include CP or CS.

[00152] Figure 2J shows an example illustration of a PSS sequence which is a pre-DFT sequence, where PSS base sequence is repeated N times to generate an OTFDM symbol in time. Figure 2K shows an example illustration of a SSS sequence which is a pre-DFT sequence, where SSS base sequence is repeated N times to generate an OTFDM symbol in time.

[00153] Figure 2L shows an illustration of a SS Block, in accordance with an embodiment of the present disclosure. The SS Block is a multiplexed sequence comprising at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence, and a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence.

[00154] In an embodiment, the shaded portion is a portion from PSS sequence. In another embodiment, the shaded portion may be a portion from PBCH sequence.

[00155] As shown in the Figure 2L, the shaded portion at the beginning of the symbol structure is a portion from PBCH sequence and the shaded portion at the end of the symbol structure is a portion from PSS sequence.

[00156] The shaded portion at the beginning of the symbol is referred as first shaded portion. The shaded portion at the end of the symbol is referred as second shaded portion. In an embodiment, the first shaded portion and second shaded portion is a combination of portions from at least one of PSS sequence, SSS sequence and PBCH.

[00157] In an embodiment, the symbol includes only first shaded portion along with the PSS sequence, SSS sequence and PBCH, where the first shaded portion is from PBCH sequence. In another embodiment, the symbol includes only first shaded portion along with the PSS sequence, PBCH, SSS sequence, where the first shaded portion is from SSS sequence. In another embodiment, the symbol includes only first shaded portion along with the SSS sequence, PBCH and PSS sequence, where the first shaded portion is from PSS sequence.

[00158] In an embodiment, the symbol includes only second shaded portion along with the PSS sequence, SSS sequence and PBCH, where the second shaded portion is from PSS sequence. In another embodiment, the symbol includes only second shaded portion along with the SSS sequence, PSS sequence, PBCH, where the second shaded portion is from SSS sequence. In another embodiment, the symbol includes only second shaded portion along with the PBCH, PSS sequence, and SSS sequence, where the second shaded portion is from PBCH sequence.

[00159] In another embodiment, some part of the shaded portion is from SSS sequence and remaining part of the shaded portion is from PBCH sequence. In yet another embodiment, some part of the shaded portion is from PSS sequence and another part of the shaded portion is from SSS sequence. In yet another embodiment, some part of the shaded portion is from PSS sequence, another part of the shaded portion is from SSS sequence, and yet another part is from PBCH sequence.

[00160] Figure 2M shows an illustration of a SS Block, in accordance with another embodiment of the present disclosure. The SS Block is a multiplexed sequence comprising at least one of a PSS sequence, a SSS sequence, a PBCH sequence, a PBCH RS, and a portion of the at least one of the PSS sequence, the SSS sequence, the PBCH sequence, the PBCH RS. The time multiplexed sequence of symbol structure is cyclic.

[00161] Figure 2N shows an illustration of a SS Block, in accordance with another embodiment of the present disclosure. The SS Block is a multiplexed sequence comprising at least one of a PSS CP, a PSS sequence, a PSS CS, a SSS CP, a SSS sequence, a SSS CS, a PBCH CP, a PBCH sequence, a PBCH CS and a portion of the at least one of a PSS CP, a PSS sequence, a PSS CS, a SSS CP, a SSS sequence, a SSS CS, a PBCH CP, a PBCH sequence, a PBCH CS. In an embodiment, the shaded portion is a portion of the at least one of PSS sequence, SSS sequence and PBCH sequence.

[00162] Figure 3A shows an illustration of PSS, SSS, PBCH carried in one OTFDM SSB symbol, in accordance with an embodiment of the present disclosure.

[00163] Figure 3A is showing different steps involved in the generation of the above explained time multiplexed filtered-extended bandwidth single symbol. As shown in the Figure 3A, CP is added to PSS, SSS and PBCH. As part of CP and CS addition, after DFT spreading of the data, the bandwidth of the signal is extended and this extended bandwidth signal is used for OTFDM generation by passing it through the IFFT. This method is without CP addition. Also, the input symbol structure shown in Figure 3A is as an illustration. The input is at least one of the symbol structures shown in the Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N. These time multiplexed symbol structures are circular or cyclic in nature.

[00164] In another embodiment, as shown in the Figure 3A the PSS, SSS and PBCH, after DFT spreading of the data, the bandwidth of the signal is extended and this extended bandwidth signal is used for OTFDM generation by passing it through the IFFT and CP addition modules. In an embodiment, the input is one of the symbol structures shown in the Figures 2B, 2D, 2F, 2G, 2I.

[00165] Figure 3B shows an illustration of multiple SS block OTFDM symbols in a slot. The pattern of SS block OTFDM symbol positions in time within a half frame repeats itself with a periodicity of a half frame.

[00166] The Figure 3B illustrates the transmission of SS burst, where multiple OTFDM SS block symbols are transmitted in a half frame. Different SS blocks associated with different beams are occupying different symbols in a slot. A maximum of $L_{\max}$ SS blocks are transmitted in a half frame, where $L_{\max}$ defines the maximum number of the beams

having unique beam IDs. The periodicity of the SS burst transmission can be a half frame, a frame, two frames etc. In the example figure, it is showing the periodicity of SS burst transmission as a half frame. The candidate OTFDM SS block symbols in a half frame are indexed in an ascending order in time from 0 to $L_{\max}-1$. In the Figure 3A, $2n$ slots are there in a frame. The slots in the frame are numbered from 0 to $2n-1$ in ascending order in time.

[00167] Figure 3C shows an illustration of multiple SS block OTFDM symbols in a slot associated with different beams. As shown in Figure 3C, the transmission of different OTFDM SS block symbols in time, having different beam IDs, associated with different beams in different directions is provided. To construct a beam in a specific direction, the SS block OTFDM symbol as shown in the Figure 3C is precoded by multiplying with antenna port weight factors and transmitted over the antenna ports.

[00168] One embodiment of the present disclosure is Beam sweeping system. Figure 3D shows a beam sweeping over successive OTFDM symbols, in a downlink transmitter. As shown in Figure 3D, a beam sweeping is performed over successive OTFDM symbols. As shown in Figure 3D, the synchronization channel structure in the beam sweeping systems where each symbol undergoes transmission in a specific beam. A synchronization comprising of PSS, SSS, PBCH is transmitted in one symbol dedicated to one beam number. In an embodiment, the OTFDM symbols are generated using the time multiplexing of the PSS, SSS, PBCH to generate the symbols structures as shown in Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N, which are circular. These multiplexed symbol structures are fed to the filter 120, for the OTFDM waveform generation, and there is no requirement of CP addition post IFFT. In another embodiment, the OTFDM symbols are generated using the time multiplexing of the PSS, SSS, PBCH to generate the symbols structures as shown in Figures 2B, 2D, 2F, 2G, 2I. These multiplexed symbols may not be circular. These multiplexed symbol structures are fed to the filter 120, for the OTFDM waveform generation. The same sequence may be transmitted in successive symbols or the sequence may be function of one or more combinations of: OTFDM symbol number, and cell ID or sector ID or beam ID.

[00169] Figure 3E shows a beam sweeping in a single OTFDM symbol, in a downlink transmitter. As shown in Figure 3E, the synchronization channel structure is for beam sweeping systems wherein a symbol is divided into multiple sub-symbols, and each sub-symbol undergoes transmission in a specific beam. A synchronization comprising of PSS,

SSS, PBCH is transmitted in one sub-symbol dedicated to one beam number. The same RS sequence may be transmitted in successive sub-symbols or the sequence may be function of one or more combinations of OTFDM sub-symbol number, and sector ID or beam ID. In an embodiment, the OTFDM symbols are generated using the time multiplexing of the PSS, SSS, PBCH to generate the symbols structures as shown in Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N, which are circular. These multiplexed symbol structures are fed to the filter 120, for the OTFDM waveform generation, and there is no requirement of CP addition post IFFT. In another embodiment, the OTFDM symbols are generated using the time multiplexing of the PSS, SSS, PBCH to generate the symbols structures as shown in Figures 2B, 2D, 2F, 2G, 2I. These multiplexed symbols may not be circular. These multiplexed symbol structures are fed to the filter 120, for the OTFDM waveform generation.

[00170] Figure 3F shows an illustration of generation of an OTFDM symbol where two SS blocks are time multiplexed and each SS block is associated with a different beam. It illustrates the case where multiple SS blocks are transmitted over the same OTFDM symbol in time. Two pre DFT SS blocks having PSS, SSS and PBCH sequences are placed along with some guard sequence R in between. These SS blocks are one of the symbol structures as shown in Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N. The figure shown for an example illustration only. The inputs symbol structures may be altered. Thus, arranged sequence is then passed through precoder, DFT spread and BW extension and filtering module to generate a filtered bandwidth extended signal. This signal is then subcarrier mapped and IFFT is performed on it to generate an OTFDM symbol.

[00171] In another embodiment, two pre DFT SS blocks having PSS, SSS and PBCH sequences are placed along with some guard sequence R in between and the symbol structures used are one of the symbol structures as shown in Figures 2B, 2D, 2F, 2G, 2I. Thus, arranged sequence is then passed through precoder, DFT spread and BW extension and filtering module to generate a filtered bandwidth extended signal. This signal is then subcarrier mapped, IFFT and CP addition is performed on it to generate an OTFDM symbol.

[00172] In another embodiment, the generation of an OTFDM symbol where two SS blocks are time multiplexed and each SS block is associated with a different beam. The multiple SS blocks are transmitted over the same OTFDM symbol in time. Two pre DFT SS blocks having PSS, SSS and PBCH sequences are placed along with some guard

sequence R in between. The thus arranged sequence is then passed through precoder, DFT spread and BW extension and filtering module to generate a filtered bandwidth extended signal. This signal is then subcarrier mapped followed by IFFT to generate an OTFDM symbol. The symbol structures used are at least one of the symbols as shown in 2A, 2C, 2E, 2H, 2L, 2M, 2N.

[00173] Figure 4A shown an illustration of generation of PSS OTFDM symbol, SSS OTFDM symbol and PBCH OTFDM symbol. The input symbol structures as shown in the Figure 4A is only for illustration purpose, and these input symbol structures may be modified using other symbol structures described in this present disclosure. The input multiplexed sequence or symbol structure is any one of the symbol structures as shown and described in Figures 2A, 2C, 2E, 2H, 2L, 2M, 2N. These input symbols are circular or cyclic. The input symbol structures as shown in the Figure 4A is for an illustration.

[00174] As shown in Figure 4A, the input sequences are processed using DFT, DFT spread followed by filtering, mapping, IFFT to generate OTFDM symbol. The PDCH data may optionally include PT-RS for phase compensation at the receiver. This symbol is cyclic in nature. As shown in Figure 4A, the input multiplexed symbol is an OTFDM symbol comprising of at least one of 1st input symbol i.e. PSS CP and PSS, 2nd input symbol is SSS CP, SSS and 3rd input symbol is PBCH RS CP, PBCH RS and PBCH data. The PDCCH data may optionally include PT-RS for phase compensation at the receiver.

[00175] In another embodiment, the input symbol structures of Figure 4A are one of the symbol structures as shown and described in Figures 2B, 2D, 2F, 2G, 2I. As shown in Figure 4A, the input sequences are processed using DFT, DFT spread followed by filtering, mapping and IFFT and CP addition to generate OTFDM symbol. The input symbols may not be cyclic. The PBCH data may optionally include PT-RS for phase compensation at the receiver. As shown in Figure 4A, the symbol is an OTFDM symbol comprising of 1st symbol as PSS, 2nd symbol as SSS, and 3rd symbol as PBCH RS CP, PBCH RS, and PBCH data. The PBCH data may optionally include PT-RS for phase compensation at the receiver.

[00176] Figure 4B shows an illustration of an SS block consisting of 3 OTFDM symbols in time. As shown in the Figure 4B, the SS block comprises 1st symbol as PSS OTFDM symbol which is generated using the filter or OTFDM symbol generating unit 104, when

the input multiplexed sequence comprises only PSS sequence. The SS block comprises 2nd symbol which is SSS OTFDM symbol and 3rd symbol is PBCH OTFDM symbol. The SS OTFDM symbol is generated using the OTFDM symbol generating unit 104, when the input multiplexed sequence comprises only SSS sequence. Similarly, the PBCH OTFDM symbol is generated using the OTFDM symbol generating unit 104, when the input multiplexed sequence comprises only PBCH. The PBCH comprises a PBCH data and DMRS.

[00177] Figure 4C shows an illustration SS block consisting of 2 OTFDM symbols in time. As shown in the Figure 4C, the SS block comprises 1st symbol as PSS OTFDM symbol which is generated using the filter or OTFDM symbol generating unit 104, when the input multiplexed sequence comprises only PSS sequence. The SS block comprises 2nd symbol which is SSS + PBCH OTFDM symbol, which is generated using the OTFDM symbol generating unit 104, when the input multiplexed sequence comprises SSS sequence and PBCH. The PBCH comprises a PBCH data and DMRS.

[00178] Figure 4D illustrates the transmission of SS burst, where multiple SS blocks are transmitted in a half frame. Each SS block consists of PSS OTFDM, SSS OTFDM and PBCH OTFDM symbol.

[00179] Each SS block is at least one symbol, wherein one symbol consists of PSS, SSS and PBCH; or two symbols with 1st symbol carrying PSS and 2nd symbol carrying SSS and PBCH; In another embodiment, the SS block with two symbols comprises 1st symbol carrying PSS and SSS, and 2nd symbol carrying PBCH; three symbols wherein 1st symbol carrying PSS, 2nd symbol carrying SSS and last symbol carrying PBCH.

[00180] Different SS blocks associated with different beams are occupying different symbols in a slot. A maximum of L_{max} SS blocks are transmitted in a half frame, where L_{max} defines the maximum number of the beams having unique beam IDs. In the example figure, the SS burst transmission periodicity is a half frame. The candidate SS blocks in a half frame are indexed in an ascending order in time from 0 to $L_{max}-1$. In the figure, $2n$ slots are there in a frame. The slots in the frame are numbered from 0 to $2n-1$ in ascending order in time.

[00181] Figure 4E shows an illustration of PSS symbol. The sequences for instance can be a single base sequence (with one of CP and CS), or multiple sequences repeated together (repeated sequences may not include CP and/or CS). An additional code cover may be applied on the base PSS sequence. The base sequence is one of $\pi/2$ BPSK and ZC sequences. The base sequence may be single sequence, or it may be sector specific sequence.

[00182] Figure 4F shows an illustration of SSS symbol. The sequences for instance can be a single base sequence (with one of CP and CS), or multiple sequences repeated together (repeated sequences may not include CP and/or CS). An additional code cover may be applied on the base SSS sequence. The base sequence is one of $\pi/2$ BPSK and ZC sequences. In another embodiment, instead of repeating the base sequence, a long SSS based on $\pi/2$ BPSK or ZC sequences may be used.

[00183] One embodiment of the present disclosure is Beam sweeping system. Figure 4G shows a beam sweeping over successive OTFDM symbols. As shown in Figure 4G, the sync channel structure in the beam sweeping systems where each symbol undergoes transmission in a specific beam. A sync comprising of PSS, SSS, PBCH is transmitted in one symbol dedicated to one beam number. The same RS sequence may be transmitted in successive symbols or the sequence may be function of one or more combinations of: OTFDM symbol number, and cell ID or sector ID or beam ID.

[00184] Figure 4H shows a synchronization channel structure in a beam sweeping systems where a symbol is divided into multiple sub-symbols and each sub-symbol undergoes transmission in a specific beam. A sync comprising of PSS, SSS, PBCH is transmitted in one sub-symbol dedicated to one beam number. The same RS sequence may be transmitted in successive sub-symbols or the sequence may be function of one or more combinations of: OTFDM sub-symbol number, and cell ID or sector ID or beam ID.

[00185] One embodiment of the present disclosure is Master Information Block (MIB) information. A communication system or a base station (BS) or gNB transmits these synchronization signal blocks using directional beams. The UE detects one of the SS block beams and the detected beam conveys the symbol location within a half frame to the UE and hence providing the timing information at symbol level granularity.

[00186] Acquiring the SSB enables the device to become downlink synchronized with the cell. Having received the SSB/PBCH the device can decode the rest of the Master Information Block (MIB). The MIB carries at least one of System Frame Number, system bandwidth and any other system information that is common for all the users.

[00187] Once the MIB is decoded, to get the Remaining Minimum System Information (RMSI) required to access the system, the UE needs to detect the System Information Block-1. The information conveyed by MIB is used to find the CORESET-0 and SS-0 locations which provides the possible location to look for PDCCH. SIB1 PDCCH is scrambled by SI RNTI. The UE blind decoded PDCCH to get Downlink Control information (DCI). The DCI contains information required to decode the corresponding SIB1 PDSCH, such as, time-frequency allocation, Modulation and Coding Scheme, Redundancy version etc. Using this information, a UE decodes SIB1 PDSCH. In the SIB1, the gNB transmits the information required by the UE to carry out the initial random-access procedure and enables further processing till the RRC attach.

[00188] Before the device can access the network, it must first select a suitable cell. The selection of a suitable cell is based on radio criteria and information sent from the cell in SIB1.

[00189] System Information Block - 1 (SIB1) is sent/broadcasted over the DL-SCH OTFDM symbols every x millisecond, where x can be 160 or other value. Its transmission can repeat at different intervals. Normally, it repeats every 20 milliseconds, but this can vary depending the network implementation. It contains information which allows a UE to determine whether or not it is permitted to access the cell. SIB-1 also provides scheduling information for all remaining system information and some radio resource configuration information, e.g. timers and constants. The Time-frequency resources in PDSCH where the SIB-1 is located is conveyed to the user via the PDCCH. The configured PDCCH may carry user specific or common information. Similarly, in another embodiment, scheduled PDSCH may carry user specific data or broadcast data.

[00190] The MIB includes information such as Control Resource Set 0 (CORESET-0) and Search Space 0 (SS-0) location required to decode PDCCH associated with the (System Information Block-1) SIB1 PDSCH, subcarrier spacing configuration to be used for SIB1, msg2/msg4 for initial access, paging and broadcast SI messages, System Frame Number

(SFN) etc. SS blocks associated with different beam IDs are allocated different symbol start locations within a half frame.

[00191] One embodiment of the present disclosure is a PDCCH and a PDSCH for SIB transmission. A SIB 1 is transmitted on at least one PDSCH-OTFDM symbol, and the Time-frequency resources in PDSCH, where the SIB-1 is located is conveyed via control information transmitted on at least one PDCCH-OTFDM symbol.

[00192] Figure 5A shows a block diagram of an OTFDM transmitter, in accordance with another embodiment of the present disclosure. The OTFDM transmitter 500 is referred to as a transmitter or a communication system.

[00193] As shown in the Figure 5A, the transmitter 500 comprises a time multiplexing unit 502 and an OTFDM symbol generating unit 104. The time multiplexing unit 502 is also referred as a time multiplexer or multiplexer or time division multiplexer or TDM. Also, the transmitter 500 comprises a plurality of antennas. The OTFDM symbol generating unit 104 is also referred as OTFDM symbol generator or symbol generator which is as shown in Figure 1B.

[00194] In an embodiment, the time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C and a portion of at least one of the RS, the control data sequence, the user data sequence to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figures 6A, 6B, 6E, 6F, 7A, 7B, 8A, 8B, 8C, 8D, 8E are the multiplexed sequences obtained using time multiplexer 502, said symbols are circular.

[00195] The OTFDM symbol generating unit 104, which is as shown in Figure 1B, generates an output 512 called as OTFDM symbol using the multiplexed sequences. As the multiplexed sequence is obtained using the control data sequence (mapped on to PDCCH) 510B, the user data sequence (mapped on to PDSCH) 510C and the RS, the generated symbol is referred as PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol or PDCCH-PDSCH OTFDM symbol. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1D to generate a OTFDM symbol. In an embodiment, the

generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00196] In another embodiment, the time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C to generate a multiplexed sequence. The symbol structures as shown in the Figures 5B, 6C, 6D, 6G, 6H, 7C, 7D, 7E, 7F are the multiplexed sequences used in this embodiment. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1C to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00197] In another embodiment, the generated OTFDM waveform undergoes a procedure known as Antenna precoding, where the purpose of precoding is to map the generated OTFDM symbols to a set of antenna ports using a precoder matrix. The generated OTFDM signal is multiplied using antenna port specific phase weights and each weighted signal is transmitted using an antenna port. Each complex weighted baseband OTFDM signal is converted to analog waveform using digital to analog converter (DAC). The analog OTFDM waveform undergoes power amplification to boost the signal strength to a level capable of transmission across the air interface. Since, OTFDM signal has low PAPR, the PA requires low back off, thereby resulting in energy efficient transmission. For $\pi/2$ BPSK OTFDM the back off may be 0 dB or very low value so that signal can be transmitted close to power amplifier (PA) saturation power. Digital pre distortion operation may be used before PA when higher order modulation is used. Further the OTFDM waveform undergoes radio frequency (RF) filtering subsequently transmitted through the antenna array.

[00198] In an embodiment, the duration of the PDCCH sequence and the PDSCH sequences is unequal. The PDCCH carries a common control information and a user specific control information. The PDSCH carries a user specific data or common broadcast data. The RS is used to demodulate the PDCCH and PDSCH by one or more receiving users. Figure 5B shows an illustration of different OTFDM Symbol carrying downlink channels.

- [00199] The PDCCH RS is at least one of ZC, $\pi/2$ BPSK, QPSK, and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences.
- [00200] The PDCCH RS is a function of at least one of a symbol ID, slot number, cell ID or physical cell ID, scrambling ID. In an embodiment, the PDCCH RS is one of user specific sequence. In an embodiment, the PDCCH RS is not a user specific sequence. In an embodiment, user specific PDCCH RS is generated by applying an Orthogonal cover code on the base sequence, where base sequence is one of ZC, $\pi/2$ BPSK, QPSK, and M-ary sequences
- [00201] PDCCH data sequence is one of $\pi/2$ BPSK, QPSK and M-ary sequences. The data sequence is spectrum shaped when it is $\pi/2$ BPSK.
- [00202] The generated OTFDM symbol is a PDCCH OTFDM symbol, when the input to the time multiplexing unit 502 is PDCCH/ control information only. In an embodiment, the generated PDCCH OTFDM symbol may be repeated N number of times, where N is natural number. Each repeated symbol may be applied with symbol specific cover code. Where the cover codes may be obtained from one of PN-sequences, or Hadamard codes.
- [00203] The generated OTFDM symbol is a PDSCH OTFDM symbol, when the input to the time multiplexing unit 502 is PDSCH/ user specific data only.
- [00204] The PDSCH RS is one of ZC, $\pi/2$ BPSK, QPSK, and M-ary sequences. The $\pi/2$ BPSK, QPSK and M-ary sequences are generated using PN sequences. The PDSCH RS is a function of at least one of a symbol ID, slot number, cell ID or physical cell ID, scrambling ID. In an embodiment, user specific PDSCH RS is generated by applying an Orthogonal cover code on the base sequence, where base sequence is one of ZC, $\pi/2$ BPSK, QPSK, and M-ary sequences
- [00205] The PDSCH user data sequence is one of $\pi/2$ BPSK, QPSK and M-ary sequences. The user data sequence is spectrum shaped when it is $\pi/2$ BPSK.
- [00206] Figure 6A shows various symbol structure with PDCCH data and optional PTRS with RS. The symbol is an OTFDM symbol of length M, comprising of PDCCH data and RS.

[00207] As shown in Figure 6A, the symbol is an OTFDM symbol of length M , comprising of PDCCH data, RS and RS cyclic prefix (CP) at the start and end of the symbol. The PDCCH data may optionally include PT-RS for phase compensation at the receiver. This symbol is cyclic in nature. As shown in Figure 6A, the symbol is an OTFDM symbol comprising of data, PDCCH data, RS CP, RS, PDCCH data and data. The PDCCH data may optionally include PT-RS for phase compensation at the receiver.

[00208] The Figure 6B shows a symbol structure of PDCCH data, in accordance with an embodiment. As shown in Figure 6B the OTFDM symbol comprising of PDCCH data and optional PT-RS, RS cyclic prefix (CP), RS, and PDCCH data and optional PT-RS. The RS CP is of length L , and RS is greater than length $2L$, where L is an integer. Also, the OTFDM symbol is a circular or cyclic. The PDCCH data may optionally include PT-RS for phase compensation at the receiver.

[00209] Figure 6C shows a symbol structure with PDCCH data and optional PTRS, the symbol is an OTFDM symbol comprising of data CP, PDCCH data plus optional PT-RS, RS CP, RS, and data. The PDCCH data may optionally include PT-RS for phase compensation at the receiver.

[00210] Figure 6D shows a symbol structure with PDCCH data and optional PTRS, in accordance with an embodiment of the present disclosure. As shown in Figure 6D shows the OTFDM symbol comprising of RS cyclic prefix (CP) of length L , RS and PDCCH data and optional PT-RS. The optionally include PT-RS is for the phase compensation at the receiver.

[00211] Figures 6E-6H shows various symbol structure with PDSCH data and optional PTRS. The data may optionally include PT-RS for phase compensation at the receiver.

[00212] As shown in Figure 6E, the symbol is of length M , comprising of a RS cyclic prefix (CP) at the start and end of the symbol, a PDSCH data and a RS. The PDSCH data may optionally include PT-RS for phase compensation at the receiver. This symbol is circular or cyclic in nature.

[00213] As shown in Figure 6F, the symbol is a cyclic symbol comprising of a PDSCH data, a RS CP, a RS and a PDSCH data. The PDSCH data may optionally include PT-RS for phase compensation at the receiver.

[00214] As shown in Figure 6G, the symbol comprises a data CP, a PDSCH data, RS CP, RS, PDSCH data and a data. The PDSCH data may optionally include PT-RS for phase compensation at the receiver.

[00215] The Figure 6H shows an OTFDM symbol comprising of RS cyclic prefix (CP) of length L, a RS and PDSCH data. The PDSCH data optionally include PT-RS is for the phase compensation at the receiver.

[00216] Figures 7A-7D shows various symbol structure with PDCCH plus PDSCH data and optional PTRS. As shown in Figure 7A, the symbol is of length M, comprising RS cyclic prefix (CP) at the start and end of the symbol, a RS, and PDCCH plus PDSCH data. The PDSCH data may optionally include PT-RS for phase compensation at the receiver. This symbol is cyclic in nature. As shown in Figure 7B, the symbol is a cyclic comprising PDCCH plus PDSCH data, RS CP, RS and PDCCH plus PDSCH data. The PDSCH data may optionally include PT-RS for phase compensation at the receiver.

[00217] Figure 7C shows a symbol comprising of a data CP, a PDCCH plus PDSCH data, a RS CP, a RS, PDCCH plus PDSCH data and a data. The PDSCH data may optionally include PT-RS for phase compensation at the receiver. The Figure 7D shows a symbol comprising of RS cyclic prefix (CP) of length L, a RS and PDCCH plus PDSCH data and optional PT-RS. The optional PT-RS is used for the phase compensation at the receiver.

[00218] Figures 7E-7H shows various symbol structure of PSS, SSS, PBCH, PDCCH and PDSCH data. In an embodiment, the symbol of as shown in Figure 7E is an OTFDM symbol. The symbol comprising CP, PSS, SSS and PBCH. Figure 7F shows a symbol comprising RS, PDCCH and PDSCH.

[00219] The symbol as shown in Figure 7G comprising CP, PSS, SSS, PBCH, RS, PDCCH and PDSCH. As shown in Figure 7H, the symbol comprising PSS-CP, PSS, SSS-CP SSS and PBCH-CP, and PBCH. In another embodiment, the symbol comprising CP for the block as shown in Figure 7H. That is the symbol comprises CP, PSS-CP, PSS, SSS-CP SSS and PBCH-CP, and PBCH.

[00220] As shown in Figure 7L, the symbol comprising PSS-CP, PSS, SSS-CP, SSS, PBCH-CP, PBCH, RS-CP, RS, PDCCH-CP, PDCCH, PDSCH-CP, and PDSCH. In

another embodiment, the symbol comprising CP for the block as shown in Figure 7L. That is the symbol comprises CP, PSS-CP, PSS, SSS-CP, SSS, PBCH-CP, PBCH, RS-CP, RS, PDCCH-CP, PDCCH, PDSCH-CP, and PDSCH.

[00221] Figures 7J-7L shows various symbol structure of SSB, PDCCH and PDSCH, PSS and SSS channel data. Figure 7J shows an OTFDM symbol in an embodiment. The symbol comprises SSB, PDCCH and PDSCH. Figure 7K shows a symbol comprising SSB-CP, SSB, PDCCH-CP, PDCCH, PDSCH-CP and PDSCH. In another embodiment, the symbol comprising CP for the block as shown in Figure 7K. That is the symbol comprises CP, SSB-CP, SSB, PDCCH-CP, PDCCH, PDSCH-CP and PDSCH. Figure 7L shows a symbol structure comprising CP, PSS, SSS, PBCH, RS, PSS, SSS.

[00222] Figures 8A-8C shows various symbol structure of RS, PDCCH, PDSCH channel data, in accordance with some embodiments of the present disclosure. The symbols shown in these Figure 8A-8C are circular or cyclic. As shown in the Figure 8A, the symbol comprises a shaded portion at the beginning and end of the symbol, a reference sequence (RS), a user data sequence (mapped on to PDSCH), a control data sequence (mapped on to PDCCH). The portion is at least one of the RS, the control data sequence, the user data sequence.

[00223] The symbol as shown in Figure 8B, the symbol comprises a PDCCH RS, control data sequence (mapped on to PDCCH), a PDSCH RS, a user data sequence (mapped on to PDSCH), and portion at the beginning and end of the symbol. The portion is at least one of a portion of PDCCH RS, portion of control data sequence, a portion of PDSCH RS, and a portion of user data sequence.

[00224] The symbol as shown in Figure 8C, the symbol comprises a PDCCH RS CP, a control data sequence (mapped on to PDCCH), a PDCCH RS CS, a PDSCH RS CP, a user data sequence (mapped on to PDSCH), a PDSCH RS CS, and portion at the beginning and end of the symbol. The portion is at least one of a portion of a PDCCH RS CP, portion of a control data sequence, a portion of PDCCH RS CS, a portion of PDSCH RS CP, a portion of user data sequence, and a portion of PDSCH RS CS.

[00225] Figures 8D-8E shows various symbol structure of SSB, PDCCH and PDSCH, PSS and SSS channel data, in accordance with another embodiment of the present disclosure.

[00226] As shown in Figure 8D, the symbol comprises a PSS, a SSS, a PCH RS CP, a PBCH RS, a PBCH data, a PDCCH RS CP, a control data sequence (mapped on to PDCCH) or PDCCH, PDCCH RS, a PDSCH RS CP, a PDSCH RS, a user data sequence (mapped on to PDSCH) or PDSCH, and a portion of at least one of the PSS, the SSS, the PCH RS CP, the PBCH RS, the PBCH data, the PDCCH RS CP, the PDCCH, the PDCCH RS, the PDSCH RS CP, the PDSCH RS and the PDSCH.

[00227] As shown in Figure 8E, comprises a PSS, a SSS, a PCH DMRS, a PBCH, a RS CP, a RS, a control data sequence (mapped on to PDCCH) or PDCCH, a user data sequence (mapped on to PDSCH) or PDSCH, and a portion of at least one of the PSS, the SSS, the PCH DMRS, the RS CP, the RS, the PDCCH and the PDSCH.

[00228] In another embodiment, as shown in Figure \$\$\$\$, PDCCH and PDSCH may be transmitted in multiple distinct OTFDM symbols i.e., at least one symbol is configured for PDCCH, and at least one symbol is configured for PDSCH. The time separation between the PDCCH and PDSCH is zero or at least one OTFDM symbol. Each configured PDCCH symbol carries at least one of at least one PDCCH-RS -CP, PDCCH-RS, PDCCH-data/control information, PDCCH-PTRS/ARS for phase or Doppler correction. Similarly, for each configured PDSCH symbol carries at least one of at least one PDSCH-RS-CP, PDSCH-RS, PDSCH-data/control information, PDSCH-PTRS/ARS for phase or Doppler correction. In another embodiment, only either PDSCH or PDCCH carries PTRS or **ARS**, and the estimate from the transmitted PTRS/ARS, is used for all the transmitted PDCCH, and PDSCH OTFDM symbols.

[00229] Figure 9 shows a block diagram of an OTFDM transmitter, in accordance with another embodiment of the present disclosure. The OTFDM transmitter 900 is referred to as a transmitter or a communication system.

[00230] As shown in the Figure 9, the transmitter 900 comprises a time multiplexing unit 902 and an OTFDM symbol generating unit 104. The time multiplexing unit 902 is also referred as a time multiplexer or multiplexer or time division multiplexer or TDM.

Also, the transmitter 900 comprises a plurality of antennas. The OTFDM symbol generating unit 104 is also referred as OTFDM symbol generator or symbol generator which is as shown in Figure 1B.

[00231] In an embodiment, the time multiplexer 902 multiplexes a plurality of data (910A, 910B, 910C), PSS sequence (912), SSS sequence (914), PBCH sequence (915), a control data sequence (mapped on to PDCCH) (916), user data sequence (mapped on to PDSCH) (918), a plurality of reference sequence (RS) (920A, 920B, 920C) and a portion of at least one of the plurality of data, PSS, SSS, PBCH, the plurality of RS, the control data sequence, and the user data sequence, to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The multiplexed symbols generated may be one of the symbol structures shown in Figures 6A, 6B, 6E, 6F, 7A, 7B, 8A, 8B, 8C, 8D, 8E, which are circular.

[00232] The OTFDM symbol generating unit 104, which is as shown in Figure 1B, generates an output 930 called as OTFDM symbol using the multiplexed sequences. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1D to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00233] In another embodiment, the time multiplexer 902 multiplexes a plurality of data (910A, 910B, 910C), PSS sequence (912), SSS sequence (914), PBCH sequence (915), a control data sequence (mapped on to PDCCH) (916), user data sequence (mapped on to PDSCH) (918), a plurality of reference sequence (RS) (920A, 920B, 920C) and a portion of at least one of the plurality of data, PSS, SSS, PBCH, the plurality of RS, the control data sequence, and the user data sequence, to generate a multiplexed sequence which may not be circular. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1C to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00234] In another embodiment, the generated OTFDM waveform undergoes a procedure known as Antenna precoding, where the purpose of precoding is to map the generated OTFDM symbols to a set of antenna ports using a precoder matrix. The generated OTFDM signal is multiplied using antenna port specific phase weights and each weighted signal is transmitted using an antenna port. Each complex weighted baseband OTFDM signal is converted to analog waveform using digital to analog converter (DAC). The analog OTFDM waveform undergoes power amplification to boost the signal strength to a level capable of transmission across the air interface. Since, OTFDM signal has low PAPR, the PA requires low back off, thereby resulting in energy efficient transmission. For $\pi/2$ BPSK OTFDM the back off may be 0 dB or very low value so that signal can be transmitted close to power amplifier (PA) saturation power. Digital pre distortion operation may be used before PA when higher order modulation is used. Further the OTFDM waveform undergoes radio frequency (RF) filtering subsequently transmitted through the antenna array.

[00235] Figure 10 shows an illustration of generation of DL OTFDM symbols. In the left figure, an OTFDM symbol is generated using only PDCCH RS CP, PDCCH RS and PDCCH. In the figure in center, it describes the generation of an OTFDM symbol where PDCCH and PDSCH are time multiplexed along with DL RS. The figure on the right end is shows generation of an OTFDM symbol consisting of PDSCH, PDSCH RS and PDSCH RS CP. The input symbol structures shown in Figure 10 are only for illustration purpose. The input sequences are processed using DFT, DFT spreaded with bandwidth extension, followed by filtering, mapping, IFFT and CP addition to generate an OTFDM symbol. The PDCH data may optionally include PT-RS for phase compensation at the receiver.

[00236] In an embodiment, the input symbols are any of the symbol structure as shown in Figures 5B, 6A to 6H, 7A to 7D, 7F, 8A to 8C. These input symbols are cyclic in nature in an embodiment. The input sequences are processed using DFT, DFT spreaded with bandwidth extension, followed by filtering, mapping, IFFT to generate an OTFDM symbol. For the input symbols which are cyclic, the processing does not include the step of CP addition to generate the OTFDM symbol.

[00237] Figure 11 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a slot with their associated beam, where a slot has N symbols. As shown in Figure 11, multiple DL OTFDM symbols are transmitted in a slot within a frame. Also in figure 11, a

slot consists of N symbols. Each symbol is associated with a beam thus enabling different beam directions for the DL OTFDM symbols.

[00238] Figure 12 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a frame with their associated beam, where a slot consisting of 1 OTFDM symbol. As shown in Figure 12, the transmission of DL OTFDM symbols is in one frame. There are n slots in a frame and each slot is consisting of 1 OTFDM symbol. The symbol in each slot is associated with a beam as shown in the figure 12.

[00239] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol. The order in which the method steps is described is not intended to be construed as a limitation, and any number of the described method steps can be combined in any order to implement the method. Additionally, individual method steps may be deleted from the methods without departing from the scope of the subject matter described herein. Furthermore, the method can be implemented in any suitable hardware, software, firmware, or combination thereof.

[00240] The method comprising time-multiplexing, by the transmitter, a physical downlink control channel (PDCCH) sequence, a physical downlink shared channel (PDSCH) sequence and a reference sequence (RS) to generate a multiplexed sequence. The method also comprises processing the time multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol.

[00241] The method of processing the multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol comprising transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. Also, the method comprises performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. Further the method comprises, mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence, which is shaped using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence. Furthermore, the method

comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The time domain sequence is processed to generate the PDCCH-PDSCH OTFDM symbol.

[00242] The processing the time domain sequence to generate a OTFDM symbol comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, phase compensation for each symbol by multiplying with a symbol specific exponential value, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate up-conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the PDCCH-PDSCH OTFDM symbol.

[00243] The duration of the PDCCH sequence and the PDSCH sequences is unequal. The PDCCH carries a common control information and a user specific control information. The PDSCH carries a user specific data. The RS is used to demodulate the PDCCH and PDSCH by one or more receiving users or user equipment's (UEs).

[00244] One embodiment of the present disclosure is a method for transmitting a PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol. The method, performed by a transmitter 500, comprising time-multiplexing a physical downlink shared channel (PDSCH) sequence and a reference sequence (RS) to generate a multiplexed sequence and processing the multiplexed sequence to generate a PDSCH OTFDM symbol. The PDSCH carries a user specific data. The RS is used to demodulate the PDSCH by one or more receiving users or user equipment's (UEs).

[00245] In another embodiment, a method for transmitting a PDCCH Orthogonal time frequency-division multiplexing (OTFDM) symbol is provided. The method, performed by a transmitter 500, comprises time-multiplexing a physical downlink control channel (PDCCH) sequence and a reference sequence (RS) to generate a multiplexed sequence. Also, the method comprises processing the multiplexed sequence to generate a PDCCH OTFDM symbol. The PDCCH carries a common control information and a user specific control information. The RS is used to demodulate the PDCCH by one or more receiving users or user equipment's (UEs).

[00246] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprising time-multiplexing, by the transmitter 500, a PDCCH-PDSCH OTFDM symbol and a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users or user equipment's (UEs). The one or more receiving users decode the control information and the data information using the received PDCCH-PDSCH slot.

[00247] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprising time-multiplexing, by the transmitter, a PDCCH OTFDM symbol, a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users. The one or more receiving UEs or user equipment's (UEs) decode the control information and the data information using the received PDCCH-PDSCH slot.

[00248] One embodiment of the present disclosure is a method for transmitting a downlink frame. The method comprises time-multiplexing, by the transmitter, at least one SS Block and at least PDCCH-PDSCH OTFDM slot to generate at least one downlink signal associated with a beam. The users or user equipment's (UEs) associated with the beam decode a SS Block and acquire PSS ID/ BS ID, and MIB. Also, the users associated with the beam decode one of corset zero, SIB1, and user data using the received DL signal associated with the beam.

[00249] One embodiment of the present disclosure is a method for transmitting a downlink frame. The method comprising time-multiplexing, by the transmitter, a plurality of SS Blocks associated with a plurality of beams and a plurality of PDCCH-PDSCH OTFDM symbols associated with a plurality of beam to generate a downlink frame. The users associated with the beam decode a SS Block and acquire PSS ID/ BS ID, and MIB. The users associated with the beam decode one of corset zero, SIB1, and user data using the received DL signal associated with the beam.

[00250] One embodiment of the present disclosure is a receiver. The receiver structures are as shown in Figures 13A, 13B and 13C.

[00251] Figure 13A shows a block diagram representation of a receiver, in accordance with an embodiment of the present disclosure. As shown in Figure 13A, the receiver is for channels like PDSCH, PDCCH, and for PBCH decoding. Here, post CP removal of the OTFDM symbol at the receiver, the received data is processed with sub-carrier de-mapper, where the data corresponding to each user for each channels mentioned above are de-mapped. The de-mapped data is processed with $M1+d$ point IDFT, which is followed by Time domain demultiplexer for each user. Here, the RS corresponding to each user is separated. The received RS samples are used for channel estimation, phase tracking, Doppler compensation CQI measurements, and data/control detection.

[00252] Figure 13B shows the receiver block diagram for SSS receiver, where the initial processing till taking IDFT of size $M1+d$ on the de-mapped data is similar to the PDSCH channel. Post IDFT SSS receiver is applied on the data operated with IDFT. Figure 13C shows a block diagram representation of a PSS receiver, in accordance with yet another embodiment of the present disclosure. Since PSS is in time domain, the receiver can detect PSS directly.

[00253] In an embodiment, a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol is disclosed. The method comprising: time-multiplexing, by the transmitter, at least one of a physical downlink control channel (PDCCH) sequence, a physical downlink shared channel (PDSCH) sequence, a reference sequence (RS), and a portion of at least one of the PDCCH sequence, the PDSCH sequence and the RS to generate a multiplexed sequence; and filtering, by the transmitter, the multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol. Duration of the PDCCH sequence and the PDSCH sequences is unequal. The PDCCH carries a common control information and a user specific control information. The PDSCH carries a user specific data. The RS is used to demodulate the PDCCH and PDSCH by one or more receiving users.

[00254] The filtering the multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol comprising transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence; performing padding

operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence; mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence; shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence; performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence; and processing the time domain sequence to generate the PDCCH-PDSCH OTFDM symbol. The value of the N1 is at least zero, and value of the N2 is at least zero. The transformed multiplexed sequence is mapped using one of localized and distributed subcarriers.

[00255] The filtering is performed on the time domain sequence to generate a OTFDM symbol. The filtering comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, phase compensation for each symbol by multiplying with a symbol specific exponential value, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate up-conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the PDCCH-PDSCH OTFDM symbol.

[00256] In an embodiment, the filtering of the multiplexed sequence to generate the OTFDM symbol comprises filtering the multiplexed sequence using circular pulse shaping filter to generate filtered sequence; performing weighted with overlap and add operation (WOLA) on the filtered sequence to generate WOLA sequence; and converting the WOLA sequence using the digital analog converter (DAC) to generate OTFDM symbol. In another embodiment, the filtering of the multiplexed sequence to generate the OTFDM symbol is performed using a linear filter.

[00257] One embodiment of the present disclosure is a method for transmitting a PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol. The method comprising: time-multiplexing, by the transmitter, a physical downlink shared channel (PDSCH) sequence, a reference sequence (RS), and a portion of at least one of the PDSCH sequence and the RS to generate a multiplexed sequence; and filtering the multiplexed

sequence to generate a PDSCH OTFDM symbol. The PDSCH carries a user specific data. The RS is used to demodulate the PDSCH by one or more receiving users.

[00258] One embodiment of the present disclosure is a method for transmitting a PDCCH Orthogonal time frequency-division multiplexing (OTFDM) symbol. The method comprising time-multiplexing, by the transmitter, a physical downlink control channel (PDCCH) sequence, a reference sequence (RS) and at least one of the PDCCH portion and the RS to generate a multiplexed sequence; and filtering the multiplexed sequence to generate a PDCCH OTFDM symbol. The PDCCH carries a common control information and a user specific control information. The RS is used to demodulate the PDCCH by one or more receiving users.

[00259] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprising time-multiplexing, by the transmitter, a PDCCH-PDSCH OTFDM symbol and a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users. The one or more receiving users decode the control information and the data information using the received PDCCH-PDSCH slot.

[00260] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprises time-multiplexing, by the transmitter, a PDCCH OTFDM symbol, a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users. The one or more receiving UEs decode the control information and the data information using the received PDCCH-PDSCH slot.

[00261] One embodiment of the present disclosure is a method for transmitting a downlink frame. The method comprises time-multiplexing at least one SS Block and at least PDCCH-PDSCH OTFDM slot to generate at least one downlink signal associated with a beam. The users associated with the beam decode a SS Block and acquire PSS ID/

BS ID, and MIB. The users associated with the beam decode one of corset zero, SIB1, and user data using the received DL signal associated with the beam.

[00262] One embodiment of the present disclosure is a method for transmitting a downlink frame. The method comprising time-multiplexing, by the transmitter, a plurality of SS Blocks associated with a plurality of beams and a plurality of PDCCH-PDSCH OTFDM symbols associated with a plurality of beam to generate a downlink frame. The users associated with the beam decode a SS Block and acquire PSS ID/ BS ID, and MIB. The users associated with the beam decode one of corset zero, SIB1, and user data using the received DL signal associated with the beam.

[00263] Figures 14A-14B shows the flow of different messages between a UE and a gNB till RRC connection is established. The UE is referred to as a user. The gNB is a base station or BS. The SS block consists of PSS, SSS and PBCH. The PSS and SSS together conveys the gNB ID or the physical Cell ID. PBCH conveys Master Information Block (MIB).

[00264] An exemplary embodiment of the present disclosure is initial access. Assuming a device has selected a suitable cell, the RA (Random Access) procedure is typically triggered. This involves a RA procedure with 4-steps.

[00265] As shown in Figure 14, a flow of different messages between a UE and a gNB is performed till RRC connection is established. The UE is referred to as a user. The gNB is a base station or BS. The SS block consists of PSS, SSS and PBCH. The PSS and SSS together conveys the gNB ID or the physical Cell ID. PBCH conveys Master Information Block (MIB). The MIB includes information such as Control Resource Set 0 (CORESET-0) and Search Space 0 (SS-0) location required to decode PDCCH associated with the (System Information Block-1) SIB1 PDSCH, subcarrier spacing configuration to be used for SIB1, msg2/msg4 for initial access, paging and broadcast SI messages, System Frame Number (SFN) etc. SS blocks associated with different beam IDs are allocated different symbol start locations within a half frame.

[00266] The base station transmits these synchronization signal blocks using directional beams. The UE detects one of the SS block beams and the detected beam conveys the symbol location within a half frame to the UE and hence providing the timing information

at symbol level granularity. Once MIB is decoded, to get the Remaining Minimum System Information (RMSI) required to access the system, the UE needs to detect the System Information Block-1. The information conveyed by MIB is used to find the CORESET-0 and SS-0 locations which provides the possible location to look for PDCCH. SIB1 PDCCH is scrambled by SI RNTI. The UE blind decoded PDCCH to get Downlink Control information (DCI). The DCI contains information required to decode the corresponding SIB1 PDSCH, such as, time-frequency allocation, Modulation and Coding Scheme, Redundancy version etc. Using this information, a UE decodes SIB1 PDSCH. In SIB1 the gNB transmits the information required by the UE to carry out the initial Random-Access Procedure and enables further processing till the RRC attach.

[00267] Once the user successfully decodes the SIB-1, it gets to know the time/frequency locations (known as PRACH occasions) where it can perform the initial random-access procedure. It picks a preamble-id and performs the random access (or sends message-1 (msg-1)) based on the RACH occasions defined in the SIB-1. In the subsequent step, the base station sends the message-2 (msg-2 or the Random-Access Response (RAR)) in the downlink and scrambles the RAR with the random access RNTI (RA-RNTI). This RA-RNTI depends on the PRACH occasions or the time-frequency resources where message-1 has been received. Later on, in message-3 (msg-3) and message-4 (msg-4), the device and the base station exchange messages to resolve the collisions caused due to picking of the same preamble-id by the users. Once the collision is resolved, the user enters the connected state and the communication between the base station and the user can happen using regular dedicated transmissions.

[00268] For Msg-1 transmission, in order to access a NR cell, a UE needs to utilize a PRACH preamble sequence/code. the UE utilizes an RSI (Root Sequence Index) which enables the device to generate the correct 64 preambles.

[00269] One embodiment of the present disclosure is a method for transmitting one or more PRACH Orthogonal time frequency-division multiplexing (OTFDM) symbols. The method being performed by a transmitter or communication system as shown in Figures 1D and 1E. The communication system comprises a plurality of transmitters or plurality of antennas, also referred to as one or more transmitters, or one or more antennas. The method comprises transforming at least PRACH sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence, followed by padding operation by prefixing the

transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed sequence.

[00270] Also, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed sequence. Further, the method comprises shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed sequence. Furthermore, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence, and processing the time domain sequence to generate the one or more PRACH OTFDM symbols.

[00271] The processing of the time domain sequence to generate one or more PRACH OTFDM symbols comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate conversion to match DAC rate and frequency shifting on the time domain waveform, to generate one or more PRACH OTFDM symbols.

[00272] The PRACH sequence is one of $\pi/2$ BPSK sequence and Zadoff-Chu (ZC) sequence. The PRACH sequence includes one of CP, CS or both CP and CS. The one or more PRACH OTFDM symbols may be transmitted on one or more antenna ports. The PRACH sequence can also be termed as Random-Access/PRACH preamble.

[00273] One embodiment of the present disclosure is PRACH in one symbol. A single symbol PRACH is one of a $\pi/2$ BPSK and ZC base sequence. The sequence is applied to the DFT, excess subcarriers are added to the DFT output followed by the spectrum shaping filter, IFFT and followed by processing. A base $\pi/2$ BPSK or ZC is determined by the cell ID, and user specific circular shifts are applied on the base sequence to determine the sequence.

[00274] In another embodiment, each PRACH sequence may be appended with in of its own CP, CS or both CP and CS. Appending of one of this makes the PRACH sequence

circular. This circular sequence is applied to the DFT, excess subcarriers are added to the DFT output followed by the spectrum shaping filter, IFFT and followed by processing. A base $\pi/2$ BPSK or ZC is determined by the cell ID, and user specific circular shifts are applied on the base sequence to determine the sequence.

[00275] In an embodiment the PRACH symbols may be repeated over multiple OFDM symbols. The CP may be added for each symbol or one CP for the first symbol and rest of the symbols have no CP. The one symbol PRACH may be repeated over multiple symbols as shown in Figure 6A. The Figure 6A shows an illustration contiguous repetition of symbols in of UL PRACH transmitter.

[00276] The random-access preamble transmission is based on OTFDM waveform, where the PRACH preamble is DFT precoded followed with bandwidth extension and spectrum shaping. When the UE transmits the preamble to the gNB, it conveys the selected SS/PBCH block index to the gNB, so that subsequent transmissions from the gNB to that UE use the same beam corresponding to the selected SS/PBCH block. This is conveyed by the preamble index and the PRACH occasion used to transmit the preamble.

[00277] After the gNB successfully detects the preamble sent by the UE, it sends a random-access preamble identifier (RAPID) along with a random-access response (RAR). The UE then checks if the received RAPID matches the sequence it had selected as its preamble. If they match, it means that the random-access response has been received successfully. The RAR, which follows the RAPID, contains various important details for the UE, including timing advance, uplink scheduling grant, and UE identity.

[00278] Figure 15A shows a block diagram of a PRACH receiver. Each received PRACH-OTFDM symbol is applied with CP removal, FFT, subcarrier de-mapping, and correlation. Depending on the correlation output, the gNB receiver detects the transmitted preamble. The preamble detection involves determining the presence of a preamble index in a PRACH Occasion and estimating the round-trip delay of the detected preamble. When the PRACH-OTFDM symbol is not appended with CP, CP removal may be avoided during receiver processing. The one symbol PRACH may be repeated over multiple symbols as shown in Figure 15B. The Figure 15B shows an illustration of contiguous repetitions PRACH symbols.

[00279] One embodiment of the present disclosure is Msg-2 transmission. On receiving the preamble, the gNB acknowledges the reception of the preamble by sending a random-access response (RAR) on a PDSCH channel. The RAR is scheduled by a downlink control information (DCI) with a CRC scrambled by the random-access radio network temporary identifier (RA-RNTI) on the corresponding PDCCH. The RAR_DCI on PDCCH is transmitted using at least one OTFDM symbols, and the RAR is transmitted on PDSCH using at least one OTFDM symbols, either refer PDSCH/CCH to PDCCH and PDSCH transmission for SIB.

[00280] Referring back to Figure 5A, the transmitter of Figure 5A performs transmission of at least one of PDCCH and PDSCH OTFDM symbols. The time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C and a portion of at least one of the RS, the control data sequence, the user data sequence to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figures 6A, 6B, 6E, 6F, 7A, 7B, 8A, 8B, 8C, 8D, 8E are the multiplexed sequences obtained using time multiplexer 502, said symbols are circular.

[00281] The OTFDM symbol generating unit 104, which is as shown in Figure 1B, generates an output 512 called as OTFDM symbol using the multiplexed sequences. As the multiplexed sequence is obtained using the control data sequence (mapped on to PDCCH) 510B, the user data sequence (mapped on to PDSCH) 510C and the RS, the generated symbol is referred as PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol or PDCCH-PDSCH OTFDM symbol. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1D to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00282] In another embodiment, the time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C to generate a multiplexed sequence. The symbol structures as shown in the Figures 5B, 6C, 6D, 6G, 6H, 7C, 7D, 7E, 7F are the multiplexed sequences used in this embodiment. The multiplexed sequence is fed to the OTFDM

symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1C to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00283] Figures 6A-6H shows various symbol structures with at least one a PDCCH data, PDSCH data and optional PTRS and RS, in accordance with an embodiment of the present disclosure. Figures 7A-7D shows various symbol structure with PDCCH plus PDSCH data and optional PTRS, in accordance with an embodiment of the present disclosure. Figures 8A-8C shows various symbol structure of RS, PDCCH, PDSCH channel data, in accordance with some embodiments of the present disclosure. Also, Figure 10 shows an illustration of generation of DL OTFDM symbols. Figure 11 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a slot with their associated beam, where a slot has N symbols. Figure 12 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a frame with their associated beam, where a slot consisting of 1 OTFDM symbol.

[00284] The method comprising time-multiplexing, by the transmitter, a physical downlink control channel (PDCCH) sequence, a physical downlink shared channel (PDSCH) sequence and a reference sequence (RS) to generate a multiplexed sequence. The method also comprises processing the time multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol.

[00285] The method of processing the multiplexed sequence to generate a PDCCH-PDSCH OTFDM symbol comprising transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. Also, the method comprises performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. Further the method comprises, mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence, which is shaped using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence. Furthermore, the method

comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The time domain sequence is processed to generate the PDCCH-PDSCH OTFDM symbol.

[00286] The processing the time domain sequence to generate a OTFDM symbol comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, phase compensation for each symbol by multiplying with a symbol specific exponential value, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate up-conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the PDCCH-PDSCH OTFDM symbol.

[00287] The duration of the PDCCH sequence and the PDSCH sequences is unequal. The PDCCH carries a common control information and a user specific control information. The PDSCH carries a user specific data. The RS is used to demodulate the PDCCH and PDSCH by one or more receiving users or user equipment's (UEs).

[00288] One embodiment of the present disclosure is a method for transmitting a PDSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol. The method, performed by a transmitter 500, comprising time-multiplexing a physical downlink shared channel (PDSCH) sequence and a reference sequence (RS) to generate a multiplexed sequence and processing the multiplexed sequence to generate a PDSCH OTFDM symbol. The PDSCH carries a user specific data. The RS is used to demodulate the PDSCH by one or more receiving users or user equipment's (UEs).

[00289] In another embodiment, a method for transmitting a PDCCH Orthogonal time frequency-division multiplexing (OTFDM) symbol is provided. The method, performed by a transmitter 500, comprises time-multiplexing a physical downlink control channel (PDCCH) sequence and a reference sequence (RS) to generate a multiplexed sequence. Also, the method comprises processing the multiplexed sequence to generate a PDCCH OTFDM symbol. The PDCCH carries a common control information and a user specific control information. The RS is used to demodulate the PDCCH by one or more receiving users or user equipment's (UEs).

[00290] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprising time-multiplexing, by the transmitter 500, a PDCCH-PDSCH OTFDM symbol and a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users or user equipment's (UEs). The one or more receiving users decode the control information and the data information using the received PDCCH-PDSCH slot.

[00291] One embodiment of the present disclosure is a method for transmitting a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The method comprising time-multiplexing, by the transmitter, a PDCCH OTFDM symbol, a plurality of PDSCH OTFDM symbols to generate a PDCCH-PDSCH Orthogonal time frequency-division multiplexing (OTFDM) slot. The PDCCH-PDSCH slot comprises a control information and a data information intended for one or more receiving users. The one or more receiving UEs or user equipment's (UEs) decode the control information and the data information using the received PDCCH-PDSCH slot.

[00292] One embodiment of the present disclosure is Msg-3. A UE transmits Msg-3 on a PUSCH in response to the uplink grant of the RAR. The contents of Msg3 depends upon the reason for RACH trigger. During initial access, the Msg3 contains RRC setup request (RRCSetupRequest). During Radio Resource Control (RRC) re-establishment, Msg3 contains RRC re-establishment request (RRCReestablishmentRequest). A transition from the RRS inactive state (RRC_INACTIVE) to the RRC connected state (RRC_CONNECTED), the Msg3 contains RRS resume request (RRCResumeRequest) or RRC resume request (RRCResumeRequest1).

[00293] Figure 16A shows a block diagram of an Orthogonal time frequency-division multiplexing (OTFDM) communication system, in accordance with an embodiment of the present disclosure. The OTFDM communication system is referred to as a OTFDM transmitter or a transmitter or an uplink transmitter.

[00294] As shown in the Figure 16A, the transmitter 1600 comprises a time multiplexing unit 1602 and an OTFDM symbol generating unit, also referred to as an Msg3-PUSCH OTFDM symbol generating unit 1604. The time multiplexing unit 1602 is also referred as

a time multiplexer or multiplexer or time division multiplexer or TDM. Also, the transmitter 1600 comprises a plurality of antennas which is referred to as one or more antennas. The one or more transmitters is one of spatially multiplexed transmitters and uplink users. The OTFDM symbol generating unit 104 is also referred as Msg3-PUSCH OTFDM symbol generator or symbol generator.

[00295] In an embodiment, the time multiplexer 1602 multiplexes at least one of a Physical Uplink Shared Channel (PUSCH) data sequence 1610B, and a PUSCH-RS sequence 1610C to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figures 17A-17M are the multiplexed sequences obtained using time multiplexer 1602.

[00296] The OTFDM symbol generating unit 1604 generates one or more Msg3-PUSCH OTFDM symbols using the multiplexed sequences. In an embodiment, as the multiplexed sequence is obtained using the at least one of the PUSCH data sequence and the PUSCH-RS sequence, the generated symbol is referred as uplink multiplexed Orthogonal time frequency-division multiplexing (OTFDM) symbol or multiplexed OTFDM symbol or uplink multiplexed OTFDM symbol or Msg3-PUSCH OTFDM symbol.

[00297] In an embodiment, the multiplexed sequence is fed to the OTFDM symbol generating unit 104, to generate one or more Msg3-PUSCH OTFDM symbols specific to a particular antenna. The symbols generated are transmitted by the corresponding antennas.

[00298] Figure 16B shows a block diagram of an OTFDM symbol generating unit, in accordance with an embodiment of the present disclosure. As shown in the figure 16B, the Msg3-PUSCH symbol generating unit 1604 comprises a Discrete Fourier Transform (DFT) unit 1622, an excess BW addition unit 1624, a spectrum shaping unit 1626, a sub-carrier mapping unit 1628, an inverse Fast Fourier transform (FFT) unit 1630 and a processing unit 1632.

[00299] The DFT unit 1622 transforms an input 1620 i.e. multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. The excess BW addition unit 1624 performs padding operation on the transformed multiplexed sequence i.e. prefixing the transformed multiplexed sequence with a first predefined

number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero. The values of N1 and N2 may be same or different. The value of N1 and N2 may depend on the excess power that is sent by the transmitter.

[00300] The spectrum shaping unit 1626 performs shaping of the extended bandwidth transformed multiplexed sequence to obtain a shaped extended bandwidth transformed multiplexed sequence or shaped sequence. The filter used for the shaping operation on the extended bandwidth transformed multiplexed sequence is one of a Nyquist filter, square root raised cosine filter, a raised cosine filter, a hamming filter, a Hanning filter, a Kaiser filter, an oversampled GMSK filter and any filter that satisfies predefined spectrum characteristics.

[00301] The sub carrier mapping unit 1628, also referred as a mapper or a sub carrier mapper or a mapping unit, performs subcarrier mapping on the shaped extended bandwidth transformed multiplexed sequence or shaped sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. In an embodiment, the distributed subcarrier mapping includes insertion of zeros in to the extended bandwidth transformed multiplexed sequence.

[00302] The IFFT unit 1630 performs inverse IFFT on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The time domain sequence is processed by the processing unit 132 to generate an output 134, i.e. one or more Msg3-PUSCH OTFDM symbols also referred as one or more Msg3-PUSCH OTFDM symbols.

[00303] Figure 16C shows a block diagram of a processing unit of the Msg3-PUSCH OTFDM symbol generating unit 1604 as shown in Figure 16B, in accordance with an exemplary embodiment of the present disclosure. As shown in Figure 16C, the processing unit 1632 comprises a cyclic prefix (CP) addition unit 1642, an up-sampling unit 1644, a weighted with overlap and add operation (WOLA) unit 1646, a bandwidth parts (BWP) specific rotation unit 1648, a RF up-conversion unit 1650, and a digital to analog converter (DAC).

[00304] The processing unit 1632 processes the time domain sequence to generate an Msg3-PUSCH OTFDM symbol. The time domain sequence is generated by the IFFT unit 1630 of the Msg3-PUSCH OTFDM symbol generating unit. The input 1640 to this processing unit is the time domain sequence. The processing comprises performing at least one of a symbol specific phase compensation, an addition of symbol cyclic prefix using the CP addition unit 1642, up sampling using the up-sampling unit 1644, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit 1646, bandwidth parts (BWP) rotation using BWP specific rotation unit 1648, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit 1650 and converting the same into analog using the DAC 1652 to generate the output 1654, which is one or more Msg3-PUSCH OTFDM symbols, in an embodiment. In an embodiment, the generated output is referred as UL multiplexed Msg3-PUSCH OTFDM symbol. The output i.e. one or more Msg3-PUSCH OTFDM symbols or OTFDM symbols offers low peak to average ratio (PAPR).

[00305] The Msg3-PUSCH Data sequence and RS are sequence of samples. The position of RS may be in the centre or starting or ending of the OTFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix will be added to the RS in the time domain. The sequence to be used as RS is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes. The frequency spectrum of RS should be as flat as possible to ensure reliance channel estimation. RS and RS-CP or RS-CS may occupy a portion of resources allocated to the transmitter, which may depend on properties of channel conditions, Excess bandwidth, transmitter allocation size, modulation order, coding rate, and other parameters like impulse response of spectrum shaping filter. The RS sequence generation may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. Specifically, the base RS sequence will be a function of symbol index, resulting in different base sequences across the different Msg3-PUSCH OTFDM symbols.

[00306] One embodiment of the present disclosure is multi user Msg3-PUSCH transmission. Here, users are separated by allowing transmissions of user specific spectrum shaped data on distinct frequency resources.

[00307] In an embodiment, the user specific data is processed in a similar way to the conventional 5G system before multiplexing data and RS, which involves code block segmentation (only when needed), the addition of CRC bits, channel coding, rate matching and code block concatenation, scrambling.

[00308] The scrambling sequence used for randomization is based on the C-RNTI (Cell Radio Network Temporary Identifier) along with the physical-layer cell identity or a configurable virtual cell identity. This ensures that interference is randomized across cells and user equipment (UEs) that are utilizing the same set of time-frequency resources. The modulated QPSK symbols are then mapped to subcarriers across multiple resource blocks, using one or two OFDM symbols. In each OFDM symbol, a pseudo-random $\pi/2$ -BPSK or QPSK sequence is mapped along with the control data, serving as a demodulation reference signal to facilitate coherent reception at the base station.

[00309] One embodiment of the present disclosure is a method for transmitting one or more Msg3-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) symbols or one or more OTFDM symbols. The order in which the method steps is described is not intended to be construed as a limitation, and any number of the described method steps can be combined in any order to implement the method. Additionally, individual method steps may be deleted from the methods without departing from the scope of the subject matter described herein. Furthermore, the method can be implemented in any suitable hardware, software, firmware, or combination thereof.

[00310] In an embodiment, the PUSCH sequence includes a PUSCH data sequence and Phase Tracking Reference signal (PT-RS). In an embodiment, the RS is at least one of a DMRS, a PT-RS.

[00311] The method also comprises performing cyclic shifting operation on the at least one RS, wherein the cyclic shifted RS is appended with at least one of a cyclic shifted RS pre-fix and a cyclic shifted RS post-fix. The RS is at least one of a DMRS, a PT-RS.

[00312] In an embodiment of the present disclosure, a method for transmitting a Msg3-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) slot is provided. The method comprises time-multiplexing, by one or more transmitters, at least one of one or more PUSCH OTFDM symbols to generate an Orthogonal time frequency-division multiplexing (OTFDM) slot.

[00313] One embodiment of the present disclosure is Msg-4. A gNB transmits a contention resolutions message to the UE either on the PDCCH or the PDSCH depending upon of the type of c-RNTI Mac CE, that UE used in Msg-3.

[00314] If Msg3 contained the C-RNTI MAC CE, the gNB transmits a PDCCH with CRC scrambled by the C-RNTI. Upon reception of this PDCCH, the UE stops ra-ContentionResolutionTimer and considers the RACH procedure successful. If Msg3 contained the CCCH SDU, the gNB transmits a PDCCH scheduling a PDSCH with CRC scrambled by the TC-RNTI, indicated to the UE in the RAR. The corresponding PDSCH echoes back the contention resolution identity received in Msg3.

[00315] Referring back to the Figures 5A, 6A-6H, 7A-7D, 8A-8C, 10, 11, 12. The generation of PDCCH and PDSCH symbols is performed by the OTFDM transmitter as shown in the Figure 5A. Also, the various symbol structures with at least one a PDCCH data, PDSCH data and optional PTRS and RS is shown in Figures 6A-6H. Further, the Figures 7A-7D shows various symbol structure with PDCCH plus PDSCH data and optional PTRS. Figures 8A-8C shows various symbol structure of RS, PDCCH, PDSCH channel data. Figure 10 shows an illustration of generation of DL OTFDM symbols. Figure 11 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a slot with their associated beam, where a slot has N symbols. Figure 12 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a frame with their associated beam, where a slot consisting of 1 OTFDM symbol.

[00316] One embodiment of the present disclosure is Msg-5. Upon reception of the PDCCH scheduling a PDSCH and with CRC scrambled by the TC-RNTI, the UE decodes the corresponding PDSCH. If the contention resolution identity received in the PDSCH matches that transmitted in Msg3, which considers the RACH procedure successful and sends uplink Hybrid Automatic Repeat Request (HARQ) acknowledgement to the gNB on PUCCH.

[00317] One embodiment of the present disclosure is PF0. Embodiments of the present disclosure relate to a method for transmitting a waveform. The method comprising generating, by a transmitter, an orthogonal time frequency division multiplexing (OTFDM) waveform corresponding to an input bit sequence, wherein said input bit sequence is uniquely mapped to one of the plurality of OTFDM waveforms. Also, the method comprises transmitting, by the transmitter, the OTFDM waveform corresponding to the input bit sequence.

[00318] Another embodiment of the present disclosure is related to a method for transmitting a waveform. The method comprising generating, by plurality of transmitters, an orthogonal time frequency division multiplexing (OTFDM) waveform corresponding to an input bit sequence associated with one of a plurality of transmitters, wherein an input bit sequence of each of the plurality of transmitters is uniquely mapped to one of a plurality of OTFDM waveforms. Also, the method comprises transmitting, by the plurality of transmitters, the OTFDM waveform corresponding to the input bit sequence associated with each of the plurality of transmitters.

[00319] Also, embodiments of the present disclosure relate to a method for receiving a waveform. The method comprising performing, by the receiver, a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence. Also, the method comprises performing de-mapping operation on the transformed sequence using a plurality of sub-carriers to generate a de-mapped sequence. Further, the method comprises performing correlation operation on the de-mapped sequence using a plurality of sequences to obtain a correlation value and comparing the correlation value using a threshold to obtain best matched sequence. Furthermore, the method comprises demodulating the best matched sequence to obtain transmitted bit sequence.

[00320] Another embodiment of the present disclosure is related to a method for receiving a waveform. The method comprising performing, by the receiver, a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence. Also, the method comprises performing de-mapping operation on the transformed sequence using a plurality of sub-carriers to generate a de-mapped sequence. Further, the method comprises filtering and spectrum folding the de-mapped sequence to obtain a filtered, spectrum folded de-mapped sequence. Furthermore, the method comprises performing correlation operation

on the de-mapped sequence using a plurality of sequences to obtain a correlation value, and comparing the correlation value using a threshold to obtain best matched sequence. Thereafter, the method comprises demodulating the best matched sequence to obtain transmitted bit sequence.

[00321] The present disclosure provides a waveform technology that not only addresses this critical issue of reducing PAPR, improving user multiplexing ability through spreading, improving energy efficiency but also achieves one of the major goals of future wireless communication systems i.e., extremely low latency.

[00322] One possible method to meet this requirement of high-power efficiency in transmitting a modulated sequence is to use DFT-S-OFDM with spectrum shaping that helps in reducing the PAPR of the waveform, eventually resulting in better power efficiency. However, this method is proven to be work only for sequences like $\pi/2$ -BPSK and not for other modulation schemes or sequences like ZC, or M-ary PSK.

[00323] The aforementioned issue is circumvented by expanding the bandwidth i.e. by using additional subcarriers, of the DFT precoded sequence followed by shaping the spectrum by a pulse shaping filter such as raised cosine or square-root-raised-cosine pulse or filters that follows Nyquist criterion for zero ISI (when the receiver has no timing error). This method is referred to as “Orthogonal Time Frequency Division Multiplexing (OTFDM) / Pre DFT sequence modulated DFT-S-OFDM with excess bandwidth shaping”. The design parameters include, but not limited to length of sequence, the excess BW and the DFT size can be selected carefully to minimize the PAPR.

[00324] One embodiment of the present disclosure is a transmitter. The transmitter is configured to transmit either a one or more bits of control/user data, referred as input bit sequence, the input bit sequence is mapped to one of the sequences from a plurality of L-length sequences. The input bit sequence is one of Acknowledgement (ACK), Negative-Acknowledgement (NACK), and Scheduling Request (SR). The length of the sequence, L is multiple of 6 i.e., 6, 12, 18, 24, and so on. The value L can be any arbitrary natural number. The plurality of sequences is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence. If the sequence is $\pi/2$ -BPSK sequences, phase continuity across the modulated symbols is maintained for

better PAPR. The mapped sequence can be represented by $x'(n)$, where $n = 0, 1, \dots, L - 1$. L is length of the sequence, which can be a multiple of 6. The mapped sequence is fed to OTFDM waveform generating unit to generate OTFDM waveform.

[00325] One embodiment of the present disclosure is to generate waveform using a OTFDM transmitter based on an input bit sequence and transmit the generated waveform to a receiver.

[00326] The transmitter comprises a mapping unit/ sequence selection unit, an OTFDM symbol generating unit and one or more antennas for transmitting the generated OTFDM waveform. The OTFDM symbol generating unit is also referred as OTFDM symbol generator or symbol generator.

[00327] The mapping/ sequence selection unit performs mapping of the input bit sequence to one of a L -length sequence from a plurality of L -length sequences. The input bit sequence comprises one or more bits. The input bit sequence is at least one of ACK, NACK and SR. The output of the sequence selection unit is referred to as mapped sequence or mapped L -length sequence or L -length sequence. In an embodiment, the L -length sequence is a complex sequence. Each of the plurality of L -length sequences is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M -ary Phase Shift Keying (PSK) sequence. The value of L is one of 6, 12, 24, 36, 48 or any other value. In an embodiment, the L -length sequence is selected based on at least one of a scrambling ID, symbol ID, slot number, and cell ID.

[00328] The OTFDM symbol generating unit generates an output called as OTFDM waveform, also referred as an OTFDM symbol, using the mapped L -length sequence. In an embodiment, when the transmitter comprises one or more antennas, the L -length sequence is fed to the OTFDM generating unit, to generate a OTFDM waveform or symbol specific to a particular antenna port or beam. The waveform generated is transmitted by one of a specific antenna port from the one or more antenna ports.

[00329] Referring back to Figure 1B, the OTFDM symbol generating unit comprises DFT unit, an excess BW addition unit, a sub-carrier mapping unit, a spectrum shaping unit, an inverse Fast Fourier transform (IFFT) unit, optional a cyclic prefix (CP) addition unit and a processing unit. The output of OTFDM symbol generating unit is an OTFDM symbol.

[00330] The DFT unit transforms an input L-length sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence. The excess BW addition unit performs padding operation on the transformed multiplexed sequence i.e. prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero. The values of N1 and N2 may be same or different. The value of N1 and N2 may depend on the excess power that is sent by the transmitter. The value of N1 and N2 depends on one of channel conditions, modulation order, coding rate, impulse response of spectrum shaping filter.

[00331] The sub carrier mapping unit performs subcarrier mapping on the extended bandwidth transformed sequence with at least one of localized and distributed subcarriers to generate a subcarrier mapped sequence or subcarrier mapped extended bandwidth transformed sequence. In an embodiment, the distributed subcarrier mapping includes insertion of zeros in to the subcarrier mapped sequence. In an embodiment, the location of the subcarriers that are mapped to available subcarriers is specific to the transmitter or antenna port or beam or user.

[00332] In an embodiment, a length of the excess subcarriers added to the transformed sequence is explicitly indicated by one of a transmitter to a receiver and a receiver to a transmitter. The explicit indication is one of a function of allocation to the receiver and a plurality of predefined values at the transmitter. In an embodiment, length of the excess subcarriers added to the transformed sequence is explicitly indicated by a transmitter to a receiver, wherein said explicit indication is one of a function of number of subcarrier allocation and a plurality of predefined values at the transmitter and power capability of the transmitter.

[00333] The spectrum shaping unit performs shaping of the subcarrier mapped sequence to obtain a shaped subcarrier mapped sequence or shaped sequence. The IFFT unit performs inverse IFFT on the shaped subcarrier mapped sequence to produce a time domain sequence. In an embodiment, the CP addition unit performs an addition of symbol cyclic prefix on the time domain sequence to generate time domain sequence with CP, which is processed by the processing unit to generate an output i.e. an OTFDM waveform or symbol.

[00334] The processing unit processes the time domain sequence with CP to generate an OTFDM waveform or OTFDM symbol. The processing comprises performing at least one of a symbol specific phase compensation, up sampling using the up-sampling unit, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit, bandwidth parts (BWP) rotation using BWP specific rotation unit, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit and converting the same into analog using the DAC, to generate the output OTFDM symbol or OTFDM waveform. The generated OTFDM waveform offers low PAPR. In an embodiment, the OTFDM waveform or symbol is generated by performing spreading operation on the input bit sequence, the spreading helps in reducing the other user interface, increases user multiplexing ability, increases SINR and offers low PAPR. The spectrum shaping of excess BW reduces the PAPR and increases the overall transmission power.

[00335] In an embodiment, the OTFDM waveform generating unit comprises the following operations:

[00336] A DFT precoding is applied on the mapped sequence $x'(n)$ using a DFT of size L to obtain a precoded sequence $X(k)$.

$$a. X(k) = \frac{1}{\sqrt{M}} \sum_{n=0}^{L-1} x'(n) e^{-\frac{j2\pi kn}{L}}$$

[00337] Spectrum extension: The precoded sequence $X(k)$ is equipped with the excess bandwidth, where the initial $d/2$ and trailing $d/2$ samples of the precoded sequence $X(k)$ are copied to the end and start of $X(k)$ respectively as prefix and postfix. Here d is the spectrum extension factor. This results in an OTFDM symbol of size $L+d$, which can be represented as,

$$b. X_{\text{exs}}(k) = X\left(\left(k - \frac{d}{2}\right) \bmod L\right)$$

i. Or

$$c. X_{\text{exs}}(k) = X((k - k') \bmod L)$$

[00338] Where, $k=0, 1, \dots, L+d-1$. In an embodiment, the excess bandwidth (or excess subcarriers) used may be arbitrarily high and may be more than L subcarriers. k' is an arbitrary value which may configure spectrum extension. For example, if k' is $d/2$, where d is the extension factor, the spectrum extension is performed on both the ends of the

precoded sequence, if k' is zero, the extension is only to the right side of the precoded sequence. Similarly, when k' is $-L$, the extension is completely on the left side to the precoded sequence.

[00339] The additional bandwidth that needs to be used for spectrum extension is indicated to a user equipment (UE) by a base station (BS). The BS, also referred as gNB, may indicate either extension on one side of the allocated bandwidth or two sides of the allocated bandwidth in steps of half PRB or one PRB or arbitrary number of subcarriers. The signaling of the excess bandwidth may be done as a part of resource allocation. The bandwidth extension on either side of the allocated bandwidth may be almost equal such that the spectrum shaping filter can be symmetric. The spectrum extension may be asymmetric also, which means, the additional bandwidth on each side of the allocated bandwidth may be of different sizes including the case where excess BW is added on only one side

[00340] Alternately the BS or the gNB may indicate the user with 2 parameters i.e. usable BW where data is allocated and excess BW where shaping is allowed. A scheduler in the BS may take care of these 2 parameters per UE as part of the entire scheduling operations. The excess BW when symmetric can be assumed to have equal guard subcarriers on either side of the allocated spectrum. However, for asymmetric cases, an additional parameter which indicates the start location of the usable BW can be indicated between UE and gNB. The spectrum extension factor depends on channel properties, allocation size, modulation order, L-length sequence type. Pi/2-BPSK modulated sequence is a special case, where spectrum extension may not be needed.

[00341] Spectrum shaping: The spectrum shaping is performed on the spectrum extended sequence by multiplying it with the frequency response of spectrum shaping filter. The spectrum shaped data can be represented as:

$$d. X_{ss}(k) = W(k) X_{exs}(k)$$

[00342] The filter $W(k)$ can be frequency response of square root raise cosine, raised cosine, Hanning, Blackman or Hamming windows, or the filter can be an oversampled Linearized Gaussian Minimal Shifting Keying (LGMSK) pulse. Otherwise, filter $W(k)$ can be the square root of the frequency response of the above-mentioned filters. The frequency response of some of the spectrum shaping filters are shown in Figures 3, 4, 5, and square root of the frequency response of these filters are shown in Figures 6, 7, 8. The spectrum

shaping filter either be specified by the base station or can be unknown at the base station. The spectrum shaping filter may be RAN1 specified or specification transparent.

[00343] When spectrum extension factor 'd' is zero, no spectrum extension is performed, for example, sequences like $\pi/2$ -BPSK. In this case, spectrum shaping can be performed either in time-domain by circular convolving the data-RS multiplexed symbol with impulse response of the spectrum shaping filter or in frequency domain, where the DFT-pre-coded symbol is simply multiplied with the frequency response of the spectrum shaping filter. The spectrum shaping help in reduction of PAPR.

[00344] Spectrum shaped data is mapped on to the subcarriers allocated to the user, followed by an IFFT of size N to generate a time domain symbol. The time domain symbol is appended with Cyclic Prefix (CP), and sent to the processing unit to obtain an OTFDM symbol.

[00345] In the processing unit, the generated OTFDM symbol after CP insertion may be processed with at least one of Bandwidth Part (BWP) specific phase rotation, Weighted overlap and add (WOLA), Up-conversion, Digital to analog conversion (DAC) to obtain the OTFDM waveform. Figure 1C shows the block diagram for the processing unit.

[00346] In another embodiment of the present disclosure, the transmitter is configured to generating and transmitting a plurality of waveforms. The transmitter comprises mapping unit/ sequence selection unit, an OTFDM symbol generating unit, and a plurality of antennas for transmitting the generated OTFDM waveforms. The transmitter generates an orthogonal time frequency division multiplexing (OTFDM) waveform corresponding to an input bit sequence associated with one of a plurality of transmitters. The input bit sequence of each of the plurality of transmitters is uniquely mapped to one of a plurality of OTFDM waveforms. Thereafter, the OTFDM waveform corresponding to the input bit sequence is transmitted using the associated antenna.

[00347] In an embodiment a sequence mapping for an input bit sequence is performed for the generation of OTFDM waveform. The input sequence corresponding to control/user data is mapped to a sequence from a plurality of sequences. The mapped sequence is sent for OTFDM waveform generation.

[00348] The input bit sequence is mapped one of the plurality of sequences (Sequence-1, Sequence-2, Sequence-3, ..., Sequence-N). Each of the sequences is of L-length. The value of L is one of 6, 12, 24, 36, 48 or any other value. The L-length sequence is selected based on at least one of a scrambling ID, symbol ID, slot number, and cell ID. The following tables i.e., Table-1, Table-2 and Table-3 shows an illustration of the input bit sequence (ACK, NACK and SR). In an embodiment 1-bit control transmits two OTFDM waveforms each representing either a 0 or 1.

ACK	NACK	SR	Sequence
0	0	0	Sequence-1
0	1	0	Sequence-2
1	0	0	Sequence-3
1	1	0	Sequence-4
0	0	1	Sequence-5
0	1	1	Sequence-6
1	0	1	Sequence-7
1	1	1	Sequence-8

Table-1

ACK	SR	Sequence
0	0	Sequence-1
0	1	Sequence-2
1	0	Sequence-3
1	1	Sequence-4

Table-2

ACK	NACK	Sequence
0	0	Sequence-1
0	1	Sequence-2
1	0	Sequence-3
1	1	Sequence-4

Table-3

[00349] Each of the input bit sequence is mapped to a L-length sequence, using which the OTFDM waveform generating unit generates a corresponding OTFDM waveform. This generation of the OTFDM waveform is performed by mapping the input bit sequence to one of a L-length sequence from a plurality of L-length sequences and generating an OTFDM waveform using the mapped L-length sequence. This is performed for each of the plurality of input bit sequences.

[00350] In an embodiment, the plurality of transmitters is frequency multiplexed, wherein each of the plurality of transmitters occupy orthogonal frequency subcarriers in the same OTFDM waveform. Also, the plurality of transmitters is time multiplexed, wherein each of the plurality of transmitters occupy distinct OTFDM waveforms. In an embodiment, the plurality of transmitters is associated with orthogonal sequences or spreading codes in the same time frequency resources. The plurality of transmitters belongs to a same cell or different cells. Further, the plurality of transmitters belongs to a same different antenna's ports in an embodiment.

[00351] The L-length sequence of each transmitter is obtained from the same base sequence or different base sequence. In an embodiment, the L-length sequence of each transmitter is applied with one or more transmitter specific orthogonal cover codes. Each of the one or more transmitter specific code covers are orthogonal to each other. Each of the one or more transmitter specific code covers is one of a binary phase shift keying (BPSK) sequence, a Walsh Hadamard sequence, PN sequences, a DFT sequence, and a phase ramp sequence. The plurality of L-length sequences has low cross correlation.

[00352] Another embodiment of the present disclosure is generation of OTFDM waveforms for multiple transmitters at a given time instance. Input bit sequence of each transmitter is passed through sequence selection unit to obtain transmitter specific L-length mapped sequence. The transmitter specific L-length sequences may be obtained from the same or different base sequence. The transmitter specific L-length sequence may be a function of at least one of scrambling ID, symbol ID, slot number, and cell ID.

[00353] The transmitter specific L-length sequences of all the transmitters can be mapped to the same set of subcarriers or distinct subcarriers. If sequences are mapped to the same set of subcarriers, then these sequences are orthogonalized by means of exponential code covers. The mapped sequence of each transmitter is sent to OTFDM generation unit to generate transmitter specific OTFDM waveform.

[00354] One embodiment of the present disclosure is a method for transmitting a waveform in a communication network. The method comprises generating an orthogonal time frequency division multiplexing (OTFDM) waveform corresponding to an input bit sequence, wherein said input bit sequence is uniquely mapped to one of the plurality of

OTFDM waveforms. The mapping of the input bit sequence to one of a L-length sequence from a plurality of L-length sequences is performed by the sequence selection unit. The input bit sequence comprises one or more bits. The input bit sequence is at least one of ACK, NACK and SR. The output of the sequence selection unit is referred to as mapped sequence or mapped L-length sequence or L-length sequence. In an embodiment, the L-length sequence is a complex sequence. Each of the plurality of L-length sequences is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence. The value of L is one of 6, 12, 24, 36, 48 or any other value. In an embodiment, the L-length sequence is selected based on at least one of a scrambling ID, symbol ID, slot number, and cell ID.

[00355] An OFTDM waveform is generated using the OTFDM symbol generating unit generates using the mapped L-length sequence. Also, the method comprises transmitting the generated OTFDM waveform corresponding to the input bit sequence using one of the plurality of antennas of the transmitter.

[00356] A method for transmitting a waveform in a communication network comprises generating, by plurality of transmitters, an orthogonal time frequency division multiplexing (OTFDM) waveform corresponding to an input bit sequence associated with one of a plurality of transmitters, wherein an input bit sequence of each of the plurality of transmitters is uniquely mapped to one of a plurality of OTFDM waveforms. Also, the method comprises transmitting the OTFDM waveform corresponding to the input bit sequence associated with each of the plurality of transmitters.

[00357] Embodiments of the present disclosure related to a receiver for receiving an OTFDM waveform. Figure 18A shows a block diagram of a receiver, in accordance with an embodiment of the present disclosure. As shown in the Figure 18A, the receiver 1800 comprises Fast Fourier Transform (FFT) unit 1804, a subcarrier de-mapping unit 1806, a cross correlation unit 1808, and a demodulating unit 1810 to determine the received input waveform. In an embodiment, the received input waveform is an OTFDM waveform.

[00358] The FFT unit 1804 performs a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence. The de-mapping unit 1806 performs de-mapping operation on the transformed sequence using a plurality of sub-carriers to generate

a de-mapped sequence. The cross-correlation unit 1808 performs correlation operation on the de-mapped sequence using a plurality of sequences to obtain a correlation value, and compares the correlation value using a threshold to obtain best matched sequence. The plurality of sequences are real or complex-valued sequences. The demodulating unit 1810 performs demodulating the best matched sequence to obtain transmitted bit sequence.

[00359] In an embodiment, the receiver is configured with a spectrum folding unit (not shown in the figure) to perform a spectrum folding on the de-mapped sequence and obtain spectrum folded de-mapped sequence. The spectrum folded de-mapped sequence is correlated using a plurality of sequences to obtain a correlation value.

[00360] The received signal is first processed with front processing elements like ADC, CP removal and FFT. The allocated sub-carriers are de-mapped in the sub-carrier de-mapper, where L+d allocated sub-carriers are extracted from the FFT output. If spectrum shaping was performed at the transmitter and the spectrum shaping filter (W(k)) is known to the receiver, then extracted “L+d” subcarriers are multiplied with the same filter, i.e., W(k), before further processing. This helps in maximizing the receiver SNR like in matched filtering.

[00361] The spectrum shaping filter used by the transmitter and receiver is the same and is indicated (or pre-determined/ priory agreed) between the transmitter and receiver. One example of such a filter is square root raised cosine pulse which is applied in the frequency domain (in both transmitter and receiver sides).

[00362] From L+d size de-mapped data Y(k), L samples can be obtained in two identical methods. In the first method, L samples are obtained from L+d samples by taking modified IDFT of size L, which can be given by the following expression.

$$\tilde{Y}(k) = \frac{1}{\sqrt{L}} \sum_{k=0}^{L+d-1} Y(k) e^{\frac{j2\pi\left(k-\frac{d}{2}\right)n}{L}}$$

[00363] The second method, which is equivalent to the above expression involves the following steps.

[00364] From the de-mapped data Y(k), central L-subcarriers are collected and labelled as Y₁(k).

[00365] The de-mapped data is left shifted by L-subcarriers to collect central L-subcarriers which is labelled as Y₂(k).

[00366] The de-mapped data is right shifted by L-subcarriers to collect central L-subcarriers which is labelled as $Y_3(k)$.

[00367] Effective received data of size L is obtained by adding all the above collected data. The effective data can be given by

$$[00368] \quad \tilde{Y}(k) = Y_1(k) + Y_2(k) + Y_3(k)$$

[00369] In cases where the excess number of subcarriers is more than L, additional circularly shifted components (2L, 3L etc.) will be included in the above expression.

[00370] The L length sequence obtained from the above procedure is cross correlated with the possible reference sequences (known) at the receiver. The cross-correlation output for each of the reference sequences is compared with a defined threshold. From all the sequences which have got the cross-correlation value more than threshold, one sequence with the highest cross-correlation value is identified. The input bits corresponding to the identified sequence are decoded.

[00371] The cross correlation of the received sequence with possible reference sequences at the receiver may also be performed in time domain by taking an IDFT of size L+d on the matched filter output or may be performed by taking an IDFT of size L on the output of spectrum folding, where, the L subcarriers from L+d can be from the beginning or the last L subcarriers, or the central L subcarriers, or any L subcarriers from L+d subcarriers.

[00372] The receiver architecture for the receiver without any receiver filtering is as shown in Figure 18A, and the figure for the receiver block diagram with receiver filtering is shown in Figure 18B.

[00373] As shown in the Figure 18B, the receiver 1850 comprises Fast Fourier Transform (FFT) unit 1804, a subcarrier de-mapping unit 1806, a matched filter 1852, a spectrum folding unit 1854, a cross correlation unit 1808, and a demodulating unit 1810 to determine the received input waveform. In an embodiment, the received input waveform is an OTFDM waveform.

[00374] The FFT unit 1804 performs a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence. The de-mapping unit 1806 performs de-mapping operation on the transformed sequence using a plurality of sub-carriers to generate

a de-mapped sequence. The matched filter 1852 and the spectrum folding unit 1854 performs filtering and spectrum folding operations on the de-mapped sequence to obtain a filtered, spectrum folded de-mapped sequence.

[00375] The cross-correlation unit 1808 performs correlation operation on the filtered, spectrum folded de-mapped sequence using a plurality of sequences to obtain a correlation value, and compares the correlation value using a threshold to obtain best matched sequence. The demodulating unit 1810 performs demodulating the best matched sequence to obtain transmitted bit sequence.

[00376] If spectrum extension is not performed at the transmitter, the De-mapped sequence of size L is matched with the transmit spectrum shaping filter if it is known at the receiver. The matched filter output is used to correlate with the sequence known at the receiver to detect the transmit sequence to which transmit bits are mapped. Once the transmit sequence is detected at the receiver using correlation, transmit bits can be detected.

[00377] In another embodiment for the receiver, L sub-carriers are selected from the $L+d$ de-mapped sub-carriers to decode the transmitted input sequence. These L sub-carriers will be used for correlation with the sequences generated at the receiver to detect the transmit sequence. The L subcarriers from $L+d$ can be from the beginning or the end or the central L subcarriers, or any L subcarriers from $L+d$ subcarriers. The L subcarriers are correlated with all the possible reference sequence (known) at the receiver. The correlation output for each sequence is compared to a threshold, and the one sequence with the highest correlated value will be identified as the transmitted sequence. The identified transmitted sequence is eventually used for transmit bits' detection.

[00378] In the following embodiments we describe a method of design of spreading sequences that can be mapped to transmit bits.

[00379] In this method a base sequence that is obtained by taking a BPSK sequence that goes through $\pi/2$ constellation rotation. Various cyclic shifts of the base sequence may be used as inputs. The base sequences and the number of cyclic shifts that result in low PAPR and low correlation among the base sequences and zero correlation among the cyclic shifts of a base sequence may be obtained through a computer search. The base sequences are

optimized such that the generated waveforms have optimized or low PAPR. The time domain computer generated BPSK base sequences are illustrated in the below Table 1.

S. No.	Sequence
1	1 -1 -1 -1 -1 1 -1 1 -1 -1 1 1
2	-1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1
3	-1 -1 -1 -1 1 -1 -1 1 1 1 -1 1
4	1 -1 -1 -1 1 -1 1 1 1 -1 -1 1
5	-1 -1 -1 -1 1 1 -1 1 -1 -1 -1 1
6	1 -1 -1 1 -1 -1 -1 1 -1 1 1 -1
7	1 -1 -1 1 1 -1 1 1 1 1 -1 1
8	1 1 -1 -1 -1 1 -1 -1 -1 -1 1 1
9	-1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1
10	-1 1 1 -1 1 -1 1 1 1 1 1 -1
11	-1 1 1 1 -1 1 -1 -1 -1 -1 1 -1
12	1 -1 1 1 -1 -1 1 1 1 1 1 -1
13	-1 -1 -1 -1 1 -1 -1 -1 1 -1 1 1
14	1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1
15	1 -1 -1 1 -1 -1 -1 -1 1 1 -1 1
16	-1 -1 -1 1 -1 -1 1 1 1 -1 1 -1
17	1 -1 -1 1 -1 1 1 1 1 -1 1 1
18	-1 -1 1 -1 -1 -1 -1 1 -1 1 1 1
19	-1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1
20	-1 -1 1 1 -1 1 -1 -1 -1 1 -1 -1
21	1 1 -1 -1 1 1 -1 -1 -1 -1 -1 1
22	1 -1 1 -1 -1 -1 1 1 -1 1 1 1
23	1 1 -1 1 -1 1 1 1 1 1 -1 -1
24	1 1 1 1 1 -1 1 -1 1 1 -1 -1
25	1 -1 -1 -1 1 -1 1 -1 -1 1 1 -1
26	-1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1
27	1 -1 -1 1 -1 1 1 1 -1 -1 1 -1
28	1 -1 -1 1 1 -1 -1 1 -1 1 -1 -1

29	1	-1	-1	1	1	-1	1	-1	-1	-1	1	-1
30	1	-1	1	-1	-1	1	1	1	-1	1	-1	-1

Table-4

[00380] In an embodiment for using 1 or 2-bit UCI (user control information) transmission, UCI is mapped to BPSK or QPSK symbol and the symbol is mapped to a sequence code selected from Table-4. The index of the code may be signalled by the base station as a circular shift of a base $\pi/2$ BPSK sequence or a ZC sequence.

[00381] The sequence may also be allocated from Table-4 and may be signalled by the base station as a circular shift of a base $\pi/2$ BPSK sequence or a ZC sequence.

[00382] The data/control may be spreading using Walsh-Hadamard sequences of a given size or orthogonal DFT sequences.

[00383] In an embodiment, the spectrally extended DFT output sequence may be mapped to more than one symbol. In this case, the spreading sequence applied in each OFDM symbol may be distinct and is a function of at least one of OFDM symbol index and slot index.

[00384] In an embodiment, the transmission includes more than one OFDM symbol and the sequence in each symbol is selected as a function of at least one of OFDM symbol index and slot index.

[00385] A method for receiving a waveform in a communication network, in accordance with some embodiments of the present disclosure. The method comprises performing, by the receiver, a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence. Also, the method comprises performing de-mapping operation, by the receiver, on the transformed sequence using a plurality of sub-carriers to generate a de-mapped sequence. Further, the method comprises performing correlation operation on the de-mapped sequence using a plurality of sequences to obtain a correlation value. Thereafter, comparing the correlation value using a threshold to obtain best matched sequence. Further, the method comprises demodulating the best matched sequence to obtain transmitted bit sequence.

[00386] Another embodiment of the present disclosure is a method for receiving a waveform in a communication network. The method comprising performing, by the receiver, a Fast Fourier Transform (FFT) on a received waveform to obtain a transformed sequence; performing de-mapping operation, by the receiver, on the transformed sequence using a plurality of sub-carriers to generate a de-mapped sequence; filtering and spectrum folding operations are performed on the de-mapped sequence to obtain a filtered, spectrum folded de-mapped sequence; performing correlation operation on the filtered, spectrum folded de-mapped sequence using a plurality of sequences to obtain a correlation value. Thereafter, comparing the correlation value using a threshold to obtain best matched sequence. Further, the method comprises demodulating the best matched sequence to obtain transmitted bit sequence.

[00387] One embodiment of the present disclosure is PF1. Embodiments of the present disclosure relate to a method for transmitting a waveform. The method comprising generating, by a transmitter, at least one of: at least one input data and at least one reference sequence (RS). Also, the method comprises performing spreading operation on the at least one input data with a spread sequence to generate at least one spread data sequence and time-multiplexing the at least one spread data sequence with the at least one RS, to generate a multiplexed sequence. Further, the method comprises generating an OTFDM symbol using the multiplexed sequence.

[00388] Also, embodiments of the present disclosure relate to a method for receiving a waveform. The method comprising performing, by the receiver, a Fast Fourier Transform (FFT) on received time multiplexed waveform to obtain a transformed sequence. Also, the method comprises performing de-mapping operation using a plurality of sub-carriers to generate a de-mapped sequence. Further, the method comprises estimating a channel using the de-mapped sequence based on an estimation method and equalizing the de-mapped sequence using the estimated channel to obtain an equalized sequence. Further, de-spreading the equalized sequence to obtain a de-spread input data/control information.

[00389] The present disclosure provides a waveform technology that not only addresses this critical issue of reducing PAPR, improving user multiplexing ability through spreading, improving energy efficiency but also achieves one of the major goals of future wireless communication systems i.e., extremely low latency.

[00390] Embodiments of the present disclosure provides a waveform which allows data/control information, to be transmitted with low PAPR, high PA efficiency, low latency. Also, spreading operation is used with OTFDM, this is because the spreading operation helps reduce other user/cell interference, increases signal-to-noise-plus-interference-ratio (SINR), increases user multiplexing ability. Low latency is obtained from entire system operation point of view.

[00391] Embodiments of the present disclosure provides a waveform that allows time division multiplexing of data/control and RS within a single OFDM symbol (TDM within a OFDM Symbol) performed by a transmitter. The generated symbol is referred to as orthogonal time frequency division multiplexing (OTFDM) symbol, which is designed for information exchange taking place in one shot transmission. The transmitter comprises a generating unit, a spreading unit, time multiplexing unit and an OTFDM symbol generating unit. The time multiplexing unit is also referred as a time multiplexer or multiplexer or time division multiplexer or TDM.

[00392] The generating unit generates at least one of: at least one input data and at least one reference sequence (RS). The at least one input data is also referred as data sequence or input data. The at least one input data includes at least one of a user data and a control information. The control information is also referred as control or control data or control data sequence. The at least one data sequence is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Quadrature Phase Shift Keying (QPSK) sequence, M-ary Quadrature Amplitude Modulation (QAM) sequence, and an M-ary Phase Shift Keying (PSK) sequence. Each of the at least one data sequence includes at least one data, and at least one of a data cyclic prefix and a data cyclic suffix. The at least one RS is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence.

[00393] In an embodiment, each of the at least one RS sequence includes at least one RS chunk, at least one of a RS cyclic prefix and a RS cyclic suffix, size of the RS cyclic prefix is one of at least half of the RS chunk size and an arbitrary value, size of the RS cyclic suffix is one of at least half of the RS chunk size and an arbitrary value. The arbitrary value is 0 or 1/4th of RS chunk size or any other value which may be pre-defined in specification

or explicitly signalled between transmitter or receiver or implicitly understood based on the size of the RS. When the arbitrary value is zero, the RS CP or RS CS inclusion is disabled.

[00394] The spreading unit receives the at least one input data that is spread using a spread sequence to generate at least one spread data sequence. The technique of spreading may be generalized to transmission of one or more than 1 bit where each bit is mapped to a respective modulation alphabet and is spread using a spreading sequence, in one embodiment. The at least one input data includes one or more modulation alphabets in an embodiment.

[00395] In an embodiment, the input data is spread over multiple spread sequences within the OTFDM symbol and across OTFDM symbols. Each of the multiple spread sequences is one of identical and different. Each of the at least one spread sequence is a shift version sequence of the other at least one spread sequence, and are orthogonal to each other. The spread sequence is determined by at least one of a first index, a second index and an OTFDM symbol number, in an embodiment. The first index is a function of at least one of base station specific index and sector specific index associated with a transmitter. The second index is a circular shift. In an embodiment, the at least one spread data sequence is multiplied with one or more transmitter specific orthogonal code covers to obtain one or more transmitter specific spread data sequence. In an embodiment, the multiple transmitters may refer to different antenna ports or beams of a user's, or antenna ports or beams of different users, or different base stations etc. The input data from multiple transmitters are multiplexed on a plurality of OTFDM symbols. The transmitter specific modulation alphabets may be spread on to a pre-defined spread sequences to obtain the transmitter specific spread data sequences. The spread sequence corresponding to each transmitter may be obtained from the same base sequence or from different sequences. Additionally, each transmitter specific spread sequence may be multiplied with a transmitter specific orthogonal code covers.

[00396] The time multiplexing unit performs time-multiplexing of the at least one spread data sequence with the at least one RS, to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence.

[00397] The OTFDM symbol generating unit generates an output called as OTFDM symbol using the multiplexed sequences. In an embodiment, when the transmitter

comprises a plurality of antennas, the multiplexed sequence is fed to the OTFDM symbol generating unit, to generate a OTFDM symbols specific to a particular antenna port or a beam. The symbol generated is transmitted by one of a specific antenna port or beam from the plurality of antenna ports or beams.

[00398] The OTFDM symbol generating unit comprises a Discrete Fourier Transform (DFT) unit, an excess BW addition unit, a spectrum shaping with excess BW unit, a sub-carrier mapping unit, an inverse Fast Fourier transform (FFT) unit, a cyclic prefix (CP) addition unit and a processing unit. The DFT unit transforms an input i.e. multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence.

[00399] The excess BW addition unit performs padding operation on the transformed multiplexed sequence to obtain an extended bandwidth transformed multiplexed sequence. The spectrum shaping with excess BW unit performs shaping of the extended bandwidth transformed multiplexed sequence to obtain a shaped extended bandwidth transformed multiplexed sequence or shaped sequence. The sub carrier mapping unit performs subcarrier mapping on the shaped extended bandwidth transformed multiplexed sequence or shaped sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. In an embodiment, the distributed subcarrier mapping includes insertion of zeros in to the extended bandwidth transformed multiplexed sequence. In an embodiment, the location of the subcarriers that are mapped to available subcarriers is specific to the transmitter or antenna port or beam or user.

[00400] The IFFT unit performs inverse IFFT on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The CP addition unit performs an addition of symbol cyclic prefix on the time domain sequence to generate time domain sequence with CP, which is processed by the processing unit to generate an OTFDM symbol. The processing unit processes the time domain sequence to generate the output OTFDM symbol or OTFDM waveform. The generated OTFDM symbol offers low PAPR. The OTFDM symbol is generated using spreading operation on the input data, the spreading helps in reducing the other user interface, increases user multiplexing ability, increases SINR and offers low PAPR. The spectrum shaping of excess BW reduces the PAPR and increases the overall transmission power.

[00401] One embodiment of the present disclosure is generation of a single OTFDM symbol, in accordance with an embodiment of the present disclosure. The input is the modulation alphabet which is spread using spread sequence to generate a spread data sequence using a multiplier. The spread sequence is also referred to as spreading sequence or spread code or spreading code. The spread data sequence is also referred to as spread data or spreaded data sequence or spreaded data. The spread data is time multiplexed with reference sequence (RS) using the multiplexing unit to generate multiplexed sequence. Thereafter, the multiplexed sequence is processed using the OTFDM symbol generating unit to generate a single OTFDM symbol.

[00402] One embodiment of the present disclosure is generation of OTFDM symbol for spread control/data transmission. In this method, the input data for symbol generation may be either control information or user data. Also in an embodiment, the data is either related to control messages such as, but not limited to acknowledgement (ACK) or negative acknowledgement (NACK), a channel quality indicator (CQI), Scheduling Request (SR) or transmitter specific information in uplink.

[00403] The generated modulation alphabets may be spread on to a pre-defined spread sequence to obtain the spread data sequence. The spreading operation may involve multiplication of the spread sequence with the modulated alphabets. The spread sequence may be one of a $\pi/2$ -BPSK sequence, QPSK sequence, PSK sequence, and ZC sequence. The sequences may be obtained using one of m-sequences, PN sequences, Kasami, Walsh, and Hadamard codes. The length of the spread sequence used may be a function the allocated subcarriers for the data transmission. The spread sequence may be one of the base sequences, and an orthogonal cover code may be applied on it to obtain the final spread sequence. The modulation alphabets are multiplied with the respective spread sequences to obtain a spread data sequence. Since each alphabet is spread onto a pre-determined sequence, intra and inter cell interference can be randomised. This helps in improving the Signal to Interference and Noise Ratio (SINR). Hence, spreading offers better data decoding. The spread data sequence may be appended with cyclic prefix (CP), or Cyclic Suffix (CS), or both Cyclic Prefix (CP), and Cyclic Suffix (CS).

[00404] Another embodiment of the present disclosure is the generation of one or more OTFDM symbols i.e. multi symbol generation. The generation of multiple OTFDM

symbols is performed using spread data sequence multiplexed with symbol specific RS. The input data for each symbol generation may be same or different, and each symbol carries one modulation alphabet of input data. The input data (modulation alphabet) of each symbol may be spread using a spread sequence. The spread sequence may be same across all the symbols, or the spread sequence may be different across all the symbols. The spread sequence (SS) across symbols may be orthogonal to each other. In an embodiment, orthogonal cover codes may be applied on the spread sequences. Specifically, if the same spread sequence is employed on all the OTFDM symbols, then orthogonal cover codes may establish the orthogonality across the symbols. The input data is multiplied with spread sequence to obtain spread data sequence. The length of the spread sequence used is a function of the number of modulated alphabets within the symbol, and the allocated subcarriers for the input data transmission. The modulation alphabets are multiplied with the respective spread sequences (SS-1, SS-2, ... SS-N) to obtain a spread data sequence. The spread data sequence corresponding to each modulation alphabet may be appended with cyclic prefix (CP), or Cyclic Suffix (CS), or both Cyclic Prefix (CP), and Cyclic Suffix (CS).

[00405] To facilitate the decoding of the spread data sequence, spread data sequence in each symbol is multiplexed with symbol specific RS sequence (RS-1, RS-2, ... RS-N). The multiplexed symbol corresponding to each symbol is fed to corresponding OTFDM symbol generating unit is DFT precoded before processing using a processing unit to obtain symbol specific corresponding OTFDM symbols (OTFDM -1, OTFDM -2, ... OTFDM-N).

[00406] Another embodiment of the present disclosure is generation of OTFDM symbols with multiple input samples. The generation of the OTFDM symbol is performed with the input data samples and spread sequences. In this method, each symbol may have multiple modulated alphabets $d_1, d_2, \dots d_N$. The input data may be either control information or transmitter/user specific data.

[00407] Each modulated alphabet may be spread on to a pre-defined spread sequence to obtain the spread data sequence. Since there is more than one alphabet in one OTFDM symbol, there may be multiple spread sequences, each corresponding to respective modulated alphabet. The spread sequences may be obtained from the same base sequence or from different base sequences. The spreading operation may involve multiplication of the spread sequence with the modulated symbol. The modulation alphabets are multiplied

using corresponding multipliers with the respective spread sequences, and the resultant spread sequences are multiplexed to obtain a lengthy spread data sequence. The length of the spread sequence used is a function of the number of modulated alphabets within the symbol, and the allocated subcarriers for the input data transmission. The spread data sequence corresponding to each modulation alphabet may be appended with cyclic prefix (CP), or Cyclic Suffix (CS), or both Cyclic Prefix (CP), and Cyclic Suffix (CS). In another embodiment, rather than appending the cyclic prefix (CP), or Cyclic Suffix (CS) to each spread data sequence, only one CP, or CS, or both CP and CS corresponding to the lengthy spread data sequence is appended to the lengthy spread data sequence. Since, each alphabet is spread onto a pre-determined sequence, intra and inter cell interference can be randomized. This helps in improving the Signal to Interference and Noise Ratio (SINR), user multiplexing ability. Hence, spreading offers better data decoding.

[00408] To facilitate the decoding of the spread data sequence, the spread data sequence is appended with RS sequence. The position of RS may be in the center or starting or ending of the OTFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix may be added to the RS in the time domain. The Frequency spectrum of RS should be as flat as possible to ensure reliable channel estimation. RS and RS-CP or RS-CS may occupy a portion of resources allocated to the transmitter, which may depend on properties of channel conditions, Excess bandwidth, transmitter allocation size, modulation order, coding rate, and other parameters like impulse response of spectrum shaping filter. Figure 3A shows a symbol with RS in the middle of OTFDM symbol along with pre-fix and post-fix. In an embodiment, the RS-CP and RS-CS may be absent in a symbol or absent in the system.

[00409] In another embodiment, a multiple RS blocks may be used while multiplexing RS with data. Each of the multiple RS blocks is a transmitter specific RS. One possible way is to keep more than one block of RS samples with each block having same number of samples. The RS block occupies any positions in the symbol, like shown the Figures 3B to 3E, which are for 2 blocks and 3 blocks. However, it may be extended to any number of blocks and any other configuration. RS in each block may be the same sequence or different. This kind of each RS block may be referred as long/main/localized/primary RS block, and all the blocks will either have both RS pre-fix and RS-post-fix or RS-post-fix or

RS-pre-fix. Each block will be used for channel estimation and the transmitter data followed by the block will be equalized with the channel that is estimated. This kind of design helps in tracking the high Doppler channel or phase error caused by the crystal oscillator, which may vary within an OTFDM symbol. When RS samples are at the symbol boundaries, they may not need either RS-pre-fix or RS-post-fix. The different main block RS may be adjacent to each other or separated. In an embodiment, the RS-CP and RS-CS may be absent in a symbol or absent in the system.

[00410] In another embodiment, the size of each block is different. Here, size of one block may be larger, while the sizes of all the other blocks may be small or even simply once sample. The main block with larger RS sizes may have RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix. Main RS block will be used for channel estimation, while the smaller blocks may be used for phase tracking with in the OTFDM symbol. The smaller RS blocks may be referred as distributed/secondary/phase tracking RS block also. The smaller block RS samples may be at least one sample obtained from the main RS block or obtained from separately generated sequences.

[00411] In an embodiment, the OTFDM symbol may transmit only RS sequence without data/control multiplexing. This type of OTFDM RS symbol may be used for sensing applications. The RS-CP or RS-CP may be not included with the RS and the CP after IFFT may also be absent.

[00412] In another embodiment, a slot comprises of multiple contiguous OTFDM symbols where the amount of spreaded data/control information and RS is different in each symbol. Some symbols may carry RS only, some symbols may carry spreaded data/control only and some symbol may carry both spreaded data/control and RS.

[00413] In the following embodiments a method of design of spreading sequences that can be used as RS or for the purpose of spreading control or data is provided.

[00414] In this method a base sequence that is obtained by taking a BPSK sequence that goes through $\pi/2$ constellation rotation. Various cyclic shifts of the base sequence may be used as inputs. The base sequences and the number of cyclic shifts that result in low PAPR and low correlation among the base sequences and zero correlation among the cyclic shifts of a base sequence may be obtained through a computer search. The base sequences are

optimized such that the generated waveforms have optimized or low PAPR. The time domain computer generated BPSK base sequences are illustrated in the below Table 1.

S. No.	Sequence
1	1 -1 -1 -1 -1 1 -1 1 -1 -1 1 1
2	-1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1
3	-1 -1 -1 -1 1 -1 -1 1 1 1 -1 1
4	1 -1 -1 -1 1 -1 1 1 1 -1 -1 1
5	-1 -1 -1 -1 1 1 -1 1 -1 -1 -1 1
6	1 -1 -1 1 -1 -1 -1 1 -1 1 1 -1
7	1 -1 -1 1 1 -1 1 1 1 1 -1 1
8	1 1 -1 -1 -1 1 -1 -1 -1 -1 1 1
9	-1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1
10	-1 1 1 -1 1 -1 1 1 1 1 1 -1
11	-1 1 1 1 -1 1 -1 -1 -1 -1 1 -1
12	1 -1 1 1 -1 -1 1 1 1 1 1 -1
13	-1 -1 -1 -1 1 -1 -1 -1 1 -1 1 1
14	1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1
15	1 -1 -1 1 -1 -1 -1 -1 1 1 -1 1
16	-1 -1 -1 1 -1 -1 1 1 1 -1 1 -1
17	1 -1 -1 1 -1 1 1 1 1 -1 1 1
18	-1 -1 1 -1 -1 -1 -1 1 -1 1 1 1
19	-1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1
20	-1 -1 1 1 -1 1 -1 -1 -1 1 -1 -1

21	1	1	-1	-1	1	1	-1	-1	-1	-1	-1	1
22	1	-1	1	-1	-1	-1	1	1	-1	1	1	1
23	1	1	-1	1	-1	1	1	1	1	1	-1	-1
24	1	1	1	1	1	-1	1	-1	1	1	-1	-1
25	1	-1	-1	-1	1	-1	1	-1	-1	1	1	-1
26	-1	-1	-1	1	-1	1	1	-1	-1	-1	-1	1
27	1	-1	-1	1	-1	1	1	1	-1	-1	1	-1
28	1	-1	-1	1	1	-1	-1	1	-1	1	-1	-1
29	1	-1	-1	1	1	-1	1	-1	-1	-1	1	-1
30	1	-1	1	-1	-1	1	1	1	-1	1	-1	-1

Table 1

[00415] In an embodiment for using 1-bit or 2-bits UCI (user control information) transmission, UCI is mapped to BPSK or QPSK symbol and the symbol is spreaded using a spreading code selected from Table-1. The index of the code may be signalled by the base station as a circular shift of a base $\pi/2$ BPSK sequence or a ZC sequence.

[00416] The RS sequence may also be allocated from the Table 1 and may be signalled by the base station as a circular shift of a base $\pi/2$ BPSK sequence or a ZC sequence. The data/control may be spreading using Walsh-Hadamard sequences of a given size or orthogonal DFT sequences.

[00417] The advantages of the OTFDM symbol are that the spectrum shaping of excess BW reduces the PAPR and increases the overall transmission power. Also, multiple RS blocks can be multiplexed to track the channel. In one embodiment, a “long RS block” can be used to the estimate the overall channel impulse response and “short RS blocks” (including single pilot) can be distributed over the span of the symbol to track the phase changes. Alternatively, multiple RS blocks of equal length can be used to estimate the channel locally and equalize the adjacent data blocks.

[00418] One embodiment of the present disclosure is 2-step RA Procedure. The two-step RACH procedure combines the messages sent in each direction into a single message. Multiplexing PRACH and PUSCH.

[00419] In the uplink direction, from the UE to the gNB, MsgA combines the random-access preamble (Msg1), and UL scheduling transmission (Msg3) into a single message.

[00420] Embodiments of the present disclosure provides a new waveform which allows uplink channels PRACH, PUSCH to be transmitted with low PAPR, high PA efficiency, low latency using multiple antenna ports or beams. The embodiments illustrate how low latency is obtained from entire system operation point of view.

[00421] Embodiments of the present disclosure provides a new type of waveform that allows time division multiplexing of data/control and RS within a single OTFDM symbol (TDM within a OTFDM Symbol). The generated symbol is referred to as orthogonal time frequency division multiplexing (OTFDM) symbol, which is designed for information exchange taking place in one shot transmission. The duration of the OTFDM symbol (or subcarrier width) is to meet the overall latency requirement.

[00422] In an uplink (UL) transmission, a communication system or transmitter uses a method of TDM of user data/control/RS and also common channels such as PRACH, PUSCH using OTFDM waveform. However, multiple services and multiple numerologies can be frequency multiplexed using FDM based on the BWP concept that uses WOLA/filtering for frequency multiplexing of these services.

[00423] Referring back to Figure 16A which shows a block diagram of an OTFDM communication system, in accordance with an exemplary embodiment of the present disclosure.

[00424] The transmitter 1600 comprises a time multiplexing unit 1602 and an OTFDM symbol generating unit 1604. Also, the transmitter 1600 comprises a plurality of antennas which is referred to as one or more antennas. The one or more transmitters is one of spatially multiplexed transmitters and uplink users. The time multiplexer unit shown in the Figure is for illustration purpose. The inputs may be any of the uplink sequences.

[00425] In an embodiment, the time multiplexer 1602 multiplexes at least one of a physical random-access channel (PRACH) sequence, a Physical Uplink Shared Channel (PUSCH) sequence, and a RS sequence to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figure 2A-2E are the multiplexed sequences obtained using time multiplexer.

[00426] The OTFDM symbol generating unit generates one or more PRACH-PUSCH OTFDM symbols using the multiplexed sequences. In an embodiment, as the multiplexed sequence is obtained using the at least one of the PRACH sequence, the PUSCH sequence and the RS sequence, the generated symbol is referred as uplink multiplexed Orthogonal time frequency-division multiplexing (OTFDM) symbol or multiplexed OTFDM symbol or uplink multiplexed OTFDM symbol.

[00427] In another embodiment, as the multiplexed sequence is obtained using the at least one of the PRACH sequence, the PUSCH sequence, the generated symbol is referred as uplink multiplexed Orthogonal time frequency-division multiplexing (OTFDM) symbol or multiplexed OTFDM symbol or uplink multiplexed OTFDM symbol.

[00428] In an embodiment, the multiplexed sequence is fed to the OTFDM symbol generating unit, to generate one or more PRACH-PUSCH OTFDM symbols specific to a particular antenna. The symbols generated are transmitted by the corresponding antennas.

[00429] The OTFDM symbol generating unit as shown in the figure 1B, generates OTFDM symbols i.e. one or more PRACH-PUSCH OTFDM symbols also referred as one or more OTFDM symbols, in an embodiment. The generated symbol are one or more PRACH-PUCCH OTFDM symbols when the input is PRACH and PUCCH sequences.

[00430] The processing unit processes the time domain sequence to generate an OTFDM symbol. This is for the time multiplexed sequences generated by the time multiplexed unit of the transmitter is one of the symbol structures as shown in Figures 17N to 17O.

[00431] The time domain sequence is generated by the IFFT unit of the OTFDM symbol generating unit. The input to this processing unit is the time domain sequence. The processing comprises performing at least one of a symbol specific phase compensation, an addition of symbol cyclic prefix using the CP addition unit, up sampling using the up-

sampling unit, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit, bandwidth parts (BWP) rotation using BWP specific rotation unit, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit and converting the same into analog using the DAC to generate the output, which is one or more OTFDM symbols, in an embodiment. In an embodiment, the generated output is referred as UL multiplexed OTFDM symbol. The output i.e. one or more PRACH-PUCCH-PUSCH OTFDM symbols or OTFDM symbols offers low peak to average ratio (PAPR).

[00432] In another embodiment, the time multiplexed sequence generated by the time multiplexer is one of symbol structures shown in Figures 19A-19B which are cyclic or circular, then the processing unit performs at least one of windowing, weighted with overlap and add operation (WOLA) using the WOLA unit, bandwidth parts (BWP) rotation using BWP specific rotation unit, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit and converting the same into analog using the DAC to generate the output i.e. one or more PRACH-PUSCH OTFDM symbols. If the inputs are PRACH, PUCCH and RS then generated output is PRACH-PUCCH OTFDM symbol.

[00433] In an embodiment, the processing unit of the OTFDM symbol generating unit 1604 comprises a weighted with overlap and add operation (WOLA) unit 146, a bandwidth parts (BWP) specific rotation unit 148, a RF up-conversion unit 150, and a digital to analog converter (DAC).

[00434] The processing unit processes the time domain sequence to generate an OTFDM symbol. The time domain sequence is generated by the IFFT unit of the OTFDM symbol generating unit. The time multiplexed sequences generated by the time multiplexed unit of the transmitter is one of the symbol structures as shown in Figures 19A-19B, 20A-20D. The processing comprises performing at least one of a symbol specific phase compensation, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit, bandwidth parts (BWP) rotation using BWP specific rotation unit, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit and converting the same into analog using the DAC to generate the output, which is one of the

PUCCH-PUSCH OTFDM symbol or PRACH-PUCCH-PUSCH OTFDM symbol or PRACH-PUSCH OTFDM symbol, PRACH-PUSCH OTFDM symbol. In an embodiment, the generated output is referred as UL multiplexed OTFDM symbol. The output OTFDM symbols offers low peak to average ratio (PAPR).

[00435] In another embodiment, one OTFDM symbol may carry only PUSCH to generate PUSCH-OTFDM symbol. In another embodiment, one OTFDM symbol may carry only PRACH to generate PRACH-OTFDM symbol. The time unit difference between the PUSCH-OTFDM symbol and PRACH-OTFDM symbol may be at least zero.

[00436] A single symbol PRACH is one of a $\pi/2$ BPSK and ZC base sequence. The sequence is applied to the DFT, excess subcarriers are added to the DFT output followed by the spectrum shaping filter, IFFT and followed by processing. A base $\pi/2$ BPSK or ZC is determined by the cell ID, and user specific circular shifts are applied on the base sequence to determine the sequence.

[00437] The transmitter as shown in Figures 16A which transmits a OTFDM symbol, comprising of at least one of: at least one a data and at least one RS are transmitted in the same OFDM symbol. The at least one RS is referred as the RS. The data and the RS are multiplexed before DFT-precoding in the time domain. Data and RS are sequence of samples. The position of RS may be in the center or starting or ending of the OTFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix will be added to the RS in the time domain. The sequence to be used as RS is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes. The frequency spectrum of RS should be as flat as possible to ensure reliance channel estimation. RS and RS-CP or RS-CS may occupy a portion of resources allocated to the transmitter, which may depend on properties of channel conditions, Excess bandwidth, transmitter allocation size, modulation order, coding rate, and other parameters like impulse response of spectrum shaping filter.

[00438] The PUSCH data is modulated to one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK).

[00439] Figures 17A-17E shows symbol structure of physical random-access channel (PRACH) sequence, physical uplink control channel (PUCCH) sequence, Physical Uplink Shared Channel (PUSCH) sequence, modulated sequence, and control data sequence respectively.

[00440] Figure 17F-17M shows symbol structures comprising at least one of PRACH sequence, PUCCH, PUSCH, CP, PUSCH RS CP, PUSCH RS, PUCCH RS CP, PUCCH RS. Figure 17F shows various symbol structure of PRACH, PUCCH and PUSCH channels.

[00441] Figure 19A shows an illustration of a symbol structure comprising a PRACH, a PUSCH RS CP, a PUSCH CP, PUSCH and a portion of at least one of the PRACH, the PUSCH RS CP, the PUSCH RS and the PUSCH.

[00442] Figure 19B shows an illustration of a symbol structure comprising a PRACH, a PUCCH RS CP, a PUCCH CP, PUCCH and a portion of at least one of the PRACH, the PUCCH RS CP, the PUCCH RS and the PUCCH.

[00443] Figure 20A shows an illustration of an OTFDM symbol comprising a PUSCH RS CP, a PUSCH RS, a PUSCH, a PUCCH, and a portion of at least one of the PUSCH RS CP, the PUSCH RS, the PUSCH and the PUCCH.

[00444] Figure 20B shows an illustration of an OTFDM symbol comprising a PUSCH RS CP, a PUSCH RS, a PUSCH RS CS, a PUSCH, a PUCCH, and a portion of at least one of the PUSCH RS CP, the PUSCH RS, the PUSCH RS CS, the PUSCH and the PUCCH.

[00445] Figure 20C shows an illustration of an OTFDM symbol comprising a PUCCH RS, a PUCCH, a PUSCH RS, a PUSCH, and a portion of at least one of the PUCCH RS, the PUCCH, the PUSCH RS and the PUSCH.

[00446] Figure 20D shows an illustration of an OTFDM symbol comprising a PUCCH RS CP, a PUCCH, a PUSCH RS CP, a PUSCH, and a portion of at least one of the PUCCH RS CP, the PUCCH, the PUSCH RS CP and the PUSCH.

[00447] In an embodiment, the PUSCH sequence includes a PUSCH data sequence and Phase Tracking Reference signal (PT-RS). In an embodiment, the RS is at least one of a DMRS, a PT-RS and an SRS.

[00448] The at least one control sequence is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence and a Quadrature Phase Shift Keying (QPSK) sequence. In an embodiment, the control sequence includes HARQ acknowledgment, scheduling request (SR), and CSI. The control sequence is also referred to as control information or control data sequence.

[00449] The at least one RS is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence. The at least one RS comprise a plurality of samples. The at least one of the plurality of RS samples is multiplexed with the at least one data samples.

[00450] The at least one RS comprises one or more transmitter specific RS associated with each of the one or more transmitters. Each of the one or more transmitter specific RS are orthogonal to each other in at least one of time, frequency, and code, in an embodiment. Each of the one or more transmitter specific is based on at least one of a transmitter specific RS antenna port.

[00451] The at least one RS is multiplied with one or more transmitter specific code covers to obtain one or more transmitter specific RS. Each of the one or more transmitter specific code covers are orthogonal to each other. In an embodiment, each of the one or more transmitter specific code covers is one of a binary phase shift keying (BPSK) sequence, a Walsh Hadamard sequence, PN sequences, a DFT sequence, and a phase ramp sequence.

[00452] Each of the one or more transmitter specific code cover is based on at least one of a transmitter specific RS antenna port, scrambling ID, symbol ID, slot number, and cell ID. The one or more transmitter specific RS is a sequence of samples, said each sample is multiplied with an element of a transmitter specific phase ramp sequence. Each of the one or more transmitter specific RS repetition is transmitter specific cyclic shifted sequence of

the at least one RS's. In an embodiment, the number of one or more transmitter specific RS repetitions is at least zero.

[00453] The method also comprises performing cyclic shifting operation on the at least one RS, wherein the cyclic shifted RS is appended with at least one of a cyclic shifted RS pre-fix and a cyclic shifted RS post-fix. The RS is at least one of a DMRS, a PT-RS and an SRS.

[00454] In an embodiment, the OTFDM slot comprises one or more short PRACH formats. One embodiment of the present disclosure is a method for transmitting one or more PRACH Orthogonal time frequency-division multiplexing (OTFDM) symbols. The method being performed by a transmitter or communication system as shown in Figures 1D and 1E. The communication system comprises a plurality of transmitters or plurality of antennas, also referred to as one or more transmitters, or one or more antennas. The method comprises transforming at least PRACH sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence, followed by padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed sequence.

[00455] Also, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed sequence. Further, the method comprises shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed sequence. Furthermore, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence, and processing the time domain sequence to generate the one or more PRACH OTFDM symbols.

[00456] The processing of the time domain sequence to generate one or more PRACH OTFDM symbols comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate conversion to match DAC rate and frequency shifting on the time domain waveform, to

generate one or more PRACH OTFDM symbols. The PRACH sequence is one of $\pi/2$ BPSK sequence and Zadoff-Chu (ZC) sequence.

[00457] One embodiment of the present disclosure is an uplink (UL) transmitter or communication system. The transmitter comprises a time division multiplexer (TDM) performing time multiplexing within one OFDM Symbol, multiple RS within the symbol, in accordance with an embodiment of the present disclosure. The multiplexing of multiple RS blocks and data blocks in one OFDM symbol is performed. The RS blocks may comprise of one or more long RS blocks and one or more short RS blocks. Long RS blocks facilitate estimation of complete IR and equalization of the neighbour data/control chunks, whereas short RS blocks facilitate phase tracking and compensation within a OFDM symbol. Multiple long RS blocks are used to facilitate equalization of the neighbouring data/control chunks so that channel variations caused by the mobile radio channel within one symbol are compensated.

[00458] Figure 21A shows an illustration of three OTFDM symbols comprising a PRACH OTFDM symbol, 2nd symbol is PUCCH OTFDM symbol and the 3rd symbol is PUSCH OTFDM symbol.

[00459] Figure 21B shows an illustration of two OTFDM symbols comprising a PRACH OTFDM symbol, and the 2nd symbol is PUCCH plus PUSCH OTFDM symbol.

[00460] Figure 21C shows an illustration of two OTFDM symbols comprising a PRACH + PUSCH OTFDM symbol, and the 2nd symbol is PUCCH OTFDM symbol.

[00461] Figure 21D shows an illustration of two OTFDM symbols comprising a PRACH + PUCCH OTFDM symbol, and the 2nd symbol is PUSCH OTFDM symbol.

[00462] In an embodiment, the PRACH-PUSCH OTFDM symbol may be repeated N times, where N is a positive integer. Each repeated PRACH-PUSCH OTFDM symbol may be applied with symbol specific code which may help in improving coverage.

[00463] In another embodiment, the PRACH OTFDM symbol may be repeated N times, where N is a positive integer. Each repeated PRACH OTFDM symbol may be applied with symbol specific code which may help in improving coverage.

[00464] In another embodiment, the PUSCH OTFDM symbol may be repeated N times, where N is a positive integer. Each repeated PUSCH OTFDM symbol may be applied with symbol specific code which may help in improving coverage.

[00465] Similarly, in the downlink direction, MsgB combines the RAR (Msg2) and the Contention Resolution (Msg4) into a single message. “The multiplexing mechanisms to multiplex PDSCH-PDCCH in OTFDM symbol may be done similar to the mechanisms discussed in Msg2 and Msg4 of the current disclosure. Figure 22 shows an illustration of Msg2 and Msg4 between the US and the gNB.

[00466] In an embodiment, for DL data, Once UE is successfully connected to the network, it can receive the downlink data packets. The NR PDSCH is used to deliver Transport Blocks from the gNB to the UE. The PDSCH is configured using RRC signalling, namely the PDSCH-Config parameter. This is included as part of the InitialDownlinkBWP or BWP-DownlinkDedicated parameters. In addition, there are limited PDSCH configuration details included as part of the PDSCH-ConfigCommon parameter of SIB-1.

[00467] In an embodiment, the transmitter as shown Figure 5A performs transmission of at least one of PDCCH and PDSCH OTFDM symbols. The time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C and a portion of at least one of the RS, the control data sequence, the user data sequence to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figures 6A, 6B, 6E, 6F, 7A, 7B, 8A, 8B, 8C, 8D, 8E are the multiplexed sequences obtained using time multiplexer 502, said symbols are circular.

[00468] The OTFDM symbol generating unit 104, which is as shown in Figure 1B, generates an output 512 called as OTFDM symbol using the multiplexed sequences. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1D to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00469] In another embodiment, the time multiplexer 502 multiplexes a reference sequence (RS) 510A, a control data sequence (mapped on to PDCCH) 510B, user data sequence (mapped on to PDSCH) 510C to generate a multiplexed sequence. The symbol structures as shown in the Figures 5B, 6C, 6D, 6G, 6H, 7C, 7D, 7E, 7F are the multiplexed sequences used in this embodiment. The multiplexed sequence is fed to the OTFDM symbol generating unit 104 as shown in Figure 1B and the output 134 is fed to the processing unit of Figure 1C to generate a OTFDM symbol. In an embodiment, the generated OTFDM symbols are specific to a particular antenna. The symbol generated is transmitted by one of a specific antenna from the plurality of antennas.

[00470] Figures 6A-6H shows various symbol structures with at least one a PDCCH data, PDSCH data and optional PTRS and RS, in accordance with an embodiment of the present disclosure. Figures 7A-7D shows various symbol structure with PDCCH plus PDSCH data and optional PTRS, in accordance with an embodiment of the present disclosure. Figures 8A-8C shows various symbol structure of RS, PDCCH, PDSCH channel data, in accordance with some embodiments of the present disclosure. Also, Figure 10 shows an illustration of generation of DL OTFDM symbols. Figure 11 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a slot with their associated beam, where a slot has N symbols. Figure 12 shows allocation of SS block, PDCCH and PDSCH OTFDM symbols in a frame with their associated beam, where a slot consisting of 1 OTFDM symbol.

[00471] One embodiment of the present disclosure is UL data. Once UE is successfully connected to the network, it can transmit the uplink data packets. The NR PUSCH is used to deliver Transport Blocks from the gNB to the UE. The PUSCH is configured using RRC signaling, namely the PUSCH-Config parameter. This is included as part of the InitialUplinkBWP or BWP-DownlinkDedicated parameters. In addition, there are limited PDSCH configuration details included as part of the PDSCH-ConfigCommon parameter of SIB-1.

[00472] Embodiments of the present disclosure provides a new waveform which allows uplink channels PRACH, PUCCH, PUSCH to be transmitted with low PAPR, high PA efficiency, low latency using multiple antenna ports or beams. The embodiments illustrate how low latency is obtained from entire system operation point of view.

[00473] Embodiments of the present disclosure provides a new type of waveform that allows time division multiplexing of data/control and RS within a single OFDM symbol (TDM within a OFDM Symbol). The generated symbol is referred to as orthogonal time frequency division multiplexing (OTFDM) symbol, which is designed for information exchange taking place in one shot transmission. The duration of the OFDM symbol (or subcarrier width) is to meet the overall latency requirement.

[00474] In an uplink (UL) transmission, a communication system or transmitter uses a method of TDM of user data/control/RS and also common channels such as PRACH, PUCCH, and PUSCH using OTFDM waveform. However, multiple services and multiple numerologies can be frequency multiplexed using FDM based on the BWP concept that uses WOLA/filtering for frequency multiplexing of these services.

[00475] Referring back to Figure 16A, the OTFDM communication system is also referred to as a OTFDM transmitter or a transmitter or an uplink transmitter. In an embodiment, the time multiplexer multiplexes at least one of a physical uplink control channel (PUCCH) sequence, a Physical Uplink Shared Channel (PUSCH) sequence, and a RS sequence to generate a multiplexed sequence. The multiplexed sequence is also referred to as time multiplexed sequence or TDM sequence or pre-DFT symbols. The symbols shown in Figure 17I-17M are the multiplexed sequences obtained using time multiplexer.

[00476] The OTFDM symbol generating unit generates one or more PUCCH-PUSCH OTFDM symbols using the multiplexed sequences. In an embodiment, as the multiplexed sequence is obtained using the at least one of the PUCCH sequence, the PUSCH sequence and the RS sequence, the generated symbol is referred as uplink multiplexed Orthogonal time frequency-division multiplexing (OTFDM) symbol or multiplexed OTFDM symbol or uplink multiplexed OTFDM symbol.

[00477] In an embodiment, the multiplexed sequence is fed to the OTFDM symbol generating unit, to generate one or more PUCCH-PUSCH OTFDM symbols specific to a particular antenna. The symbols generated are transmitted by the corresponding antennas.

[00478] The Orthogonal time frequency-division multiplexing (OTFDM) symbol generating unit transforms an input i.e. multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. The excess BW addition unit performs padding operation on the transformed multiplexed sequence i.e. prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero. The values of N1 and N2 may be same or different. The value of N1 and N2 may depend on the excess power that is sent by the transmitter. The spectrum shaping with excess BW unit performs shaping of the extended bandwidth transformed multiplexed sequence to obtain a shaped extended bandwidth transformed multiplexed sequence or shaped sequence. The sub carrier mapping unit performs subcarrier mapping on the shaped extended bandwidth transformed multiplexed sequence or shaped sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. In an embodiment, the distributed subcarrier mapping includes insertion of zeros in to the extended bandwidth transformed multiplexed sequence.

[00479] The IFFT unit performs inverse IFFT on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. The time domain sequence is processed by the processing unit to generate an output i.e. one or more PUCCH-PUSCH OTFDM symbols also referred as one or more OTFDM symbols.

[00480] The processing unit processes the time domain sequence to generate an OTFDM symbol. This is for the time multiplexed sequences generated by the time multiplexed unit of the transmitter is one of the symbol structures as shown in Figure 17A-17O. The time domain sequence is generated by the IFFT unit of the OTFDM symbol generating unit.

[00481] In an embodiment, the processing unit of the OTFDM symbol generating unit comprises a weighted with overlap and add operation (WOLA) unit, a bandwidth parts (BWP) specific rotation unit, a RF up-conversion unit, and a digital to analog converter (DAC).

[00482] The processing unit processes the time domain sequence to generate an OTFDM symbol. The time domain sequence is generated by the IFFT unit of the OTFDM symbol

generating unit. The input to this processing unit is the time domain sequence. This is for the time multiplexed sequences generated by the time multiplexed unit of the transmitter is one of the symbol structures as shown in Figure 19A-19B, 20A-20D, 21A-21D. The processing comprises performing at least one of a symbol specific phase compensation, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA) using the WOLA unit, bandwidth parts (BWP) rotation using BWP specific rotation unit, an additional time domain filtering, sampling rate conversion to match DAC rate, frequency shifting on the time domain waveform using RF up conversion unit and converting the same into analog using the DAC to generate the output, which is one or more OTFDM symbols. In an embodiment, the generated output is referred as UL multiplexed OTFDM symbol. The output i.e. one or more PUCCH-PUSCH OTFDM symbols or OTFDM symbols offers low peak to average ratio (PAPR).

[00483] One embodiment of the present disclosure is multiple input multiple output (MIMO) with Pre-DFT RS for PUCCH with one symbol. The transmitter as shown in Figures 1A which transmits a OTFDM symbol, comprising of at least one of: at least one a data and at least one RS are transmitted in the same OFDM symbol. The at least one data is referred as the control data. The at least one RS is referred as the RS. The data and the RS are multiplexed before DFT-precoding in the time domain. Data and RS are sequence of samples. The position of RS may be in the center or starting or ending of the OTFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix will be added to the RS in the time domain. The sequence to be used as RS is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes. The frequency spectrum of RS should be as flat as possible to ensure reliance channel estimation. RS and RS-CP or RS-CS may occupy a portion of resources allocated to the transmitter, which may depend on properties of channel conditions, Excess bandwidth, transmitter allocation size, modulation order, coding rate, and other parameters like impulse response of spectrum shaping filter.

[00484] In an embodiment, the control data of multiple transmitters/UEs can be multiplexed on the same time frequency resources. In order to minimize the intra user

interference across these multiplexed UEs, the time domain RS for these UEs should be orthogonal. Each UE can be allocated with a dedicated antenna port, such that the RS across these UEs is orthogonalized. The orthogonality across RS can be established through CDM, FDM, TDM.

[00485] One embodiment of the present disclosure is RS generation for different transmitters. In one case, the RS sequence for a given transmitter may be obtained by cyclically shifting the base reference sequence. The base sequence has to obtain transmitter specific RS, which may be one of $\pi/2$ -BPSK, QPSK, PSK, and ZC sequences. The base sequence generation may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. The cyclic shifts to be used for each transmitter is port specific, i.e., the RS that is transmitted on a given port enables the corresponding cyclic shift on the base RS sequence. The cyclic shifts to be used for each transmitter may be one of factor of length of RS sequence, and ceil, floor, or round of the length of the RS sequence, and the number of transmitters to be multiplexed. The symbol structure for the transmitter is shown Figure 22A. The transmitter specific RS to be used for channel estimation may have either RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix. Figure 22B shows symbol structure where RS in multiple transmitters having only RS-pre-fix. Figure 22C shows symbol structure where RS in multiple transmitters having only RS-post-fix.

[00486] One embodiment of the present disclosure is illustration of the method of generating OTFDM symbols. Considering the number of transmitters to be used be 4. The base sequence to be used in generating the RS for multiple transmitters be $r(n)$ of length N_r . The cyclic shifts to be used to generate transmitter specific RS be $\left\{\frac{N_r}{2}, \frac{N_r}{4}, \frac{3N_r}{4}, 0\right\}$, hence, the RS sequences for transmitter 1, 2, 3, and 4 may be given by:

e. RS for user 1: $r_1(n) = r\left(n - \frac{N_r}{2}\right) \rightarrow R_1 = \text{circ}(r_1(n))$

f. RS for user 2: $r_2(n) = r\left(n - \frac{N_r}{4}\right) \rightarrow R_2 = \text{circ}(r_2(n))$

g. RS for user 3: $r_3(n) = r\left(n - \frac{3N_r}{4}\right) \rightarrow R_3 = \text{circ}(r_3(n))$

h. RS for user 4: $r_4(n) = r(n) \rightarrow R_4 = \text{circ}(r_4(n))$

$$1. R_i \times R_i = I$$

2. $R_i \times R_j = P_{ij}$ – Permutation matrix

[00487] In another embodiment, RS sequence for different transmitters is generated using a base RS repetitions and transmitter specific cover code. The RS for each transmitter is repeated at least the number of transmitters available. A transmitter specific block wise cover code is applied on the repeated sequence. Figure 22D shows RS generation with cover code. For a base sequence of length N_r and for N_t number of transmitters to be multiplexed, the length of each RS sequence of each transmitter is at least $N_r \times N_t$. The transmitter specific block wise cover codes are orthogonal to each other. The RS for each transmitter may be the same sequence obtained from a base sequence or different sequences, and sequences may be pi/2-BPSK, QPSK, PSK, or ZC sequences. The base sequence generation or the transmitter specific sequence may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. The block wise spreading codes may be a PN sequence, Hadamard codes or Walsh codes. The block wise spreading code may be obtained from one of m-sequences, PN sequences, Kasami. The transmitter specific RS to be used for channel estimation may have either RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix.

[00488] Let the base sequence of each RS block be $r(n)$ of size N_r , where N_r is the length of RS block to be used to generate RS for each transmitter. The number of transmitters that are multiplexed be N_t . Hence, the size of RS for each transmitter is $N_r \times N_t$. Considering a two-transmitter case, the length of the RS is $2 \times N_r$. The RS for first transmitter is given by

$$r_1(n) = r(n \bmod (N_r \times 2))$$

Similarly, the RS for the second user is given by

$$r_2(n) = r(n \bmod (N_r \times 2)) e^{i\pi \lfloor \frac{n}{N_r} \rfloor}$$

Here, $n = \{0, 1, 2, 3, \dots, N_r \times 2\}$

[00489] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x . With this kind of RS structure defined for the two transmitters, the Fourier transform of RS of the first transmitter will occupy the even indices, while the Fourier transform of the RS of the second transmitter will occupy the odd indices.

[00490] In another embodiment, considering the orthogonal sequence is obtained using one of the sequences defined above, the block wise cover code for each user is given by $b_1(n)$, and $b_2(n)$ of length N_t . With base RS block sequence being $r(n)$, the RS sequence for each is given by

$$r_1(n) = b_1 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

$$r_2(n) = b_2 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

[00491] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x . In an embodiment, the control payload is processed in a similar way to the conventional 5G system before multiplexing data and RS, which involves code block segmentation (only when needed), the addition of CRC bits, channel coding, rate matching and code block concatenation, scrambling.

[00492] One embodiment of the present disclosure is MIMO with Pre-DFT RS for PUCCH with more than one symbols. The communication system or transmitter transmits more than one OTFDM symbols or one or more OTFDM symbols or one or more PUCCH-PUSCH OTFDM symbols. Each of the symbol comprises at least one of: at least one a data and at least one RS are transmitted in the same OFDM symbol. The at least one data is referred as the control data. The at least one RS is referred as the RS. The data and the RS are multiplexed before DFT-precoding in the time domain. Additionally, spreading code $W(n)$ is applied on the control data across the multiple symbols.

[00493] The modulation alphabets corresponding to the control payload are divided into groups, where the number of groups equals the number of symbols used to transfer the payload. The number of modulation alphabets within each group depends upon the spreading factor of the subsequent spreading process. The spreading factor can be specified using the OCC-Length information element. The spreading factors of 2 and 4 is supported.

[00494] The RS sequence for a given transmitter may be obtained by cyclically shifting the base reference sequence. The base sequence has to obtain transmitter specific RS, which may be one of $\pi/2$ -BPSK, QPSK, PSK, and ZC sequences. The base sequence generation may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. Specifically, the base RS sequence will be a function of symbol

index, resulting in different base sequences across the different DFT-s-OFDM symbols or OTFDM symbols.

[00495] The cyclic shifts to be used for each transmitter is port specific, i.e., the RS that is transmitted on a given port enables the corresponding cyclic shift on the base RS sequence. Optionally, the cyclic shift of each RS port can also be made a function of Symbol-Index. The cyclic shifts to be used for each transmitter may be one of factor of length of RS sequence, and ceil, floor, or round of the length of the RS sequence, and the number of transmitters to be multiplexed. The symbol structure for the transmitter is shown Figure 22A. The transmitter specific RS to be used for channel estimation may have either RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix. Figure 22B shows symbol structure where RS in multiple transmitters having only RS-pre-fix. Figure 22C shows symbol structure where RS in multiple transmitters having only RS-post-fix.

[00496] One embodiment of the present disclosure is illustration of the method of generating OTFDM symbols. Let the number of transmitters to be used be 4. The base sequence to be used in generating the RS for multiple transmitters be $r(n)$ of length N_r . The cyclic shifts to be used to generate transmitter specific RS be $\left\{\frac{N_r}{2}, \frac{N_r}{4}, \frac{3N_r}{4}, 0\right\}$, hence, the RS sequences for transmitter 1, 2, 3, and 4 may be given by:

$$\text{RS for user 1: } r_1(n) = r\left(n - \frac{N_r}{2}\right) \rightarrow R_1 = \text{circ}(r_1(n))$$

$$\text{RS for user 2: } r_2(n) = r\left(n - \frac{N_r}{4}\right) \rightarrow R_2 = \text{circ}(r_2(n))$$

$$\text{RS for user 3: } r_3(n) = r\left(n - \frac{3N_r}{4}\right) \rightarrow R_3 = \text{circ}(r_3(n))$$

$$\text{RS for user 4: } r_4(n) = r(n) \rightarrow R_4 = \text{circ}(r_4(n))$$

$$R_i \times R_i = I$$

$$R_i \times R_j = P_{ij} - \text{Permutation matrix}$$

[00497] In another embodiment, RS sequence for different transmitters is generated using a base RS repetitions and transmitter specific cover code. The RS for each transmitter is repeated at least the number of transmitters available. A transmitter specific block wise cover code is applied on the repeated sequence. Figure 22D shows RS generation with cover code. For a base sequence of length N_r and for N_t number of transmitters to be multiplexed, the length of each RS sequence of each transmitter is at least $N_r \times N_t$. The transmitter specific block wise cover codes are orthogonal to each other. The RS for each

transmitter may be the same sequence obtained from a base sequence or different sequences, and sequences may be $\pi/2$ -BPSK, QPSK, PSK, or ZC sequences. The base sequence generation or the transmitter specific sequence may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. The block wise spreading codes may be a PN sequence, Hadamard codes or Walsh codes. The block wise spreading code may be obtained from one of m-sequences, PN sequences, Kasami. The transmitter specific RS to be used for channel estimation may have either RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix.

[00498] Let the base sequence of each RS block be $r(n)$ of size N_r , where N_r is the length of RS block to be used to generate RS for each transmitter. The number of transmitters that are multiplexed be N_t . Hence, the size of RS for each transmitter is $N_r \times N_t$. Considering a two-transmitter case, the length of the RS is $2 \times N_r$. The RS for first transmitter is given by

$$r_1(n) = r(n \bmod (N_r \times 2))$$

[00499] Similarly, the RS for the second user is given by

$$r_2(n) = r(n \bmod (N_r \times 2)) e^{i\pi \lfloor \frac{n}{N_r} \rfloor}$$

$$\text{Here, } n = \{0, 1, 2, 3, \dots, N_r \times 2\}$$

[00500] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x . With this kind of RS structure defined for the two transmitters, the Fourier transform of RS of the first transmitter will occupy the even indices, while the Fourier transform of the RS of the second transmitter will occupy the odd indices.

[00501] In another case, where the orthogonal sequence is obtained using one of the sequences defined above, the block wise cover code for each user is given by $b_1(n)$, and $b_2(n)$ of length N_t . With base RS block sequence being $r(n)$, the RS sequence for each is given by

$$r_1(n) = b_1 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

$$r_2(n) = b_2 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

[00502] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x .

[00503] In an embodiment, the control payload is processed in a similar way to the conventional 5G system before multiplexing data and RS, which involves code block segmentation (only when needed), the addition of CRC bits, channel coding, rate matching and code block concatenation, scrambling.

[00504] One embodiment of the present disclosure is a MIMO transmitter with pre-DFT RS for multiplexed PUCCH and PUSCH. In this embodiment, the transmitter transmits more than one OTFDM symbols, each of which is comprising of at least one of: at least one a data and at least one RS are transmitted in the same OFDM symbol. The at least one data is referred as the control data and User data. The at least one RS is referred as the RS. The data and the RS are multiplexed before DFT-precoding in the time domain. The Data and RS are sequence of samples. The position of RS may be in the center or starting or ending of the OFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix will be added to the RS in the time domain. The sequence to be used as RS is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes.

[00505] Figure 23A shows a symbol with two RS blocks at the symbol boundaries and data in the middle of OFDM symbol. Figure 23B shows a Symbol with RS with pre-fix and post-fix at $1/4^{\text{th}}$ and $3/4^{\text{th}}$ positions of OFDM symbol. Figure 23C shows a Symbol with RS with pre-fix and post-fix starting at 0^{th} and $1/2^{\text{th}}$ positions of OFDM symbol. Figure 23D shows a Symbol with two RS blocks at the symbol boundaries, one in the middle for channel estimation. The RS block occupies any positions in the symbol, like shown the Figures 23A to 23D, which are for 2 blocks and 3 blocks. However, it may be extended to any number of blocks and any other configuration. RS in each block may be the same sequence or different. This kind of each RS block may be referred as long/main/localized/primary RS block, and all the blocks will either have both RS pre-fix and RS-post-fix or RS-post-fix or RS-pre-fix. Each block will be used for channel estimation and the transmitter data followed by the block will be equalized with the channel that is estimated.

[00506] The same RS can be employed for demodulation of both Control data and user data, i.e. the channel estimates derived from the RS are used to equalize both Control and user data. In the case of multiple User transmissions, a dedicated RS port is allocated to each UE/transmitter and the RS across the ports are orthogonalized through CDM/FDM/TDM. Details of the same are given above. Also, control data of different transmitters are spreaded by employing 2 or 4 length spread codes. However, the user data is scrambled through UE/transmitter specific Identities, like nID, nSCID, RNTI, etc.

[00507] One embodiment of the present disclosure is a MIMO transmitter with Pre-DFT RS for PUSCH. The MIMO transmitter transmits more than one OTFDM symbols, each of which is comprising of at least one of: at least one a data and at least one RS are transmitted in the same OTFDM symbol. The at least one data is referred User data which also includes the control data of the user piggybacked along with the user data. The at least one RS is referred as the RS. The data and the RS are multiplexed before DFT-precoding in the time domain. The data and RS are sequence of samples. The position of RS may be in the center or starting or ending of the OFDM symbol. This kind of RS may be referred as long/main/localized RS. To support better channel estimation either cyclic pre-fix (RS-CP) or cyclic post-fix (RS-CS) or both pre-fix and post-fix will be added to the RS in the time domain. The sequence to be used as RS is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes.

[00508] In the case of multiple User transmissions, a dedicated RS port is allocated to each UE/transmitter and the RS across the ports are orthogonalized through CDM/FDM/TDM. Details of the same are given above. However, the User data is scrambled by means of UE/Transmitter specific Identities, like nID, nSCID, RNTI, etc. Prior to data and RS multiplexing, the user payload is processed in a similar way to the conventional 5G system, which involves code block segmentation (Only when needed), the addition of CRC bits, channel coding, rate matching and code block concatenation, layer mapping, scrambling.

[00509] One embodiment of the present disclosure is a pre-DFT Sequence selection-based control data transmission. The transmitter transmits more than one OTFDM symbols, each of which is comprising of at least one of UE/transmitter specific sequence. The

UE/transmitter specific sequence conveys 1 or 2 bits of UE control data implicitly. The UE specific sequence is DFT precoded before transmission. In an embodiment, the RS is not transmitted so the Base Station receiver uses non-coherent detection to extract the control data. Each UE is allocated a specific sequence to transmit, this sequence has length 12 so there is a single entry for each subcarrier. The UE transfers control information by applying a UE specific cyclic shift α_i to the base sequence. The Base Station identifies the cyclic shift and subsequently deduces the corresponding information content. The sequence to be used as base sequence is one of $\pi/2$ - binary phase shift keying (BPSK), a Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), and Zadoff-chu (ZC) sequence. The sequences may be obtained using one of m-sequences, Pseudo-Noise (PN) sequences, Kasami, Walsh, and Hadamard codes.

[00510] Figures 24A-24B shows a various block diagram of PRACH transmitter. One embodiment of the present disclosure is PRACH in one symbol. A single symbol PRACH structure is illustrated in Figures 24A and 24B where a one of $\pi/2$ BPSK and ZC base sequence is applied to the DFT, excess subcarriers are added to the DFT output followed by the spectrum shaping filter, IFFT and the rest of the processing. Figures 24A and 24B illustrate block diagrams of an UL PRACH transmitter. Base $\pi/2$ BPSK or ZC is determined by the cell ID, and user specific circular shifts are applied on the base sequence to determine the sequence. In an embodiment the PRACH symbols may be repeated over multiple OFDM symbols. The CP may be added for each symbol or one CP for the first symbol and rest of the symbols have no CP. The one symbol PRACH may be repeated over multiple symbols

[00511] Figure 25 shows a block diagram of an OTFDM transmitter, in accordance with an embodiment of the present disclosure. The inputs to the time multiplexed unit or TDM is at least one of one or more data sequences, one or more RSs, a PRACH, a PUCCH sequence, a PUSCH sequence, and a portion of at least one of the one or more data sequences, the one or more RSs, the PRACH, the PUCCH sequence and the PUSCH sequence to generate a multiplexed sequence. The multiplexed sequence is fed to the OTFDM symbol generating unit to generate one or more OTFDM symbol or waveforms.

[00512] One embodiment of the present disclosure is a method for transmitting one or more PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) symbols or one or more OTFDM symbols. The order in which the method steps is described

is not intended to be construed as a limitation, and any number of the described method steps can be combined in any order to implement the method. Additionally, individual method steps may be deleted from the methods without departing from the scope of the subject matter described herein. Furthermore, the method can be implemented in any suitable hardware, software, firmware, or combination thereof.

[00513] The method comprising time-multiplexing, by the transmitter, at least one of a physical uplink control channel (PUCCH) sequence, a Physical Uplink Shared Channel (PUSCH) sequence and a reference sequence (RS) to generate a multiplexed sequence. Thereafter, generating one or more PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) symbols, which are referred to as OTFDM symbols, by processing the multiplexed sequence. The generated OTFDM symbols are transmitted using the one or more antennas (not shown in the figure) of the transmitter. In an embodiment, the number of generated symbols is one. In an embodiment, the number of symbols generated are more than one.

[00514] The method of generating the one or more PUCCH-PUSCH OTFDM symbols by processing the multiplexed sequence comprising transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence. Also, the method comprises performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence. The value of the N1 is at least zero, and value of the N2 is at least zero.

[00515] Further, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence. A shaping is performed on the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence.

[00516] Furthermore, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence. Thereafter, the method comprises processing the time

domain sequence to generate one or more PUCCH-PUSCH OTFDM symbols or referred to as OTFDM symbols.

[00517] This generation of the one or more PUCCH-PUSCH OTFDM symbols by processing the time domain sequence comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, phase compensation for each symbol by multiplying with a symbol specific exponential value, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate up-conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the one or more PUCCH-PUSCH OTFDM symbols.

[00518] In an embodiment, the time multiplexing is performed on at least one of the PUCCH sequence and the RS. The time multiplexed sequence is processed through the OTFDM symbol generating unit 104 to generate one or more PUCCH OTFDM symbols. The one or more transmitters is one of spatially multiplexed transmitters and uplink users.

[00519] In an embodiment, the time multiplexing is performed on at least one of the PUSCH sequence and the RS. The time multiplexed sequence is processed through the OTFDM symbol generating unit 104 to generate one or more PUSCH OTFDM symbols.

[00520] The RS comprises a base RS sequence, and at least one a RS CP and a RS CS. In an embodiment, the PUCCH sequence comprises one of a format 0 sequence, format 1 sequence, and format 2 sequence.

[00521] The format 0, also referred as PUCCH format 0, is a short format that can transmit up to two bits. It is used for transmitting acknowledgments and scheduling requests. The sequence selection is bias for PUCCH format 0. In this format 0, RS is not sent, so the Base Station receiver uses non-coherent detection to extract control data. Each UE is assigned a specific sequence of length M $M \in \{12, 18, 24\}$, with one entry per subcarrier. To transfer control information, the UE applies a UE-specific cyclic shift α_i to the base sequence. The Base Station detects the cyclic shift and infers the corresponding control information. The base sequence can be $\pi/2$ -binary phase shift keying (BPSK), Quadrature Phase Shift Keying (QPSK), M-ary Phase Shift Keying (PSK), or Zadoff-chu (ZC) sequence.

[00522] The format 1, also referred as PUCCH format 1, is a format that can transmit up to two bits. It uses a varying number of OFDM symbols, ranging from 4 to 14 symbols, with each symbol occupying one resource block in the frequency domain. The information bits to be transmitted are either BPSK or QPSK modulated, depending on whether one or two bits are being transmitted, respectively. These modulated bits are then multiplied by a low-PAPR sequence of length M , where M can be 12, 18, 24, and so on. Sequence and cyclic shift hopping techniques can be applied to introduce randomness and minimize interference.

[00523] The resulting modulated sequence of length M is spread in a block-wise manner using an orthogonal DFT code. This use of an orthogonal code in the time domain increases the capacity to accommodate multiple devices. Even if multiple devices have the same base sequence and phase rotation, they can still be separated by employing different orthogonal codes. Also, reference signals are inserted in the time domain along with the control sequence. Additionally, the reference sequences are spread in a block-wise fashion using an orthogonal sequence and then mapped to the OTFDM (Orthogonal Time Frequency Division Multiplexing) symbols. Therefore, the length of the orthogonal code, along with the number of cyclic shifts, determines the number of devices that can transmit using PUCCH format 1 on the same resource.

[00524] The format 2, also referred as PUCCH format 2, is a short format used for transmitting more than two bits of information. It is commonly used for simultaneous CSI reports and hybrid-ARQ acknowledgments, or when a larger number of hybrid-ARQ acknowledgments need to be transmitted. For larger payloads, a CRC (Cyclic Redundancy Check) is added. The control information, after the CRC is attached, is then encoded using Reed-Muller codes for payloads up to 11 bits. For larger payloads, Polar coding is used instead. After encoding, the data is scrambled and modulated using QPSK modulation.

[00525] The scrambling sequence used for randomization is based on the C-RNTI (Cell Radio Network Temporary Identifier) along with the physical-layer cell identity or a configurable virtual cell identity. This ensures that interference is randomized across cells and user equipment (UEs) that are utilizing the same set of time-frequency resources. The modulated QPSK symbols are then mapped to subcarriers across multiple resource blocks, using one or two OFDM symbols. In each OFDM symbol, a pseudo-random $\pi/2$ -BPSK or

QPSK sequence is mapped along with the control data, serving as a demodulation reference signal to facilitate coherent reception at the base station.

[00526] In an embodiment, the PUSCH sequence includes a PUSCH data sequence and Phase Tracking Reference signal (PT-RS). In an embodiment, the RS is at least one of a DMRS, a PT-RS and an SRS.

[00527] The at least one control sequence is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence and a Quadrature Phase Shift Keying (QPSK) sequence. In an embodiment, the control sequence includes HARQ acknowledgment, scheduling request (SR), and CSI. The control sequence is also referred to as control information or control data sequence.

[00528] The at least one RS is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence. The at least one RS comprise a plurality of samples. The at least one of the plurality of RS samples is multiplexed with the at least one data samples.

[00529] The at least one RS comprises one or more transmitter specific RS associated with each of the one or more transmitters. Each of the one or more transmitter specific RS are orthogonal to each other in at least one of time, frequency, and code, in an embodiment. Each of the one or more transmitter specific is based on at least one of a transmitter specific RS antenna port.

[00530] The at least one RS is multiplied with one or more transmitter specific code covers to obtain one or more transmitter specific RS. Each of the one or more transmitter specific code covers are orthogonal to each other. In an embodiment, each of the one or more transmitter specific code covers is one of a binary phase shift keying (BPSK) sequence, a Walsh Hadamard sequence, PN sequences, a DFT sequence, and a phase ramp sequence.

[00531] Each of the one or more transmitter specific code cover is based on at least one of a transmitter specific RS antenna port, scrambling ID, symbol ID, slot number, and cell ID. The one or more transmitter specific RS is a sequence of samples, said each sample is multiplied with an element of a transmitter specific phase ramp sequence. Each of the one

or more transmitter specific RS repetition is transmitter specific cyclic shifted sequence of the at least one RS's. In an embodiment, the number of one or more transmitter specific RS repetitions is at least zero.

[00532] The method also comprises performing cyclic shifting operation on the at least one RS, wherein the cyclic shifted RS is appended with at least one of a cyclic shifted RS pre-fix and a cyclic shifted RS post-fix. The RS is at least one of a DMRS, a PT-RS and an SRS.

[00533] In an embodiment of the present disclosure, a method for transmitting a PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) slot is provided. The method comprises time-multiplexing, by one or more transmitters, at least one of one or more PUCCH-PUSCH OTFDM symbols, one or more PUCCH OTFDM symbols and one or more PUSCH OTFDM symbols to generate an Orthogonal time frequency-division multiplexing (OTFDM) slot. In an embodiment, the OTFDM slot comprises one or more short PRACH formats

[00534] One embodiment of the present disclosure is a method for transmitting one or more PRACH Orthogonal time frequency-division multiplexing (OTFDM) symbols. The method being performed by a transmitter or communication system as shown in Figures 1D and 1E. The communication system comprises a plurality of transmitters or plurality of antennas, also referred to as one or more transmitters, or one or more antennas. The method comprises transforming at least PRACH sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence, followed by padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed sequence.

[00535] Also, the method comprises mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed sequence. Further, the method comprises shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed sequence. Furthermore, the method comprises performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence, and

processing the time domain sequence to generate the one or more PRACH OTFDM symbols.

[00536] The processing of the time domain sequence to generate one or more PRACH OTFDM symbols comprises performing at least one of addition of symbol cyclic prefix, addition of symbol cyclic suffix, windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate conversion to match DAC rate and frequency shifting on the time domain waveform, to generate one or more PRACH OTFDM symbols. The PRACH sequence is one of $\pi/2$ BPSK sequence and Zadoff-Chu (ZC) sequence.

[00537] One embodiment of the present disclosure is a method for transmitting an uplink frame. The method comprises multiplexing, by one or more transmitters, at least one of: one or more PRACH OTFDM symbols and one or more PUCCH-PUSCH OTFDM slots to generate at least one uplink signal associated with a beam.

[00538] One embodiment of the present disclosure is uplink signalling. Figure 5 shows an illustration of uplink signalling. As shown in Figure 5, when a user equipment (UE) is initially entering the coverage area of a Base station (BS), it doesn't have any information about the Base station, like the carrier frequency (f_c) used, the Bandwidth of the carrier, and the subcarrier spacing (SCS) employed, etc. The initial process of identifying the Base station by a UE to which it can communicate is termed a cell search. To facilitate the cell search procedure, the base station periodically broadcasts a specific type of signals known as Synchronization Signal Blocks (SSBs).

[00539] One important thing about NR SSB is the ability to use beam-sweeping for transmitting SS blocks. This means that SS blocks can be sent in different beams, one after the other. A group of SS blocks transmitted in this way is called an SS burst set. By using beam-forming for the SS block, the coverage area of each SS block transmission is expanded.

[00540] In beam-based systems, both the user equipment (UE) and gNodeB (gNB) have to find the most suitable beam for communication when they first connect. The gNB uses directional beams for transmitting and receiving signals within the cell. It sends out SS/PBCH blocks using different indices on various beams. When a UE is turned on, it

listens to these SS/PBCH blocks while scanning across its receiving beams. The UE identifies an SS/PBCH block index with a power level that surpasses a predefined threshold called rsrp-ThresholdSSB , which is set by higher-level parameters.

[00541] This process determines which pair of beams the gNB and UE will use to communicate with each other. The UE sends a preamble based on the chosen SS/PBCH block index, using a beam determined by the beam it used to receive the SS/PBCH block. The gNB receives the preamble and decides on the most optimal beam to communicate with the UE. From that point onwards, both transmitting and receiving data between the gNB and UE occur using the same pair of beams.

[00542] Once the UE has acquired downlink synchronization through SSB and has successfully decoded the System Information Block (SIB-1), UE will initiate the random access procedure by transmitting a specific signal called random access preamble over Physical Random Access Channel (PRACH).

[00543] The random access preamble transmission is based on OTFDM waveform, where the PRACH preamble is DFT precoded followed with bandwidth extension and spectrum shaping. When the UE transmits the preamble to the gNB, it conveys the selected SS/PBCH block index to the gNB, so that subsequent transmissions from the gNB to that UE use the same beam corresponding to the selected SS/PBCH block. This is conveyed by the preamble index and the PRACH occasion used to transmit the preamble.

[00544] After the gNB successfully detects the preamble sent by the UE, it sends a random access preamble identifier (RAPID) along with a random access response (RAR). The UE then checks if the received RAPID matches the sequence it had selected as its preamble. If they match, it means that the random access response has been received successfully. The RAR, which follows the RAPID, contains various important details for the UE, including timing advance, uplink scheduling grant, and UE identity.

[00545] The random access response (RAR) is transmitted by the gNB is on the physical downlink shared channel (PDSCH). Information sent on the physical downlink control channel (PDCCH) makes it possible to identify the resource blocks that carry the response.

[00546] After receiving all the necessary information from the random access response (RAR), the UE can now utilize the allocated uplink resources to send its Msg3 on the uplink

shared channel (PUSCH). Using Msg3, the UE sends an RRCSetupRequest to the network, which triggers the initiation of the initial attach procedure towards the 5G core network. RRC connection establishment starts with the UE sending an RRCSetupRequest as a Msg3 PUSCH transmission to the network.

[00547] In our proposal, we consider UE employs PUSCH-OTFDM waveform to transmit Msg-3, where the Msg-3 data is multiplexed with RS in time domain followed with DFT precoding, bandwidth expansion and spectrum shaping.

[00548] The corresponding response from the network is transmission of the RRCSetup message or RRCReject message, and the same is transmitted on the downlink shared channel PDSCH. This is often termed as Msg-4.

[00549] The connection setup message is acknowledged by the UE by sending an RRCSetupComplete message back to the network. In the present disclosure, considering that UE employs PUSCH-OTFDM waveform to transmit Msg-4 acknowledgement (ACK/NACK), where the Msg-3 data is multiplexed with RS in time domain followed with DFT precoding, bandwidth expansion and spectrum shaping.

[00550] One embodiment of the present disclosure is an uplink (UL) transmitter or communication system. The transmitter comprises a time division multiplexer (TDM) performing time multiplexing within one OFDM Symbol, multiple RS within the symbol, in accordance with an embodiment of the present disclosure. The multiplexing of multiple RS blocks and data blocks in one OFDM symbol is performed. The RS blocks may comprise of one or more long RS blocks and one or more short RS blocks. Long RS blocks facilitate estimation of complete IR and equalization of the neighbour data/control chunks, whereas short RS blocks facilitate phase tracking and compensation within a OFDM symbol. Multiple long RS blocks are used to facilitate equalization of the neighbouring data/control chunks so that channel variations caused by the mobile radio channel within one symbols are compensated.

[00551] In another embodiment, an uplink (UL) transmitter comprising a TDM performs multiplexing within an OFDM Symbol. The method of multiplexing is performed on at least one of PUSCH data and RS, PUCCH data and RS, PUCCH format-0 sequence in one OFDM symbol. The PUSCH data and RS may be one or more chunks, PUCCH data and

RS may be one or more chunks. This single symbol structure enables transmission of information with extremely low latency. Higher latency slots may be constructed by mapping data/control and RS over multiple OFDM symbols as well. When multiple uplink channels are multiplexed in time in single OFDM symbol, data corresponding to each user is considered as an independent data chunk. To avoid leakages of one channel on to the other at the receiver, data chunk corresponding to the channels are added with post-fix and pre-fix.

[00552] One embodiment of the present disclosure is Multi-user multiplexing in one symbol. The PUCCH/PUSCH transmission data/control information of multiple users is multiplexed by using spreading user data/control/RS using orthogonal spreading codes. This method has the advantage of transmitting data/control information with low latency by sharing a single OFDM symbol among multiple users. For PUCCH/PUSCH, base RS such as $\pi/2$ BPSK or ZC that is cell specific. Circularly shifted version of the base RS is used within a cell where each user applies a distinct value of the shift. The circularly shifted sequences are orthogonal to the base sequence.

[00553] One embodiment of the present disclosure is PRACH in one symbol. A single symbol PRACH is one of a $\pi/2$ BPSK and ZC base sequence. The sequence is applied to the DFT, excess subcarriers are added to the DFT output followed by the spectrum shaping filter, IFFT and followed by processing. A base $\pi/2$ BPSK or ZC is determined by the cell ID, and user specific circular shifts are applied on the base sequence to determine the sequence.

[00554] One embodiment of the present disclosure is Paging. When a device is in the RRC_IDLE state, it doesn't have any resources allocated to it in the gNB, and the 5G Core network doesn't know which cell or gNB the device is connected to. So, if there's any data to be sent to the device from the network, a paging procedure needs to be initiated. This paging procedure prompts the device to initiate a service request. This way, the 5G Core can find out which gNB the device is connected to and set up a Packet Data Unit (PDU) Session. In order to page a device, the NR RRC Paging message needs to be sent. This is scheduled by DCI Format 1_0 with the CRC masked by the P-RNTI (Paging - RNTI). The DCI is transmitted on PDCCH using one or more OFDM symbols the structure of PDCCH are provided in the previous sections of Msg2 and Msg4.

[00555] The Sounding Reference Signal (SRS) is an uplink sounding signal that provides the gNB with uplink channel quality information which can be used to assist scheduling, beam management or antenna switching. Figure 23E shows an illustration of various SRS symbol structures, in an embodiment. The SRS sequence can be one of a $\pi/2$ BPSK, a QPSK, and a ZC sequences and transmitted using OTFDM framework to generate SRS-OTFDM symbol. Each SRS-OTFDM symbol may carry SRS of at least one SRS transmitting device. SRS for each device may be derived from the same base sequence or different base sequences. Base sequence may be one of $\pi/2$ -BPSK, a QPSK, or ZC sequences. $\pi/2$ -BPSK, and QPSK sequences may be derived from one of PN-sequences using same initial value for all the devices or different initial values. Device can sound the entire SRS bandwidth using a single OTFDM symbol or it can sound by hopping over a number of smaller BW allocations in different OTFDM symbols. SRS can be mapped to OTFDM symbol using comb-1, comb-2 or comb-4 structures. OTFDM SRS can be time multiplexed with other OTFDM SRS transmissions. Also, SRS can be time multiplexed with PUSCH or PUCCH transmissions.

[00556] One embodiment of the present disclosure is illustration of the method of generating SRS sequence corresponding to each transmitter. Considering the number of transmitters to be used be 4. The base sequence to be used in generating the SRS for multiple transmitters be $r(n)$ of length N_r . The cyclic shifts to be used to generate transmitter specific RS be $\left\{\frac{N_r}{2}, \frac{N_r}{4}, \frac{3N_r}{4}, 0\right\}$, hence, the RS sequences for transmitter 1, 2, 3, and 4 may be given by:

$$\text{RS for user 1: } r_1(n) = r\left(n - \frac{N_r}{2}\right) \rightarrow R_1 = \text{circ}(r_1(n))$$

$$\text{RS for user 2: } r_2(n) = r\left(n - \frac{N_r}{4}\right) \rightarrow R_2 = \text{circ}(r_2(n))$$

$$\text{RS for user 3: } r_3(n) = r\left(n - \frac{3N_r}{4}\right) \rightarrow R_3 = \text{circ}(r_3(n))$$

$$\text{RS for user 4: } r_4(n) = r(n) \rightarrow R_4 = \text{circ}(r_4(n))$$

$$R_i \times R_i = I$$

$$R_i \times R_j = P_{ij} - \text{Permutation matrix}$$

[00557] In another embodiment, SRS sequence for different transmitters is generated using a base RS repetitions and transmitter specific cover code. The RS for each transmitter is repeated at least the number of transmitters available. A transmitter specific block wise

cover code is applied on the repeated sequence. Figure 3D shows RS generation with cover code. For a base sequence of length N_r and for N_t number of transmitters to be multiplexed, the length of each RS sequence of each transmitter is at least $N_r \times N_t$. The transmitter specific block wise cover codes are orthogonal to each other. The RS for each transmitter may be the same sequence obtained from a base sequence or different sequences, and sequences may be $\pi/2$ -BPSK, QPSK, PSK, or ZC sequences. The base sequence generation or the transmitter specific sequence may depend on the cell ID, transmitter specific ID, symbol index, scrambling ID, antenna port, and slot number. The block wise spreading codes may be a PN sequence, Hadamard codes or Walsh codes. The block wise spreading code may be obtained from one of m-sequences, PN sequences, Kasami. The transmitter specific SRS to be used for channel estimation may have either RS-pre-fix or RS-post-fix or both RS-pre-fix and RS-post-fix.

[00558] Let the base sequence of each SRS block be $r(n)$ of size N_r , where N_r is the length of RS block to be used to generate SRS for each transmitter. The number of transmitters that are multiplexed be N_t . Hence, the size of SRS for each transmitter is $N_r \times N_t$. Considering a two-transmitter case, the length of the RS is $2 \times N_r$. The SRS for first transmitter is given by

$$r_1(n) = r(n \bmod (N_r \times 2))$$

Similarly, the RS for the second user is given by

$$r_2(n) = r(n \bmod (N_r \times 2)) e^{i\pi \lfloor \frac{n}{N_r} \rfloor}$$

Here, $n = \{0, 1, 2, 3, \dots, N_r \times 2\}$

[00559] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x . With this kind of SRS structure defined for the two transmitters, the Fourier transform of SRS of the first transmitter will occupy the even indices, while the Fourier transform of the SRS of the second transmitter will occupy the odd indices.

[00560] In another embodiment, considering the orthogonal sequence is obtained using one of the sequences defined above, the block wise cover code for each user is given by $b_1(n)$, and $b_2(n)$ of length N_t . With base SRS block sequence being $r(n)$, the RS sequence for each is given by

$$r_1(n) = b_1 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

$$r_2(n) = b_2 \left(\left\lfloor \frac{n}{N_r} \right\rfloor \right) r(n \bmod (N_r \times 2))$$

[00561] Here, $\lfloor \cdot \rfloor$ is a flooring operation, where for a real number x , $\lfloor x \rfloor$ gives the greatest integer, which is less than or equal to x .

[00562] PDCCH Monitoring: In an embodiment, the user/device/node terminal may be monitoring PDCCH to check for any resources allocated for user transmission. The user may be checking for the resource allocation by de-scrambling the data received on the coreset of PDCCH. The resource allocation may be used for paging, system information.

[00563] One embodiment of the present disclosure is frame structure for uplink and downlink in FDD and TDD systems. The generated OTFDM symbols are transmitted in a time unit termed as Slot. Each slot contains at least one OTFDM symbol. In one embodiment, all OTFDM symbols in a slot are either configured for Uplink or Downlink. If the slot is configured for Downlink, the OTFDM symbol in that slot carries at least one of PSS, SSS, PBCH, PDCCH, PDSCH, CSI-RS. If the slot is configured for Uplink, the OTFDM symbol carries at least one of PRACH, PUSCH, PUCCH, SRS.

[00564] The Uplink transmission is from device to the base station, and Downlink transmission is from base station to the device. In another embodiment, Uplink and Downlink transmission are from base station to base station or from any transmitting node to any receiving node.

[00565] Figures 26A, 26B, 26C shows an illustration of downlink slot structure. Figures 26D, 26E, 26F show the illustration of uplink slot structure. In another embodiment, a group of N slots is termed as a frame. Here, N is a positive integer.

[00566] In another embodiment, the slots in a frame are used for Uplink and Downlink depending on the type of Duplexing method used. Two possible Duplexing methods are Time Division Duplexing (TDD) or Frequency Division Duplexing.

[00567] When TDD is used, all the symbols in the slot may be either configured for Uplink transmission or Downlink transmission. When the slot is used for Downlink transmission, the symbols in the slot are used to transmit at least one of PSS, SSS, PBCH, PDCCH, PDSCH, CSI-RS. Similarly, when slot is configured as uplink slot, all the symbols

are used for transmission of at least one of PRACH, PUSCH, PUCCH, SRS. In an embodiment, there could be at least one Downlink slots and one Uplink slot. A time separation may be applied between the Uplink and Downlink slot. Same carrier is used for Uplink and Downlink transmission in TDD systems as shown in Fig. 26G.

[00568] Figures 26H-26I shows an illustration of symbol structures in FDD systems, Uplink and Downlink transmissions may happen on dedicated carriers, and their respective bandwidths. If Uplink transmission is scheduled, the slots in the frame are used for Uplink transmission, similarly, all slots in the frame are used for Downlink, when Downlink is scheduled.

[00569] In another embodiment, each symbol in a slot may be configured for either Uplink or Downlink. If the symbol in a slot is configured for Downlink, the OTFDM symbol carries at least one of PSS, SSS, PBCH, PDCCH, PDSCH, CSI-RS. If the symbol in a slot is configured for Uplink, the OTFDM symbol carries at least one of PRACH, PUSCH, PUCCH, SRS. A guard interval of G symbols is kept between simultaneous Uplink and Downlink transmission. CSI-RS are reference signals specifically configured for sounding the downlink radio channel. These signals facilitate to acquire channel characteristics of the radio channel at various levels. This spans from basic insights, such as Reference Signal Received Power (RSRP) estimates, to comprehensive amplitude and phase estimates across frequency, time, and space.

[00570] The CSI-RS introduces several applications, including, but not limited to, facilitating downlink CSI acquisition for tasks such as link adaptation and codebook-based precoding for downlink Multiple Input Multiple Output (MIMO) systems; managing downlink beams effectively; conducting Radio Link Monitoring (RLM) measurements, and detecting beam failures. The Sequence generation is similar to SRS, and the generated CSI-RS-OTFDM symbols may be repeated across OTFDM symbols. The repeated OTFDM symbols may be applied with symbol specific weights or codes.

[00571] Further, the code implementing the described operations may be implemented in “transmission signals”, where transmission signals may propagate through space or through a transmission media, such as an optical fiber, copper wire, etc. The transmission signals in which the code or logic is encoded may further comprise a wireless signal, satellite transmission, radio waves, infrared signals, Bluetooth, etc. The transmission

signals in which the code or logic is encoded is capable of being transmitted by a transmitting station and received by a receiving station, where the code or logic encoded in the transmission signal may be decoded and stored in hardware or a non-transitory computer readable medium at the receiving and transmitting stations or devices. An “article of manufacture” comprises non-transitory computer readable medium, hardware logic, and/or transmission signals in which code may be implemented. A device in which the code implementing the described embodiments of operations is encoded may comprise a computer readable medium or hardware logic. Of course, those skilled in the art will recognize that many modifications may be made to this configuration without departing from the scope of the invention, and that the article of manufacture may comprise suitable information bearing medium known in the art.

[00572] A description of an embodiment with several components in communication with each other does not imply that all such components are required. On the contrary a variety of optional components are described to illustrate the wide variety of possible embodiments of the invention. When a single device or article is described herein, it will be clear that more than one device/article (whether they cooperate) may be used in place of a single device/article. Similarly, where more than one device or article is described herein (whether they cooperate), it will be clear that a single device/article may be used in place of the more than one device or article or a different number of devices/articles may be used instead of the shown number of devices or programs. The functionality and/or the features of a device may be alternatively embodied by one or more other devices which are not explicitly described as having such functionality/features. Thus, other embodiments of the invention need not include the device itself.

[00573] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the invention be limited not by this detailed description. Accordingly, the disclosure of the embodiments of the invention is intended to be illustrative, but not limiting, of the scope of the invention. While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting.

Claims

What is claimed is:

1. A method for generating a PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) symbol, comprising:

time-multiplexing, by one or more transmitters, at least one of a physical uplink control channel (PUCCH) sequence, a Physical Uplink Shared Channel (PUSCH) sequence, a reference sequence (RS), and a portion of at least one of the PUCCH sequence, the PUSCH sequence and the RS to generate a multiplexed sequence; and

filtering, by the one or more transmitters, the multiplexed sequence to generate a PUCCH-PUSCH OTFDM symbol.
2. The method as claimed in claim 1, wherein the time multiplexing is performed on at least one of the PUCCH sequence and the RS and filtered to generate one or more PUCCH OTFDM symbols.
3. The method as claimed in claim 1, wherein the time multiplexing is performed on at least one of the PUSCH sequence and the RS and filtered to generate one or more PUSCH OTFDM symbols.
4. The method as claimed in claim 1, wherein the RS comprises a base RS sequence, and at least one a RS CP and a RS CS.
5. The method as claimed in claim 1, wherein the PUCCH sequence comprises one of a format 0 sequence, format 1 sequence, and format 2 sequence.
6. The method as claimed in claim 1, wherein the PUSCH sequence includes a PUSCH data sequence and Phase Tracking Reference signal (PT-RS).
7. The method as claimed in claim 1, wherein generating the one or more PUCCH-PUSCH OTFDM symbols by processing the multiplexed sequence comprising:

transforming the multiplexed sequence using a Discrete Fourier Transform (DFT) to generate a transformed multiplexed sequence;

performing padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed

sequence with a second predefined number (N_2) of subcarriers to obtain an extended bandwidth transformed multiplexed sequence;

mapping the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed multiplexed sequence;

shaping the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed multiplexed sequence;

performing an Inverse Fast Fourier Transform (IFFT) on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence; and

processing the time domain sequence to generate the one or more PUCCH-PUSCH OTFDM symbols.

8. The method as claimed in claim 7, wherein value of the N_1 is at least zero, and value of the N_2 is at least zero.
9. The method as claimed in claim 7, wherein processing the time domain sequence to generate one or more PUCCH-PUSCH OTFDM symbols comprises performing at least one of windowing, weighted with overlap and add operation (WOLA), bandwidth parts (BWP) rotation, additional time domain filtering, sampling rate conversion to match DAC rate and frequency shifting on the time domain waveform, to generate the PUCCH-PUSCH OTFDM symbol.
10. The method as claimed in claim 1, wherein the one or more transmitters is one of spatially multiplexed transmitters and uplink users.
11. The method as claimed in claim 1, wherein the at least one control sequence is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence and a Quadrature Phase Shift Keying (QPSK) sequence.
12. The method as claimed in claim 1, wherein the control sequence includes HARQ acknowledgment, scheduling request (SR), and CSI.
13. The method as claimed in claim 1, wherein the at least one RS is one of a $\pi/2$ binary phase shift keying (BPSK) sequence, a BPSK sequence, a Zadoff-Chu (ZC) sequence, a Quadrature Phase Shift Keying (QPSK) sequence, and a M-ary Phase Shift Keying (PSK) sequence.

14. The method as claimed in claim 1, wherein the at least one RS comprise a plurality of samples, wherein at least one of: the plurality of RS samples is multiplexed with the at least one data sample.
15. The method as claimed in claim 1, wherein the at least one RS comprises one or more transmitter specific RS associated with each of the one or more transmitters.
16. The method as claimed in claim 15, wherein each of the one or more transmitter specific RS are orthogonal to each other in at least one of time, frequency, and code.
17. The method as claimed in claim 15, wherein each of the one or more transmitter specific is based on at least one of a transmitter specific RS antenna port.
18. The method as claimed in claim 1, wherein the at least one RS is multiplied with one or more transmitter specific code covers to obtain one or more transmitter specific RS.
19. The method as claimed in claim 18, wherein each of the one or more transmitter specific code covers are orthogonal to each other.
20. The method as claimed in claim 18, wherein each of the one or more transmitter specific code covers is one of a binary phase shift keying (BPSK) sequence, a Walsh Hadamard sequence, PN sequences, a DFT sequence, and a phase ramp sequence.
21. The method as claimed in claim 18, wherein each of the one or more transmitter specific code cover is based on at least one of a transmitter specific RS antenna port, scrambling ID, symbol ID, slot number, and cell ID.
22. The method as claimed in claim 18, wherein the one or more transmitter specific RS is a sequence of samples, said each sample is multiplied with an element of a transmitter specific phase ramp sequence.
23. The method as claimed in claim 18, wherein each of the one or more transmitter specific RS repetition is transmitter specific cyclic shifted sequence of the at least one RS.
24. The method as claimed in claim 23, wherein number of one or more transmitter specific RS repetitions is at least zero.

25. The method as claimed in claim 1, wherein the method comprises performing cyclic shifting operation on the at least one RS, wherein the cyclic shifted RS is appended with at least one of a cyclic shifted RS pre-fix and a cyclic shifted RS post-fix.
26. The method as claimed in claim 1, wherein the RS is at least one of a DMRS, a PT-RS and an SRS.
27. A method for transmitting a PUCCH-PUSCH Orthogonal time frequency-division multiplexing (OTFDM) slot, comprising:
time-multiplexing, by one or more transmitters, at least one of: one or more PUCCH-PUSCH OTFDM symbols, one or more PUCCH OTFDM symbols and one or more PUSCH OTFDM symbols to generate an Orthogonal time frequency-division multiplexing (OTFDM) slot.
28. The method as claimed in claim 27, wherein the OTFDM slot comprises one or more short PRACH formats.
29. A method for transmitting one or more PRACH Orthogonal time frequency-division multiplexing (OTFDM) symbols, comprising:
transforming, by one or more transmitters, at least one PRACH sequence and a portion of the PRACH sequence using a Discrete Fourier Transform (DFT) to generate a transformed sequence;
performing, by the one or more transmitters, padding operation by prefixing the transformed multiplexed sequence with a first predefined number (N1) of subcarriers and post-fixing the transformed multiplexed sequence with a second predefined number (N2) of subcarriers to obtain an extended bandwidth transformed sequence;
mapping, by the one or more transmitters, the extended bandwidth transformed multiplexed sequence with at least one of localized and distributed subcarriers to generate a mapped extended bandwidth transformed sequence;
shaping, by the one or more transmitters, the mapped extended bandwidth transformed multiplexed sequence using a filter to obtain a shaped extended bandwidth transformed sequence;

performing an Inverse Fast Fourier Transform (IFFT), by the one or more transmitters, on the shaped extended bandwidth transformed multiplexed sequence to produce a time domain sequence; and

processing, by the one or more transmitters, the time domain sequence to generate the one or more PRACH OTFDM symbols.

30. The method as claimed in claim 29, wherein processing the time domain sequence to generate one or more PRACH OTFDM symbols comprises performing at least one of a windowing, a weighted with overlap and add operation (WOLA), a bandwidth parts (BWP) rotation, an additional time domain filtering, a sampling rate conversion to match DAC rate and a frequency shifting on the time domain waveform, to generate one or more PRACH OTFDM symbols.
31. The method as claimed in claim 29, wherein the PRACH sequence is one of $\pi/2$ BPSK sequence and Zadoff-chu (ZC) sequence.
32. A method for transmitting an uplink frame, comprising:
multiplexing, by one or more transmitters, at least one of: one or more PRACH OTFDM symbols and one or more PUCCH-PUSCH OTFDM slots to generate at least one uplink signal associated with a beam.
33. An Orthogonal time frequency-division multiplexing (OTFDM) symbol transmitter to generate and transmit OTFDM symbols using the methods as claimed in claims 1-32.
34. A downlink transmission method performed by a communication system, the method comprising:
initiating, by the communication system, at least one of
a synchronous signal (SS) burst carrying at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence;
a physical downlink control channel (PDCCH) carrying control information of one or more users;
a physical downlink shared channel (PDSCH) carrying traffic data of one or more users; and

a physical downlink channel state information reference signals (CSI-RS) carrying data, paging, and signaling messages;

wherein the at least one of the SS Burst, the PDCCH, the PDSCH and the CSI-RS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

35. A method of uplink transmission in a communication network, said communication network comprises a communication system configured with one or more user equipment's (UEs) for performing an uplink transmission, the method comprising:

performing, by at least one UE, at least one of a cell search, a physical random-access channel (PRACH) transmission carrying traffic data of one or more users in uplink; a physical uplink control channel (PUCCH) transmission carrying control data of users in uplink; a physical uplink shared channel (PUSCH) transmission carrying traffic data of users in uplink; and a sounding reference signal (SRS) transmission;

wherein the at least one of the PRACH, the PUCCH and the PUSCH are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

36. A transmission method performed by a communication system, the method comprising:

initiating, by the communication system, at least one of

a synchronous signal (SS) burst carrying at least one of a primary synchronization signal (PSS) sequence, a secondary synchronization signal (SSS) sequence, a physical broadcast channel (PBCH) sequence;

a physical downlink control channel (PDCCH) carrying control information of one or more users;

a physical downlink shared channel (PDSCH) carrying traffic data of one or more users;

a physical downlink channel state information reference signals (CSI-RS) carrying data, paging, and signaling messages;

wherein the at least one of the SS Burst, the PDCCH, the PDSCH, the CSI-RS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame;

a physical random-access channel (PRACH) transmission carrying traffic data of one or more users in uplink;

a physical uplink control channel (PUCCH) transmission carrying control data of users in uplink;

a physical uplink shared channel (PUSCH) transmission carrying traffic data of users in uplink; and

a sounding reference signal (SRS) transmission;

wherein the at least one of the PRACH, the PUCCH, the PUSCH and the SRS are transmitted using one or more Orthogonal time frequency-division multiplexing (OTFDM) symbols in one of a half frame and a full frame.

37. A communication system performing downlink and uplink transmission method as claimed in claim 36.

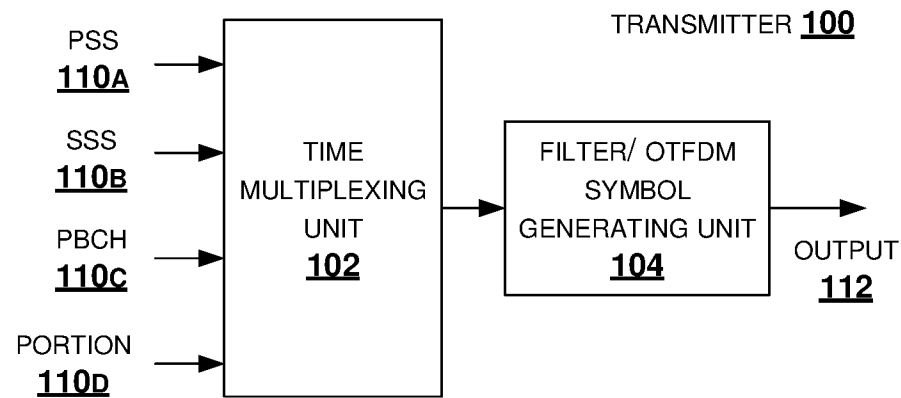


Figure 1A

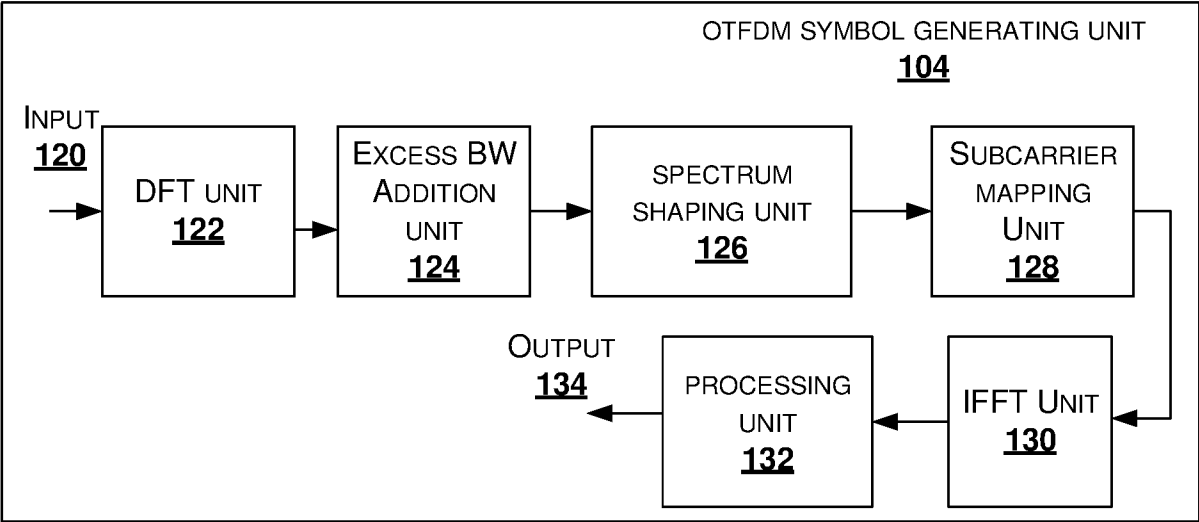


Figure 1B

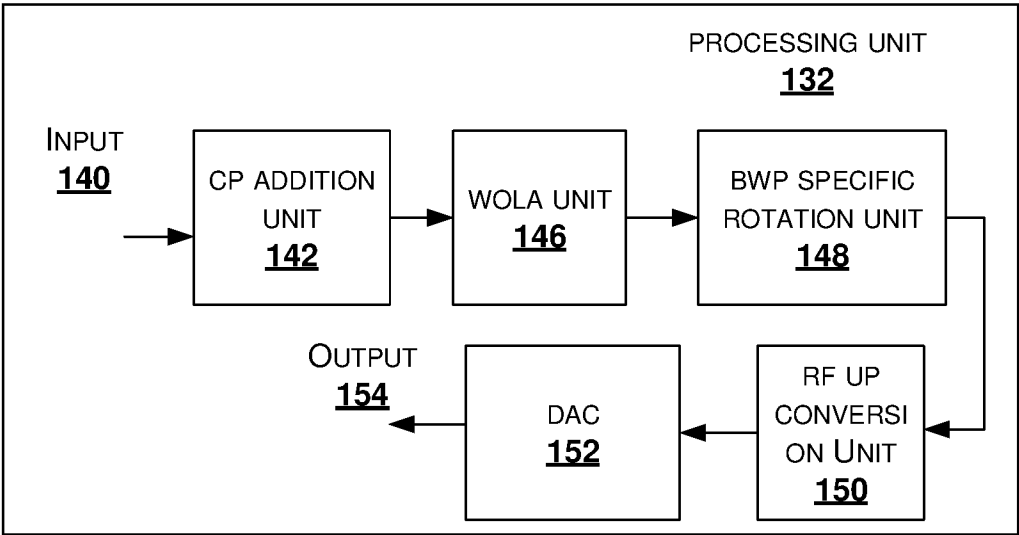


Figure 1C

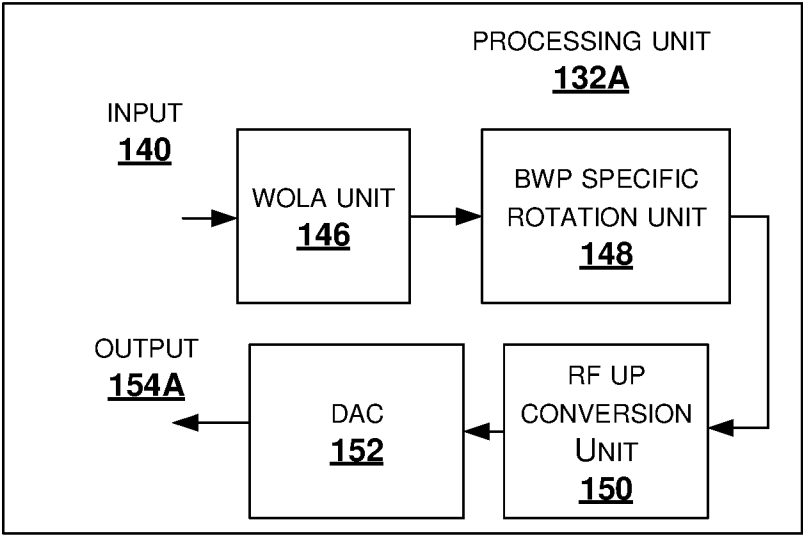


Figure 1D

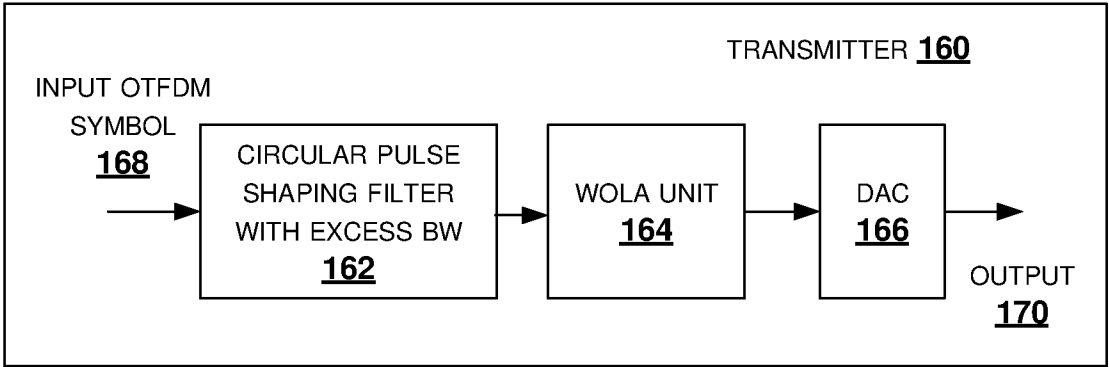


Figure 1E

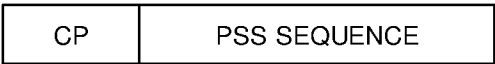


Figure 2A

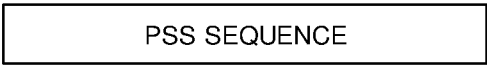


Figure 2B

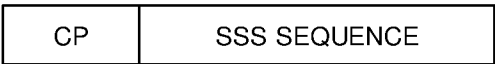


Figure 2C



Figure 2D

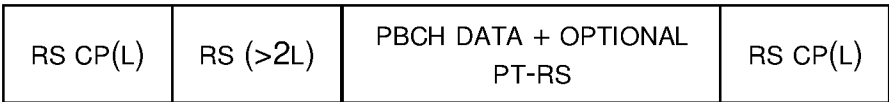


Figure 2E

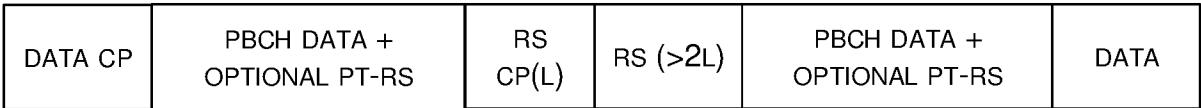


Figure 2F

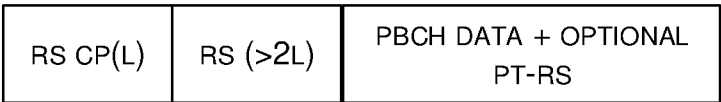


Figure 2G

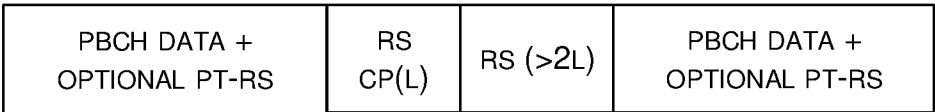


Figure 2H

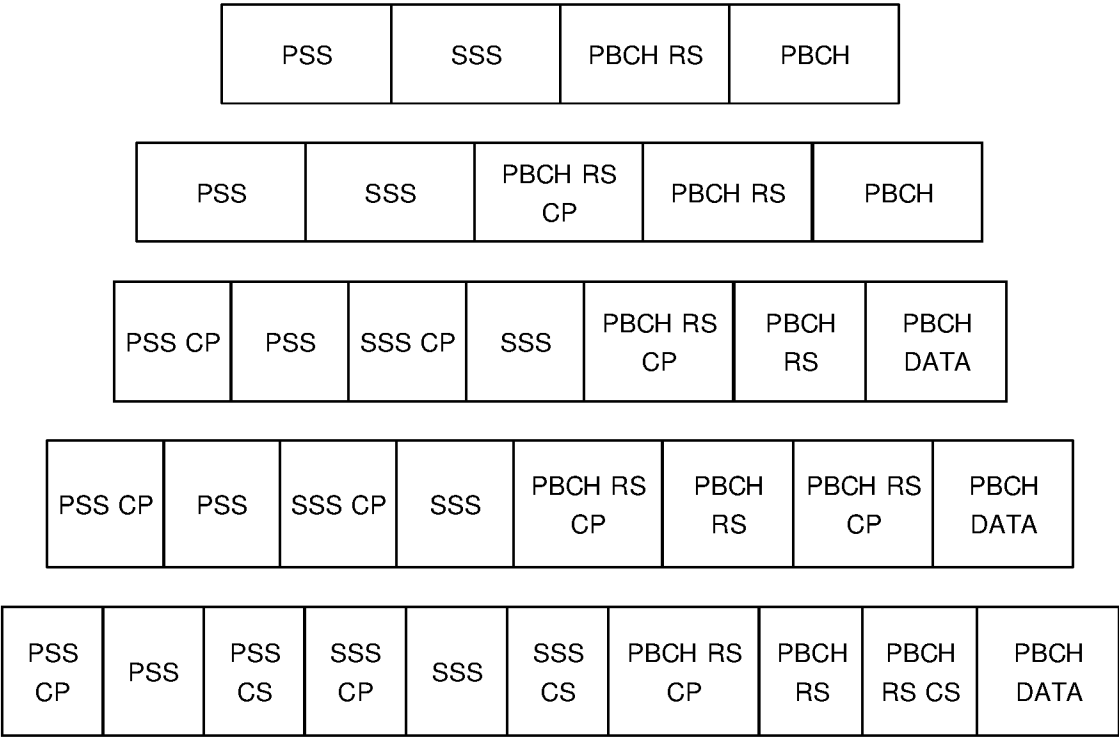


Figure 2I

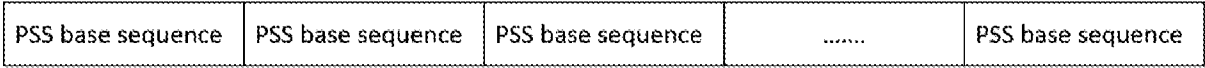


Figure 2J

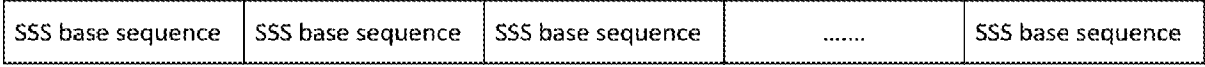


Figure 2K

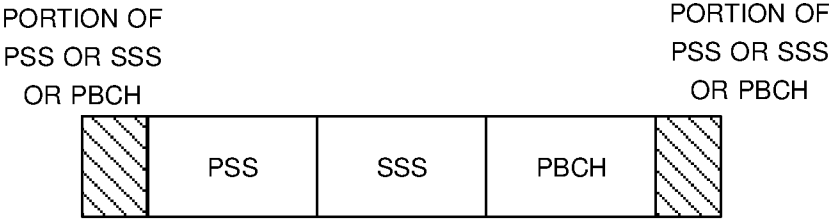


Figure 2L

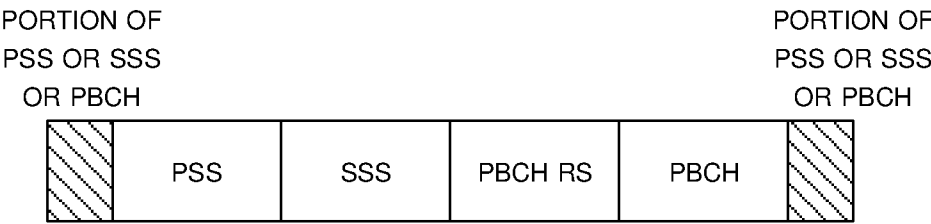


Figure 2M

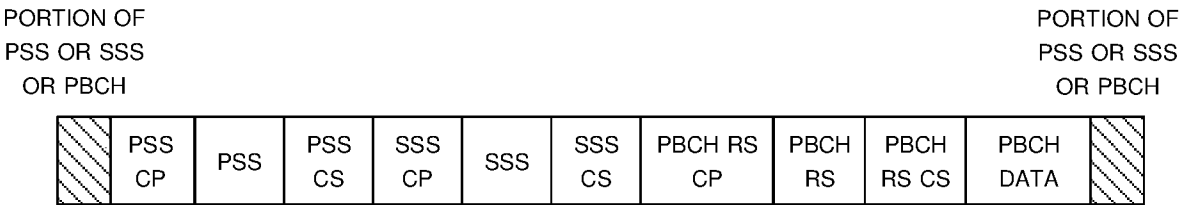


Figure 2N

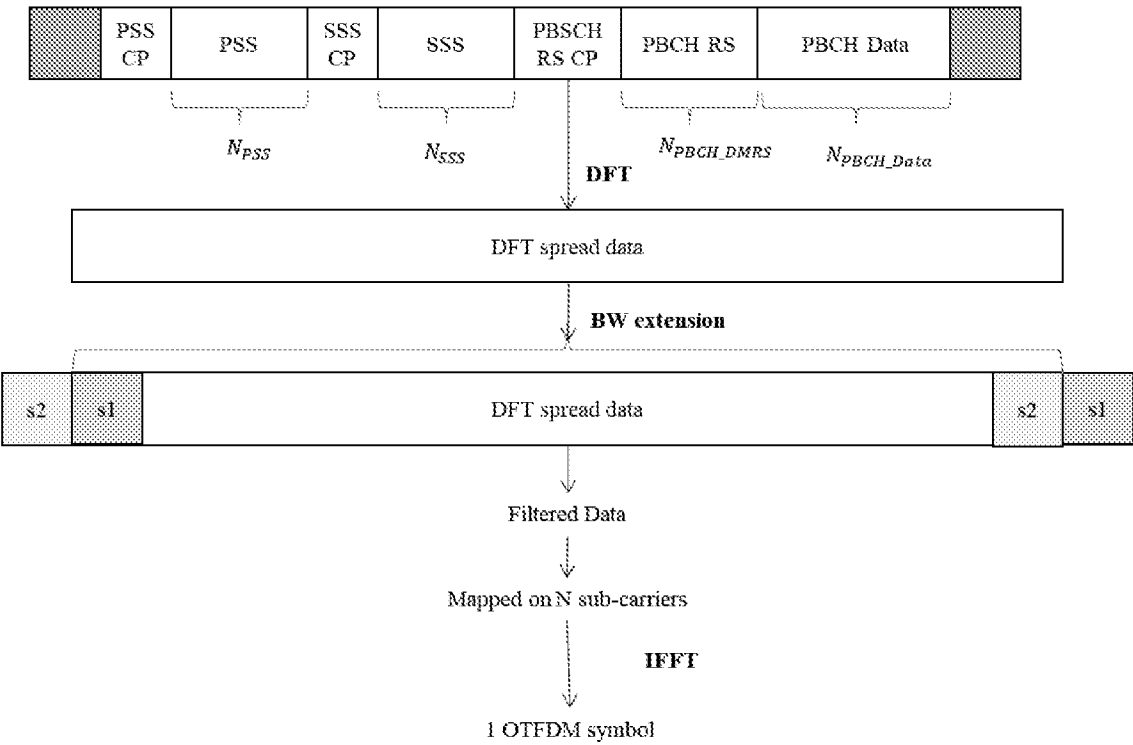


Figure 3A

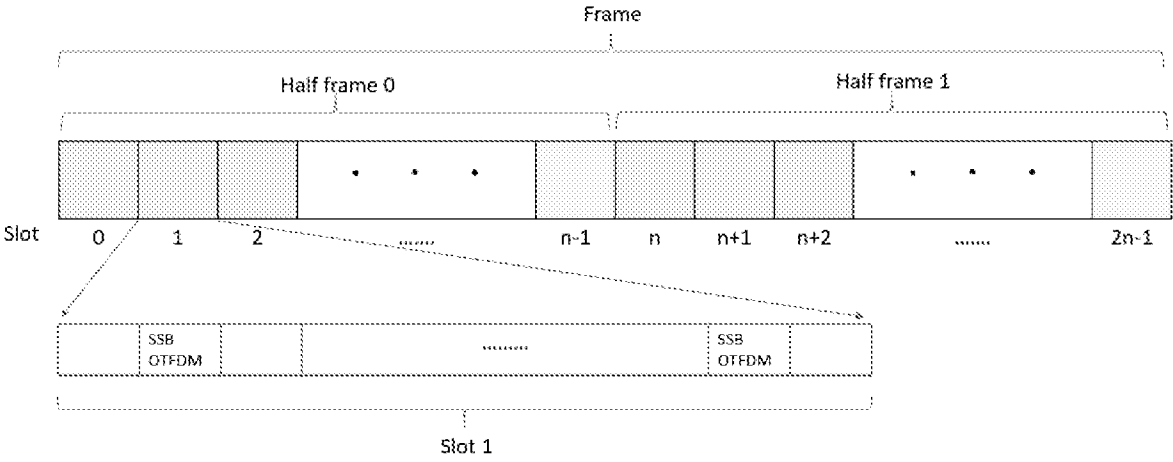


Figure 3B

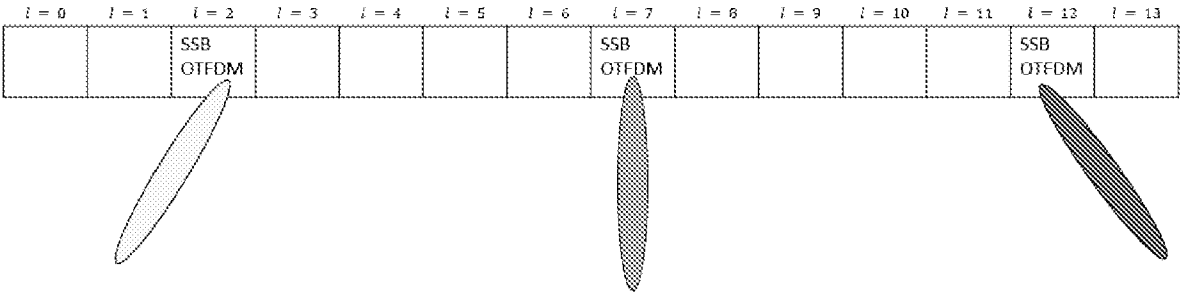


Figure 3C

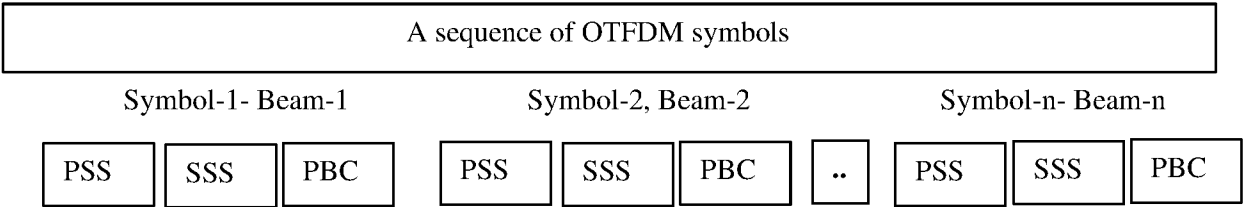


Figure 3D

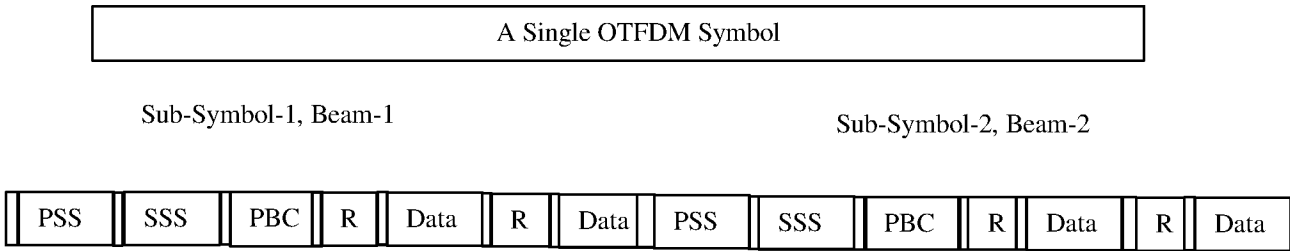


Figure 3E

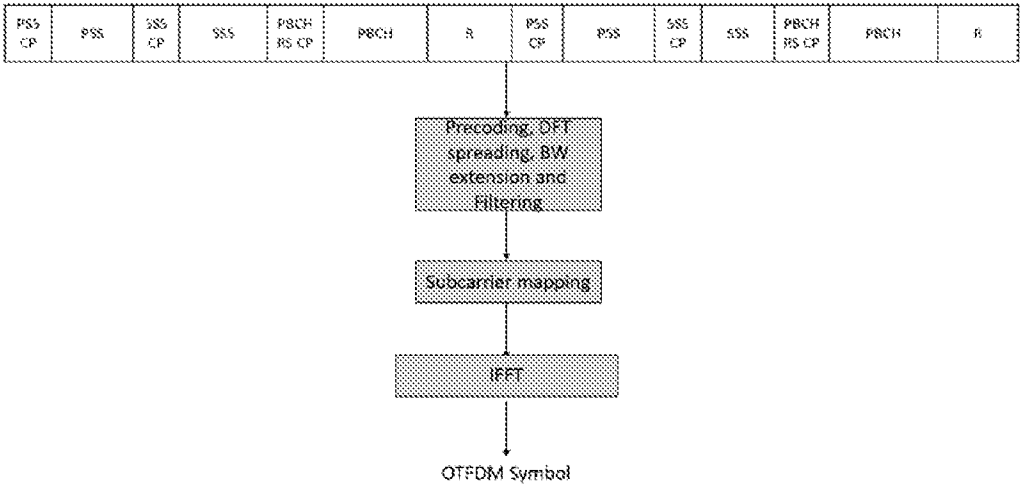


Figure 3F

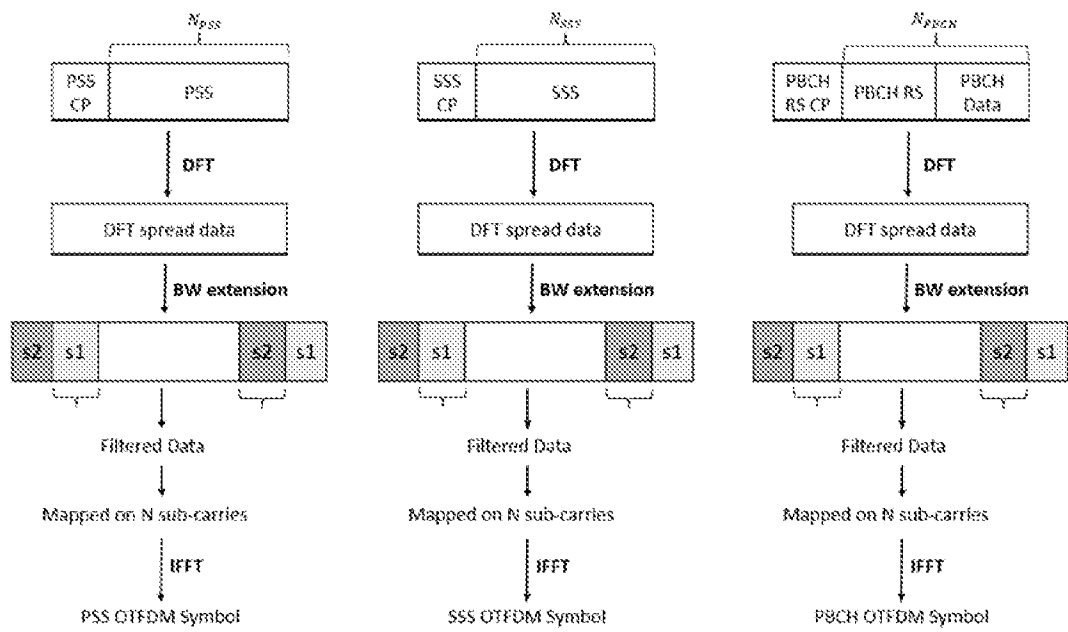


Figure 4A

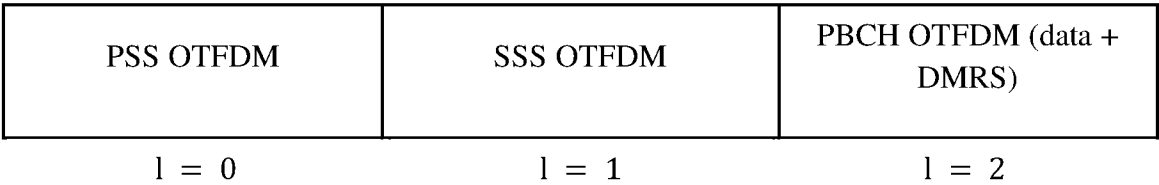


Figure 4B

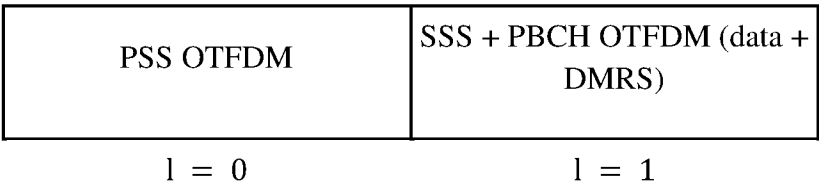


Figure 4C

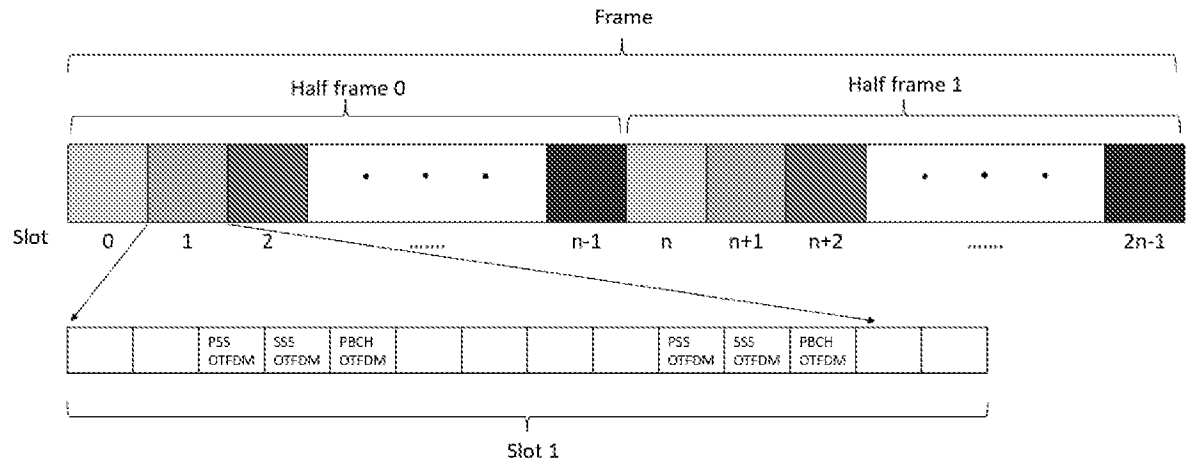


Figure 4D

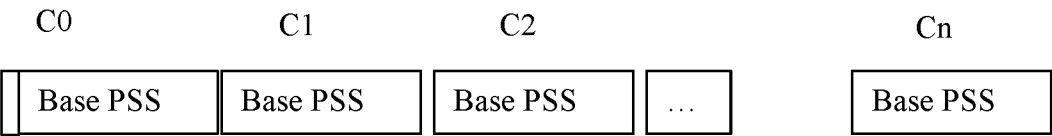


Figure 4E

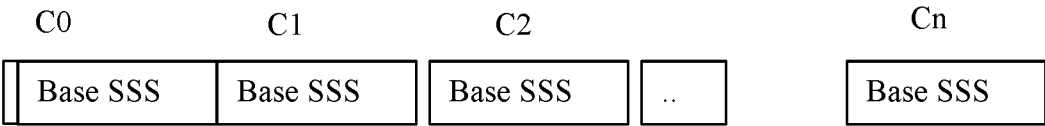


Figure 4F

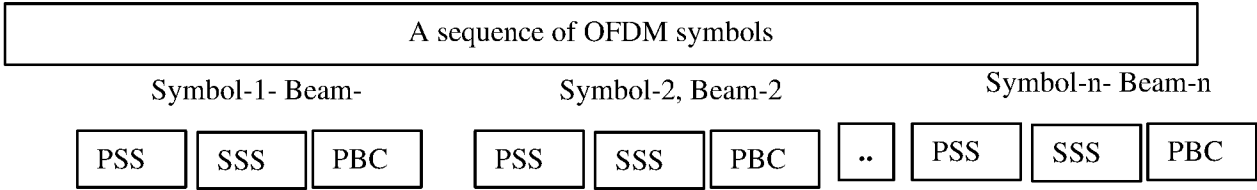


Figure 4G

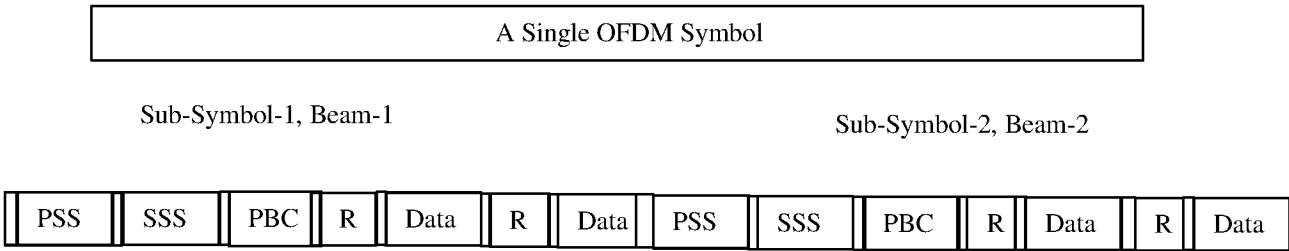


Figure 4H

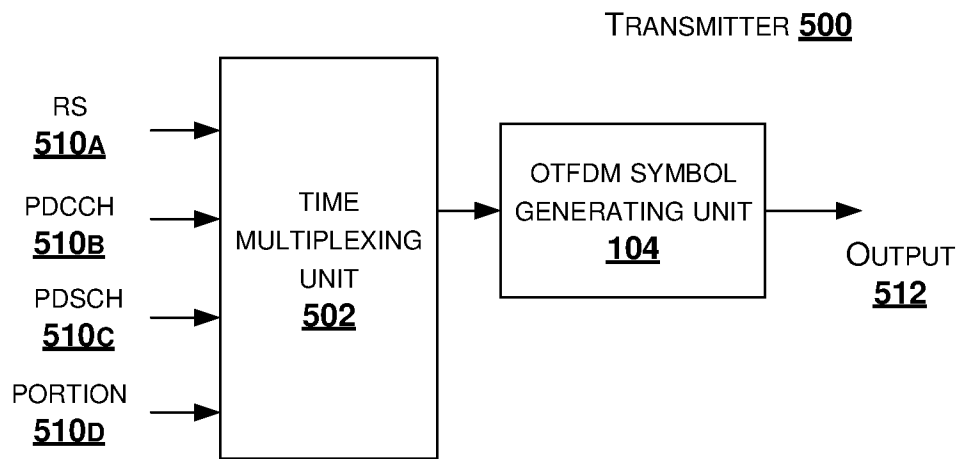


Figure 5A

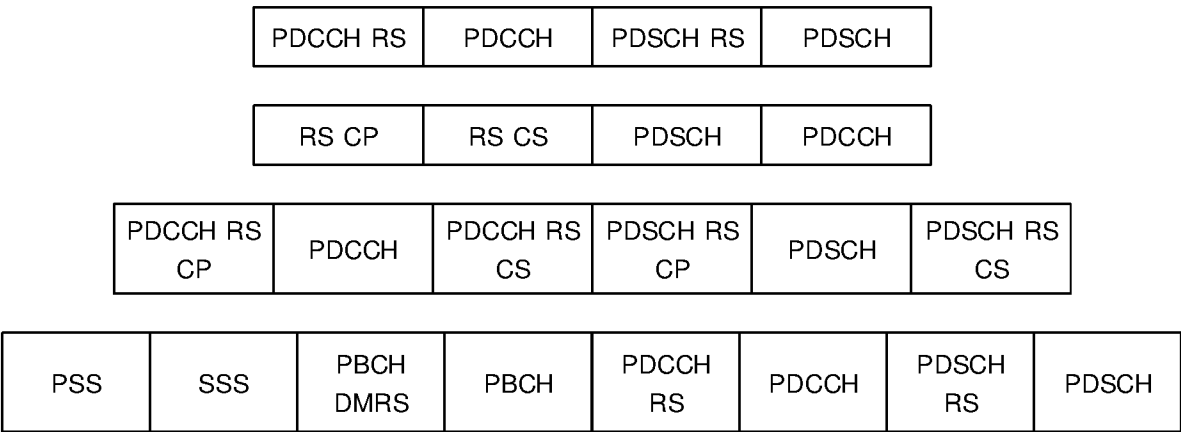


Figure 5B



Figure 6A

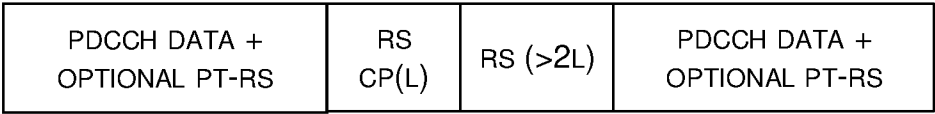


Figure 6B

DATA CP	PDCCH DATA + OPTIONAL PT-RS	RS CP(L)	RS (>2L)	PDCCH DATA + OPTIONAL PT-RS	DATA
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Figure 6C

RS CP(L)	RS (>2L)	PDCCH DATA + OPTIONAL PT-RS
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Figure 6D

RS CP(L)	RS (>2L)	PDSCH DATA + OPTIONAL PT-RS	RS CP(L)
----------	----------	--------------------------------	----------

Figure 6E

PDSCH DATA + OPTIONAL PT-RS	RS CP(L)	RS (>2L)	PDSCH DATA + OPTIONAL PT-RS
--------------------------------	-------------	----------	--------------------------------

Figure 6F

DATA CP	PDSCH DATA + OPTIONAL PT-RS	RS CP(L)	RS (>2L)	PDSCH DATA + OPTIONAL PT-RS	DATA
---------	--------------------------------	-------------	----------	--------------------------------	------

Figure 6G

RS CP(L)	RS (>2L)	PDSCH DATA + OPTIONAL PT-RS
----------	----------	--------------------------------

Figure 6H

RS CP(L)	RS (>2L)	PDCCH + PDSCH + OPTIONAL PT-RS	RS CP(L)
----------	----------	-----------------------------------	----------

Figure 7A

PDCCH + PDSCH + OPTIONAL PT-RS	RS CP(L)	RS (>2L)	PDCCH + PDSCH + OPTIONAL PT-RS
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Figure 7B

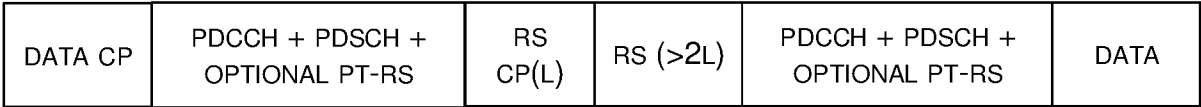


Figure 7C

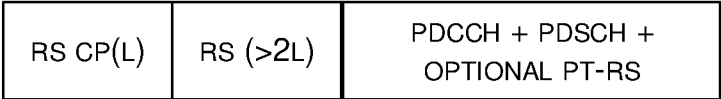


Figure 7D

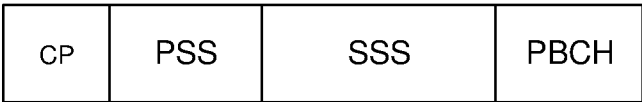


Figure 7E

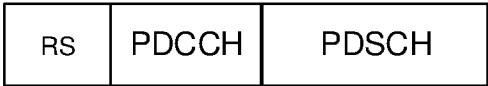


Figure 7F



Figure 7G

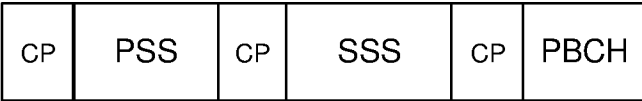


Figure 7H



Figure 7I

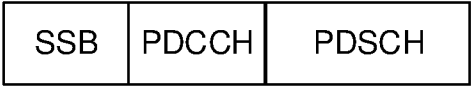


Figure 7J



Figure 7K

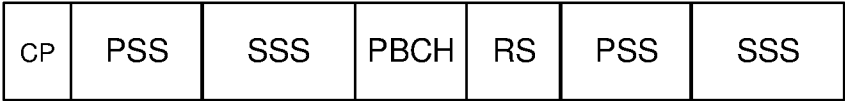


Figure 7L

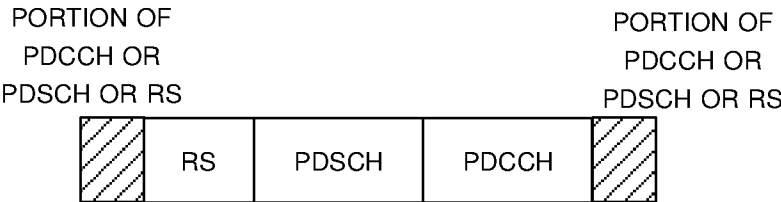


Figure 8A

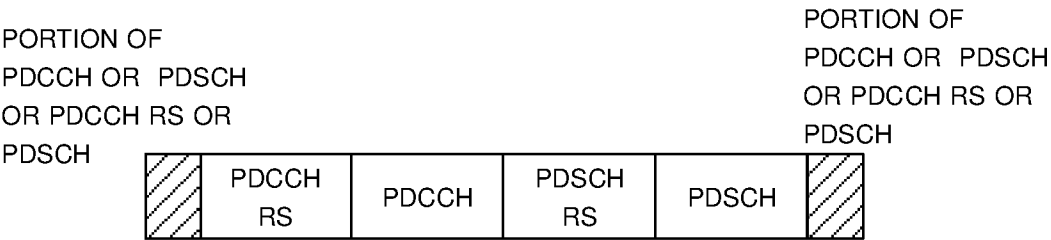


Figure 8B

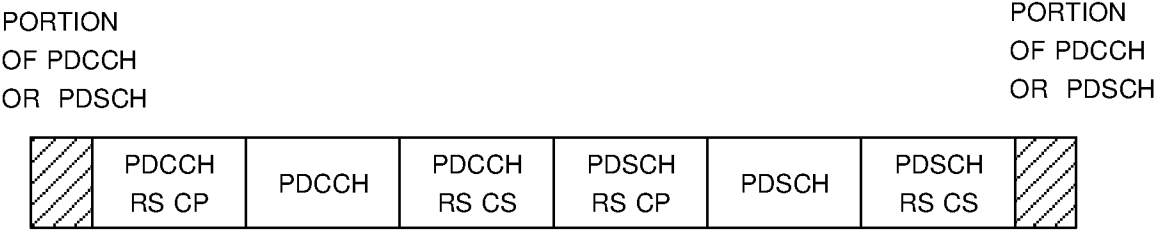


Figure 8C

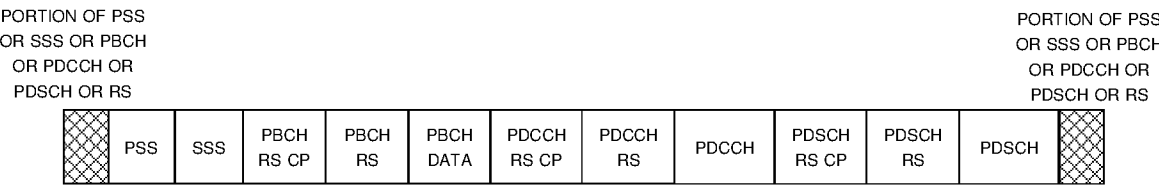


Figure 8D

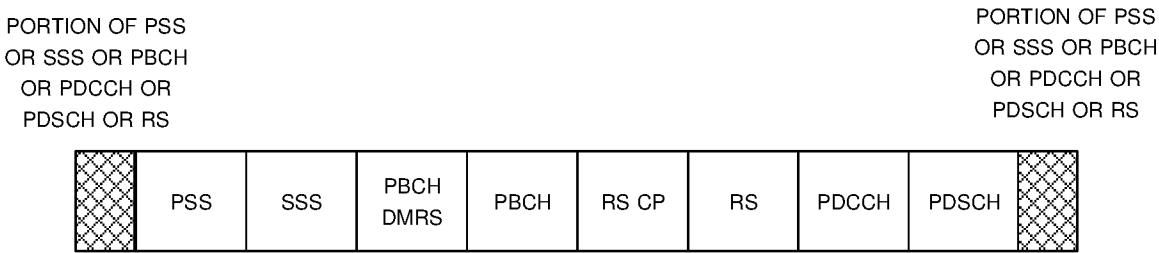


Figure 8E

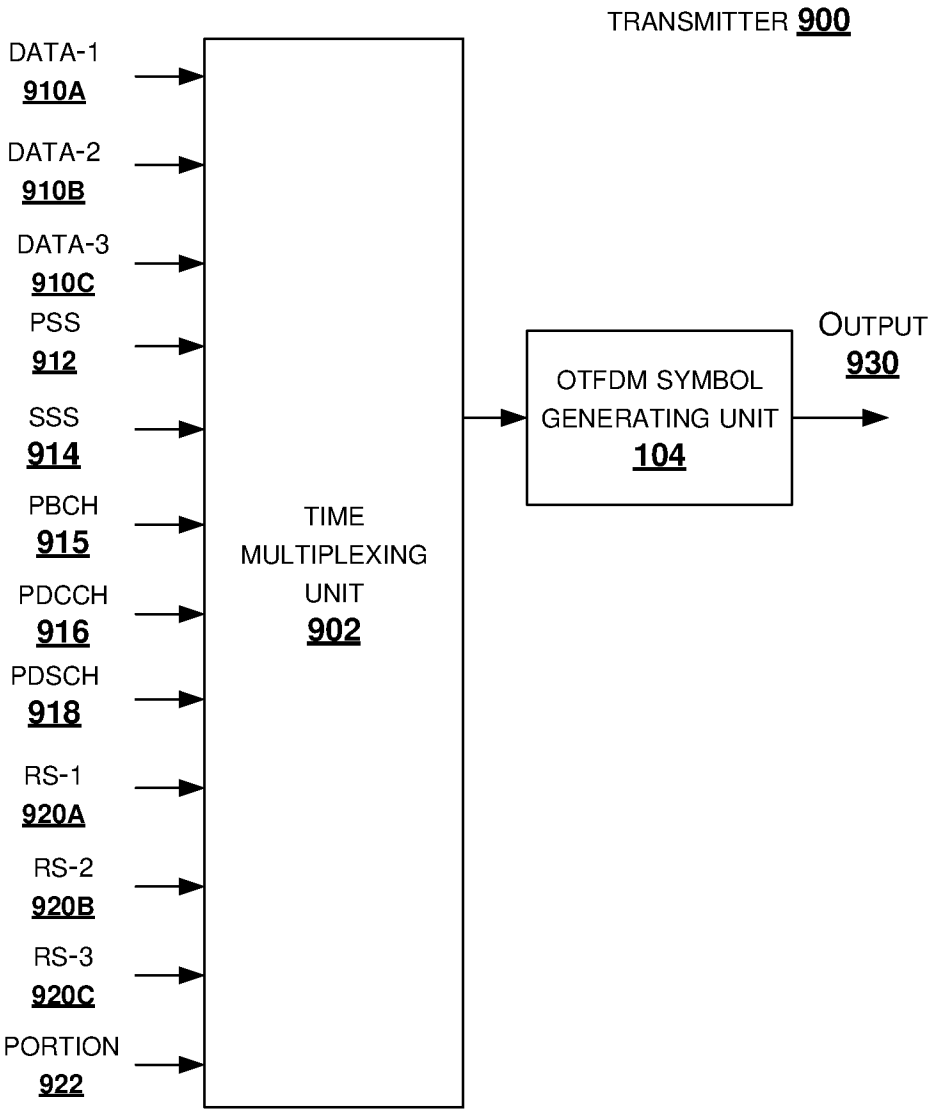


Figure 9

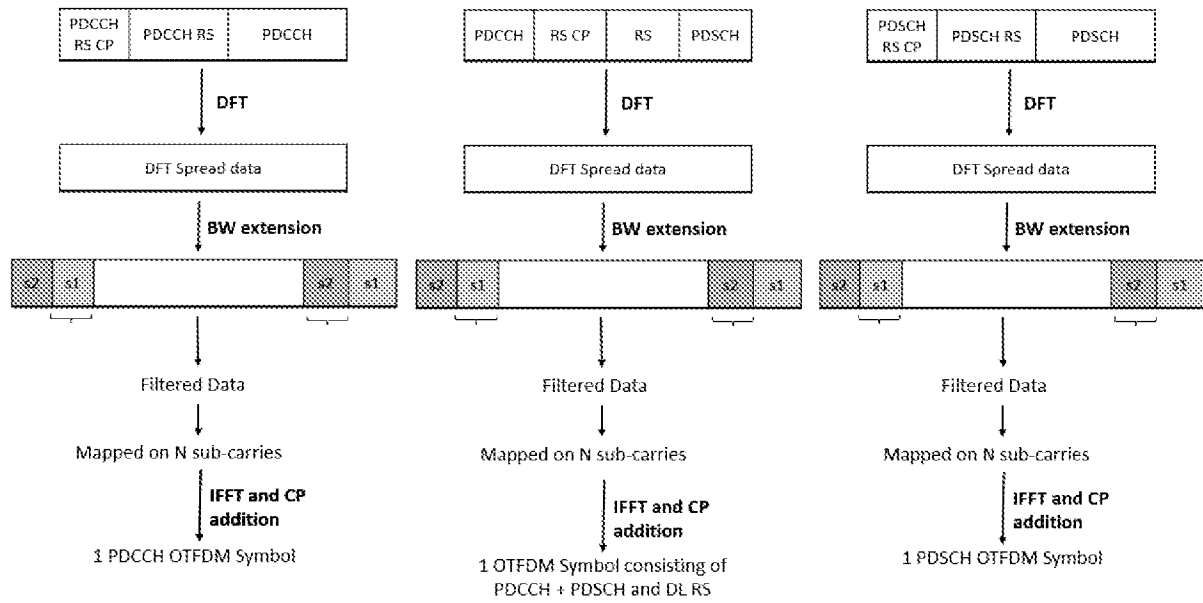


Figure 10

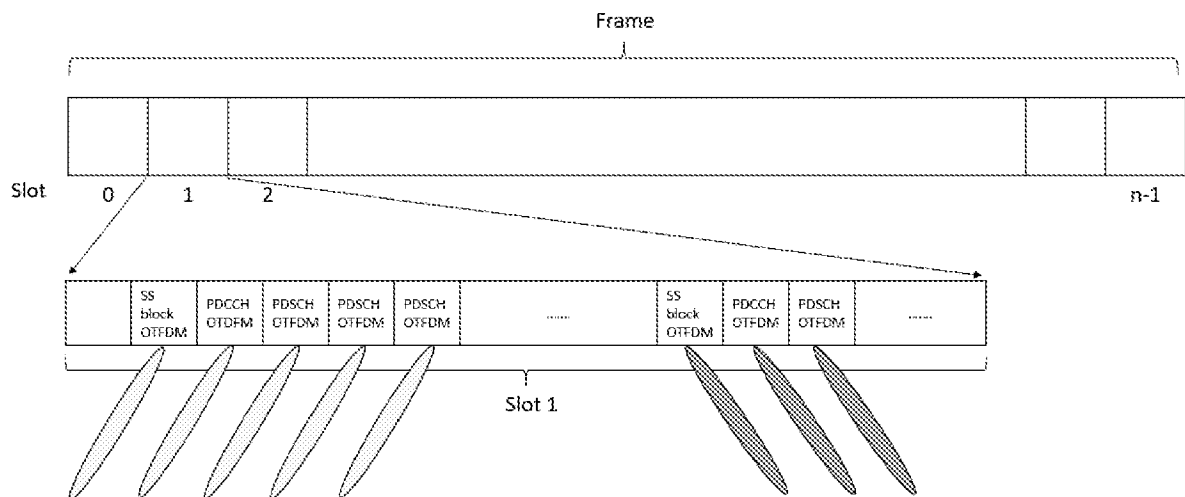


Figure 11

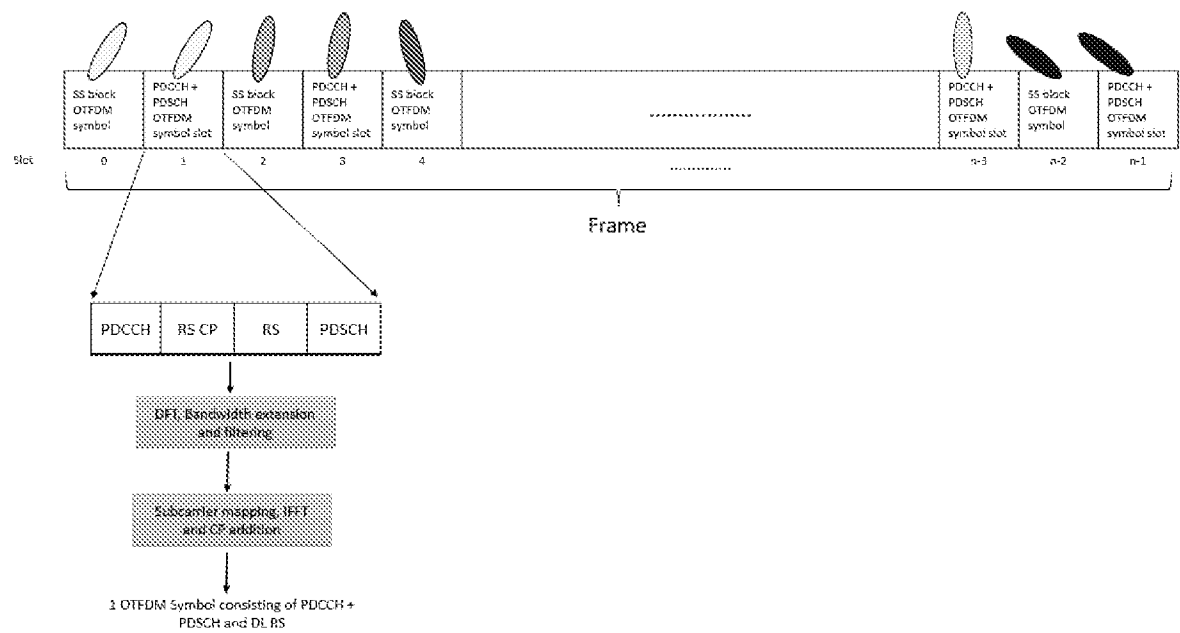


Figure 12

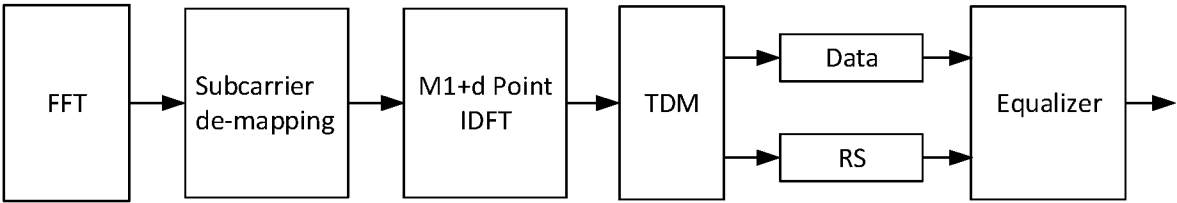


Figure 14A

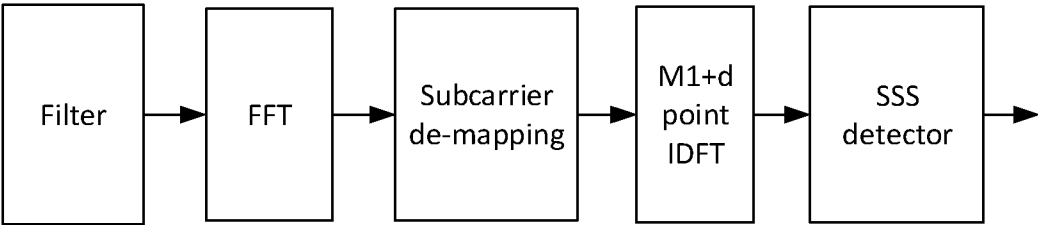


Figure 13B

Since PSS is in time domain, the receiver can detect PSS directly

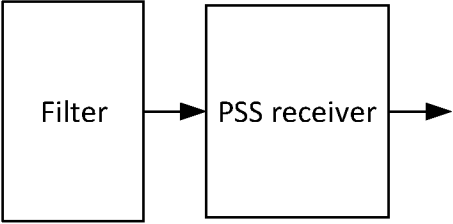


Figure 13C

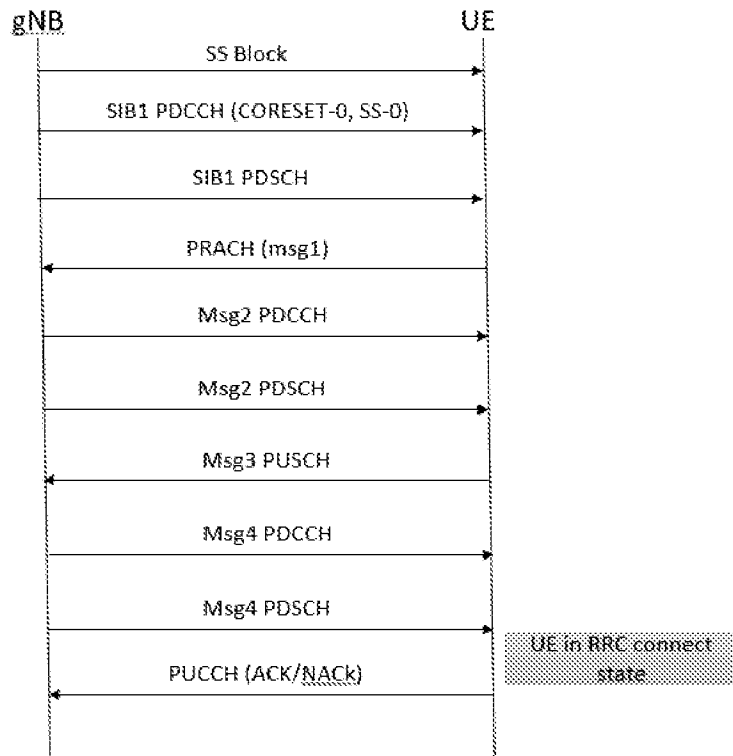


Figure 14A

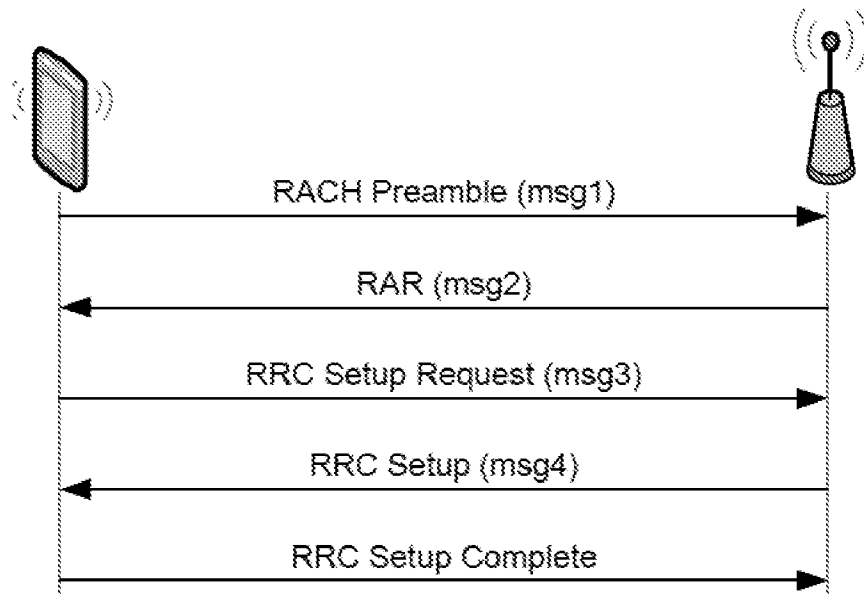


Figure 14B

PRACH symbols may be repeated over multiple OFDM symbols. The CP may be added for each symbol or one CP for the first symbol and rest of the symbols have no CP

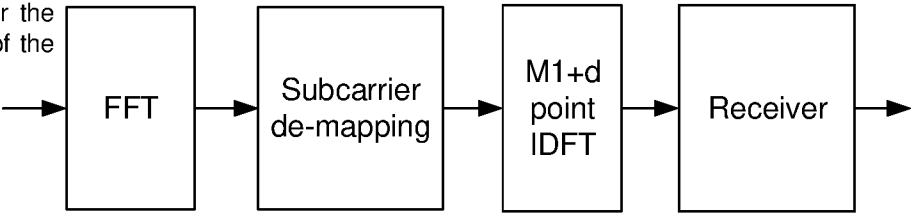


Figure 15A

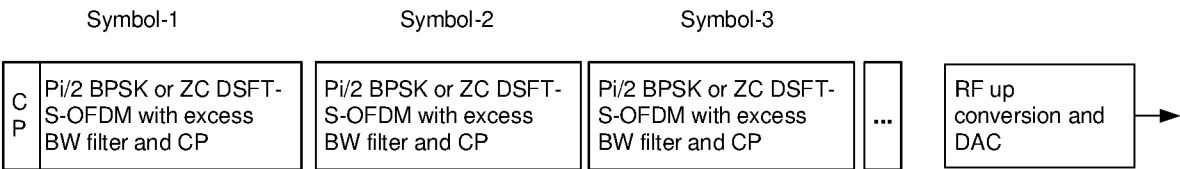


Figure 15B

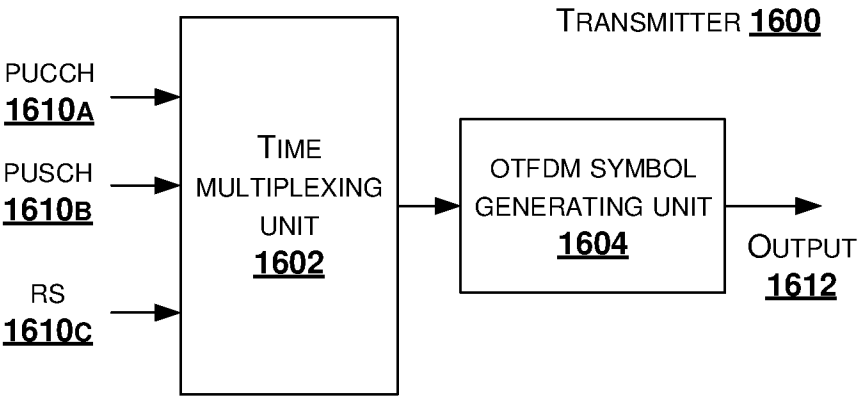


Figure 16A

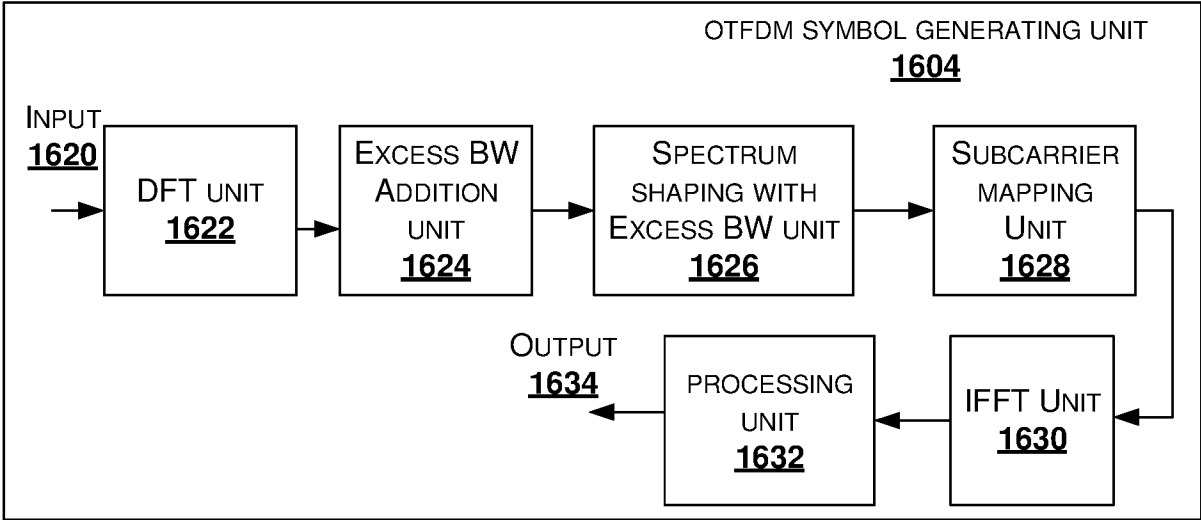


Figure 16B

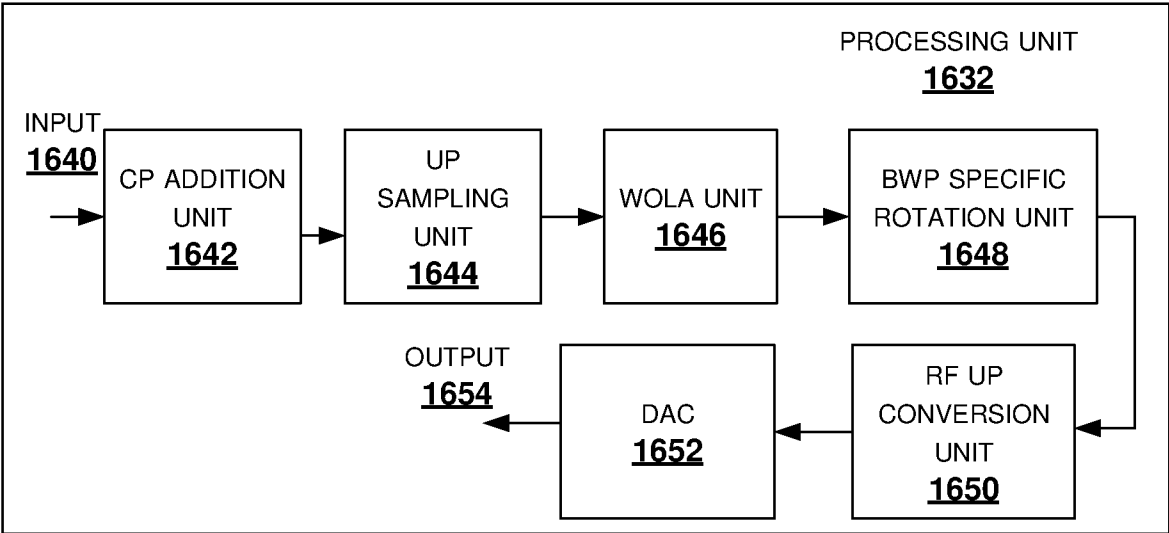


Figure 16C

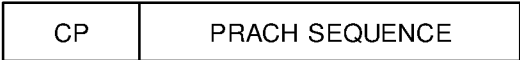


Figure 17A

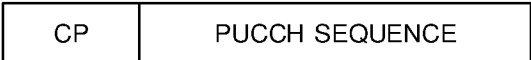


Figure 17B

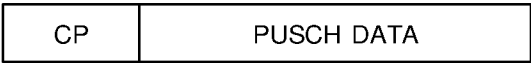


Figure 17C

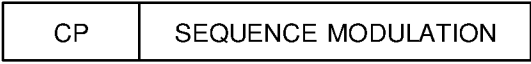


Figure 17D



Figure 17E

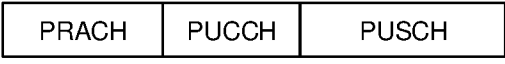


Figure 17F

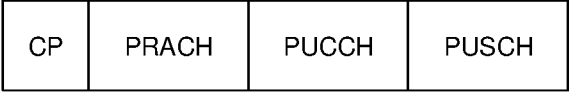


Figure 17G

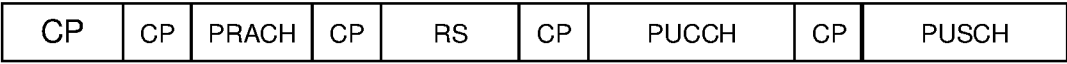


Figure 17H



Figure 17I

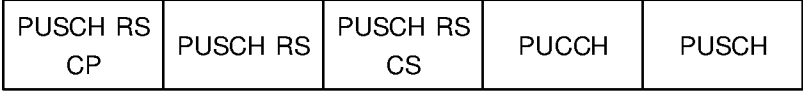


Figure 17J

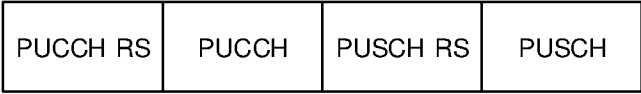


Figure 17K

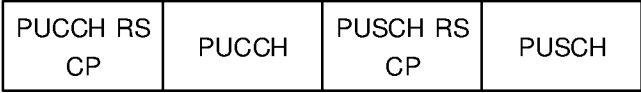


Figure 17L

PUCCH RS	PUCCH RS	PUCCH RS		PUCCH RS
PUCCH x w0	PUCCH x w1	PUCCH x w2		PUCCH x wn

Figure 17M

PRACH	PUSCH RS CP	PUSCH RS	PUSCH
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$l=0$

Figure 17N

PRACH	PUCCH RS CP	PUCCH RS	PUCCH
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$l=0$

Figure 17O

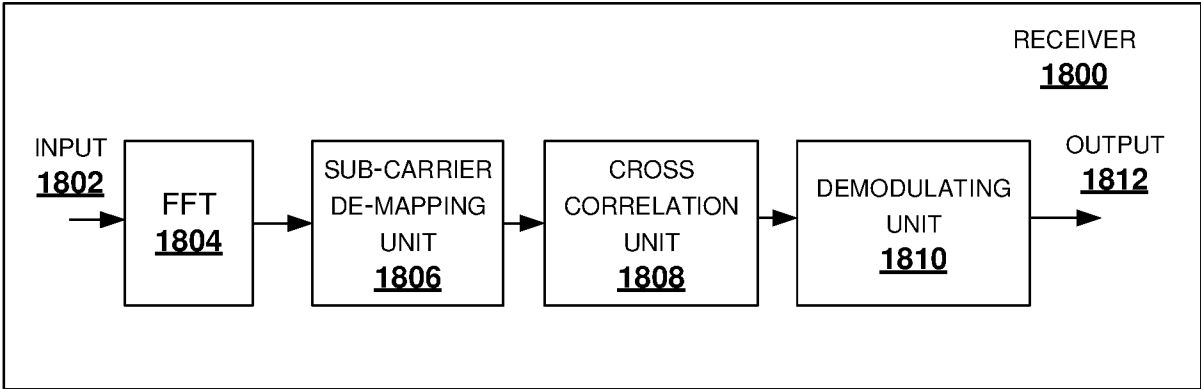


Figure 18A

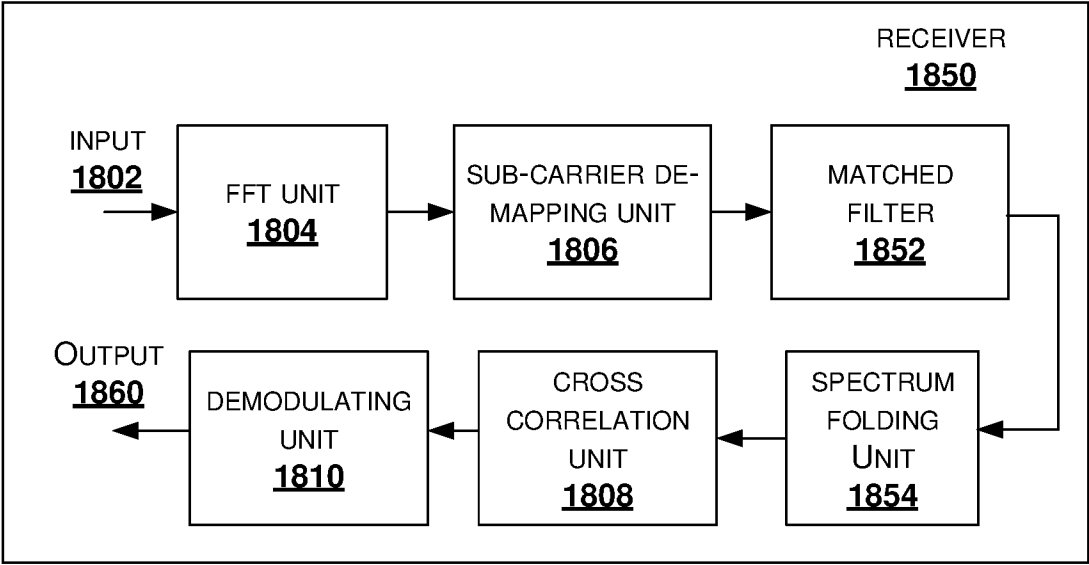


Figure 18B

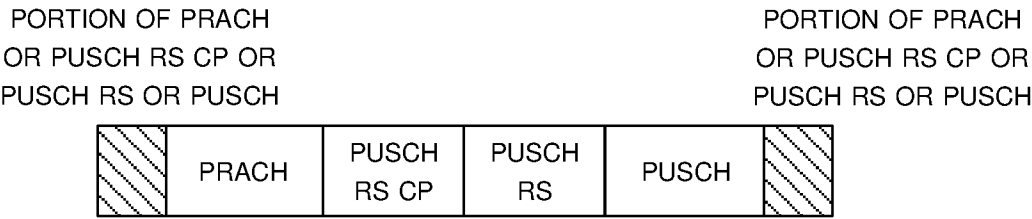


Figure 19A

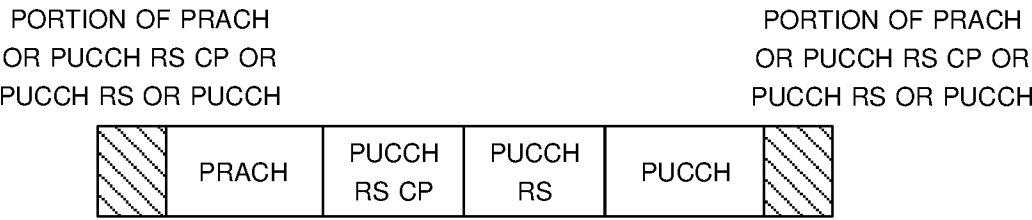


Figure 19B

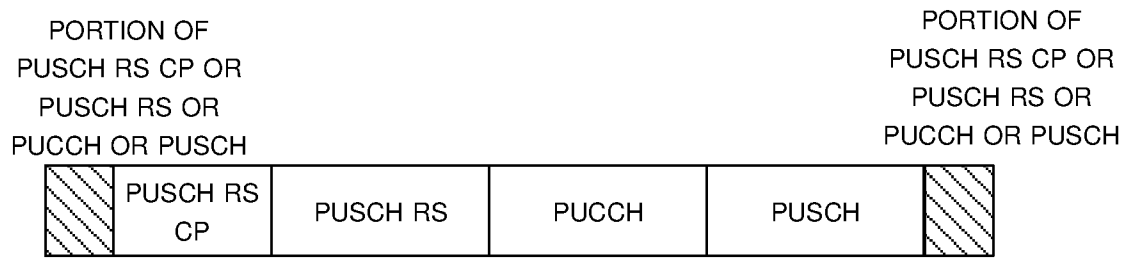


Figure 20A

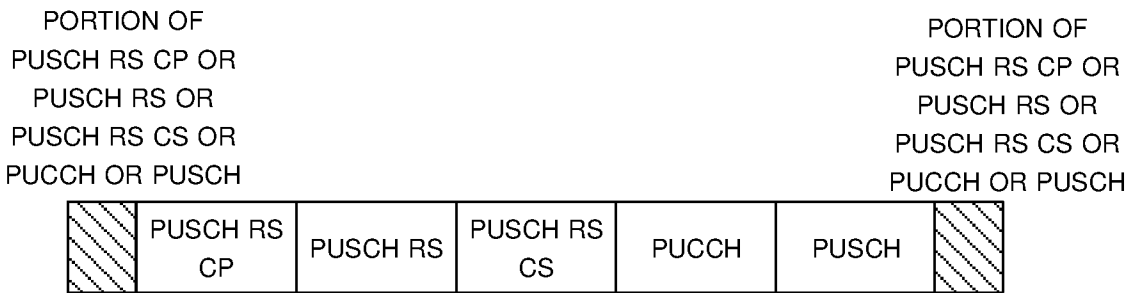


Figure 20B

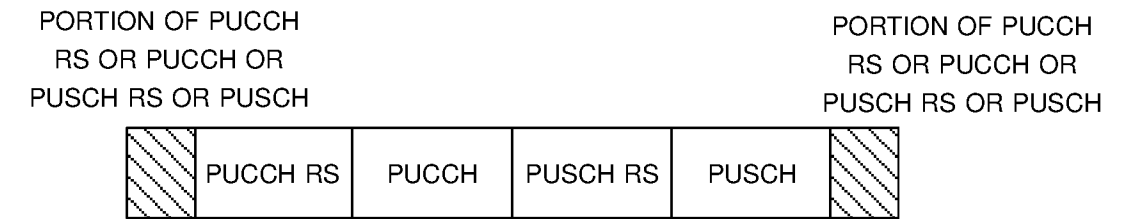


Figure 20C

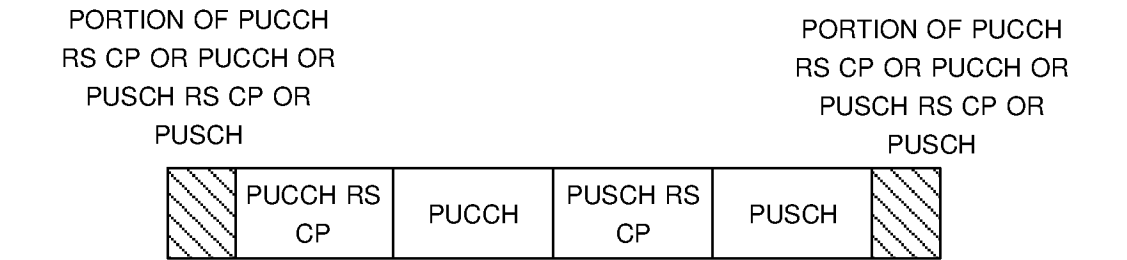


Figure 20D

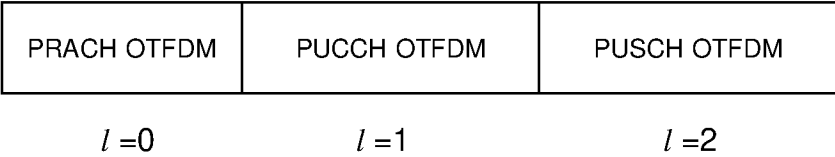


Figure 21A

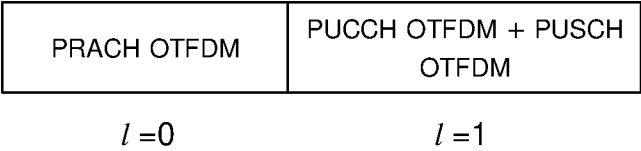


Figure 21B

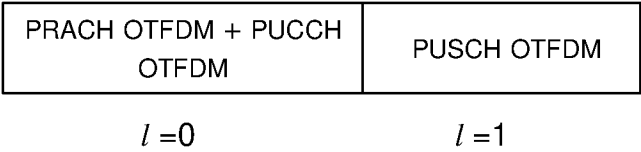


Figure 21C

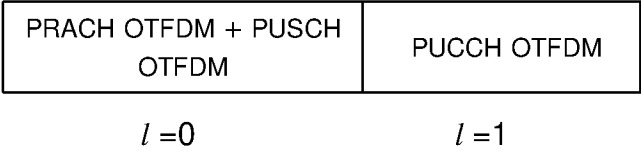


Figure 21D

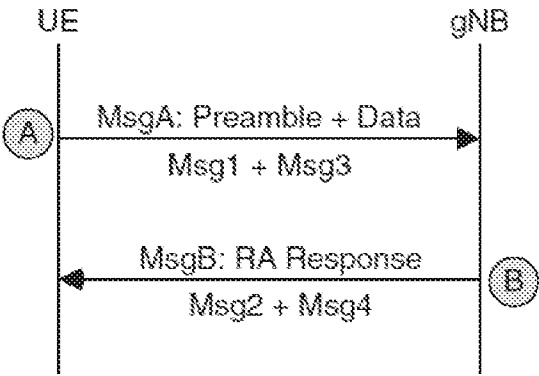


Figure 22

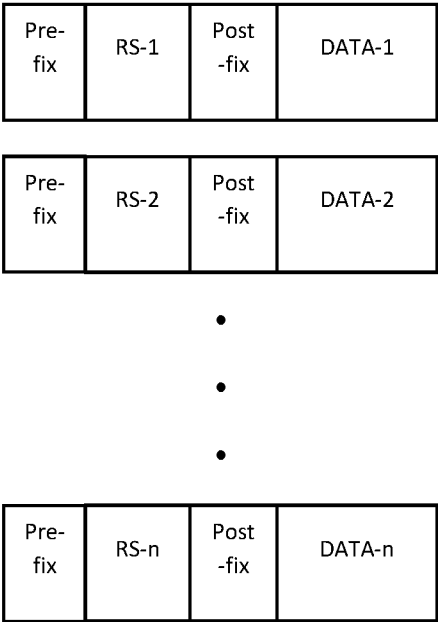


Figure 23A

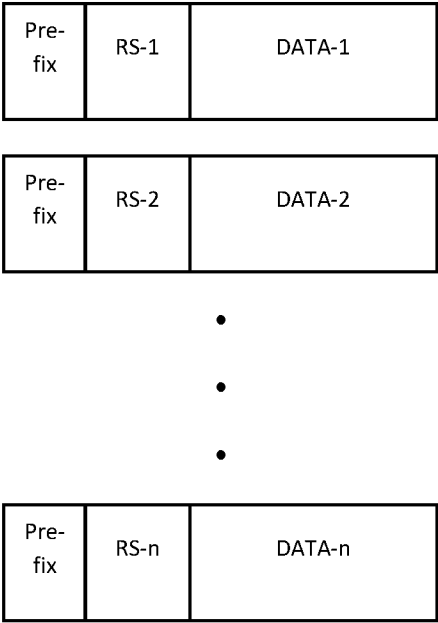


Figure 22B

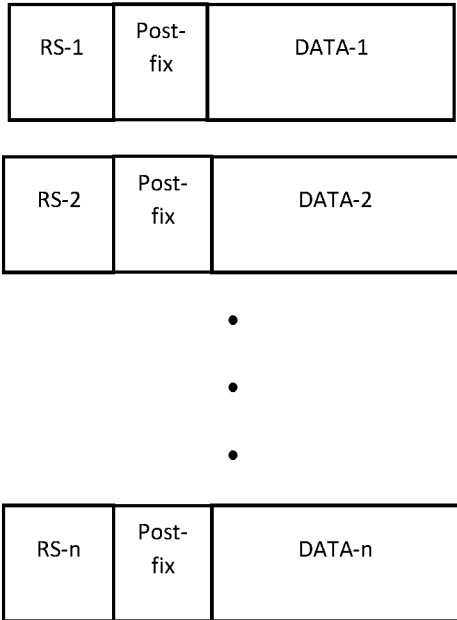


Figure 22C

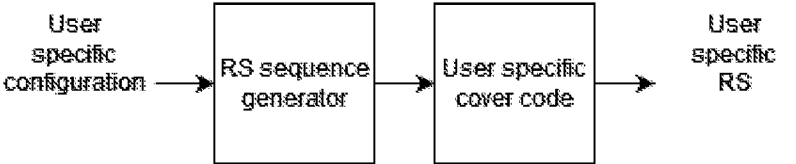


Figure 22D



Figure 23A



Figure 23B

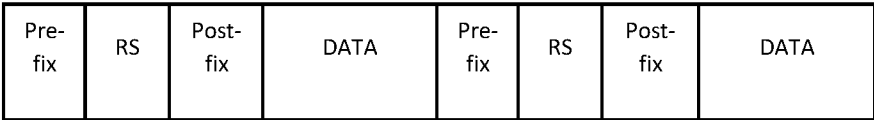


Figure 23C

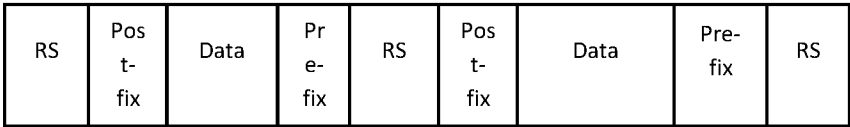


Figure 23D

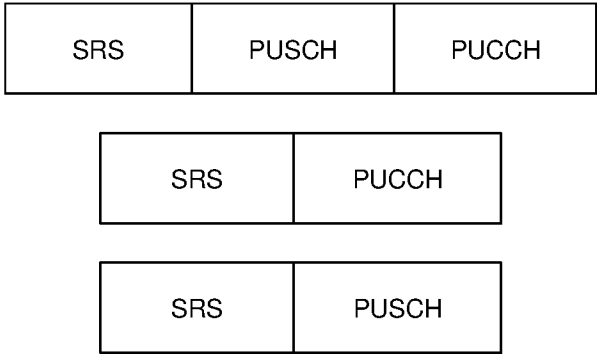
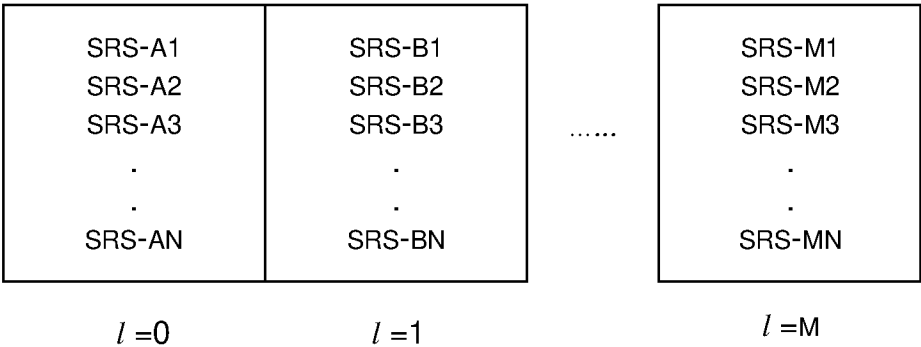


Figure 23E

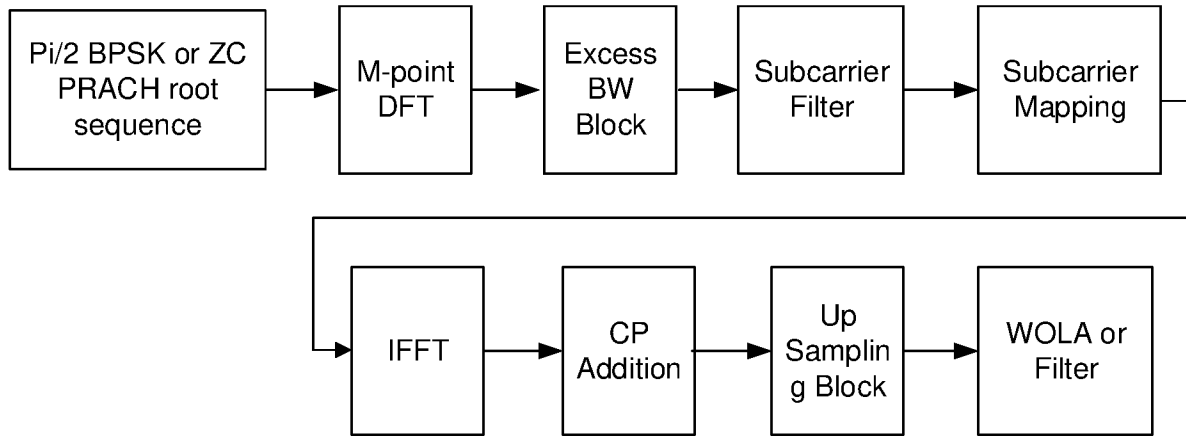


Figure 24A

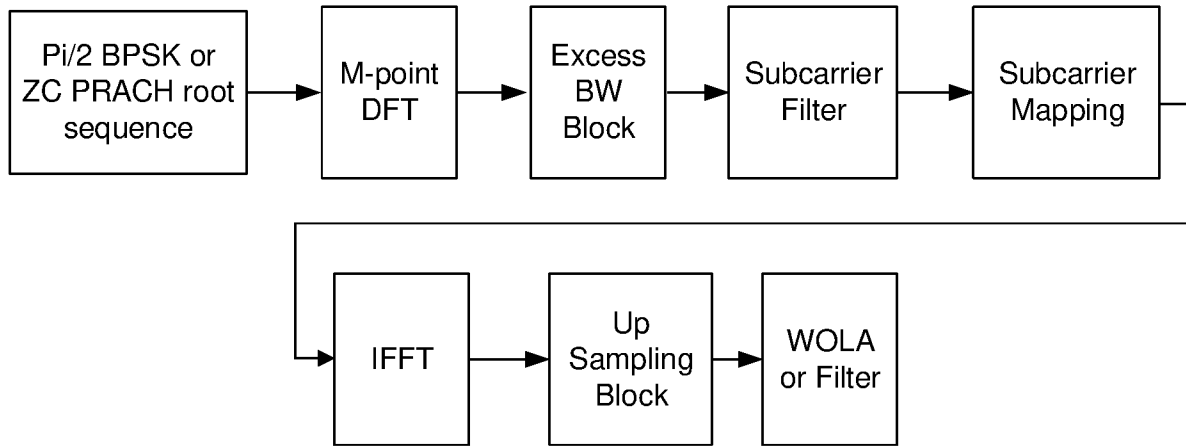


Figure 24B

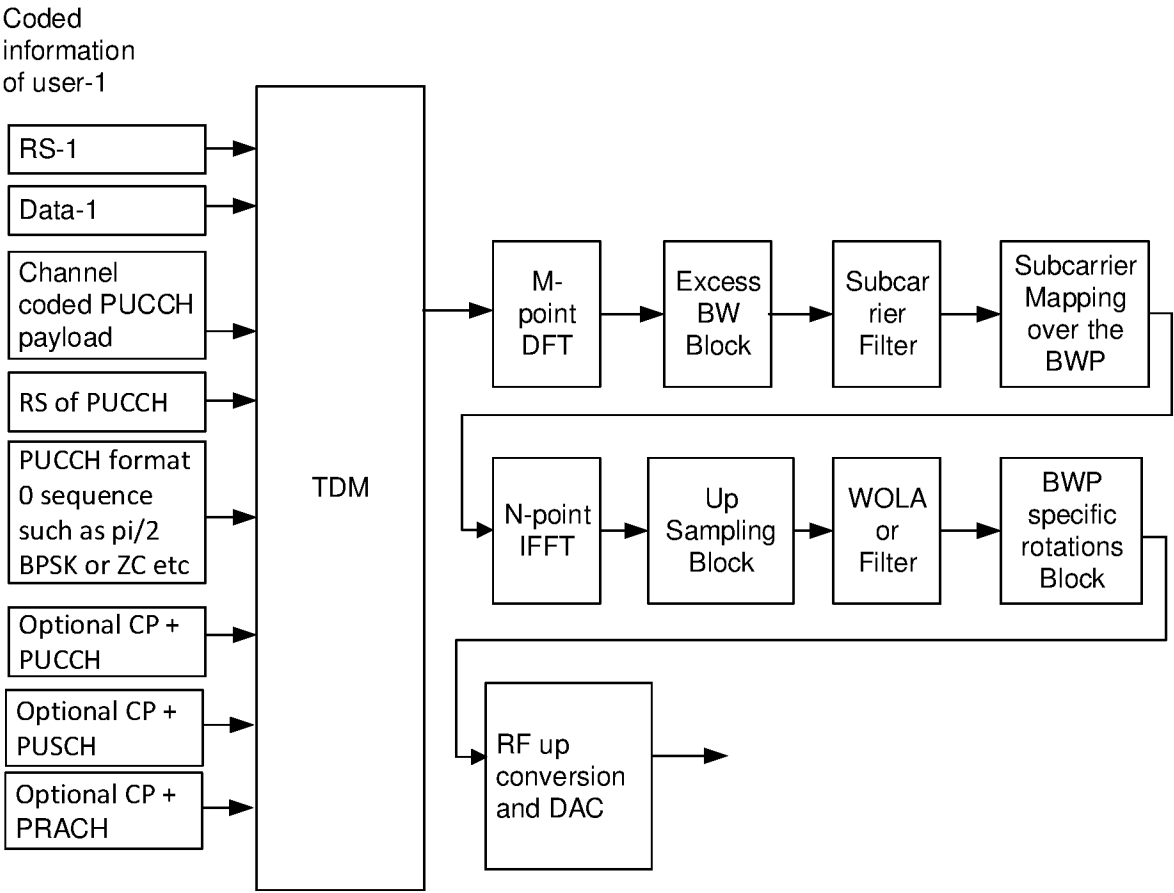
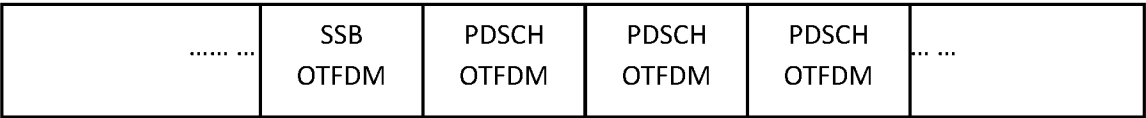
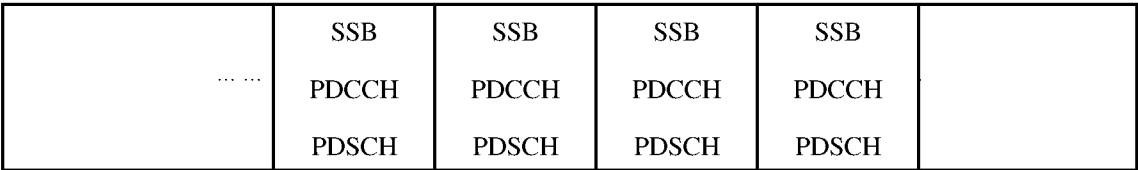


Figure 25



Type-1 DL slot

Figure 26A



Type-2 DL slot

Figure 26B

... ..	SSB	PDCCH	PDCCH	SSB	
		PDSCH	PDSCH		
		CSI-RS	CSI-RS		

Type-3 DL slot

Figure 26C

.....	PRACH	PUSCH	PUSCH	PUSCH	
		PUCCH	PUCCH	PUCCH	

Type-1 UL slot

Figure 26D

.....	PRACH	PUSCH	PUSCH	PUSCH	
		PUCCH	PUCCH	PUCCHSR	

Type-2 UL slot

Figure 26E

.....	PRACH	PUSCH	PRACH	PUSCH	...
	PUSCH	PUCCH	PUSCH	PUCCH	
			PUCCH	SRS	
			SRS		

Type-3 UL slot

Figure 26F

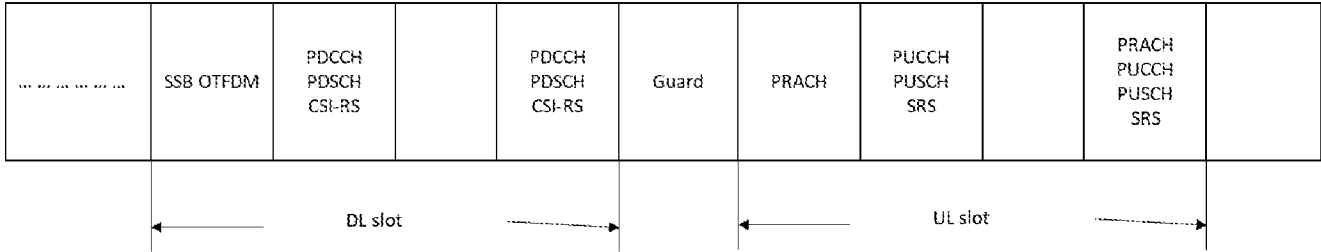
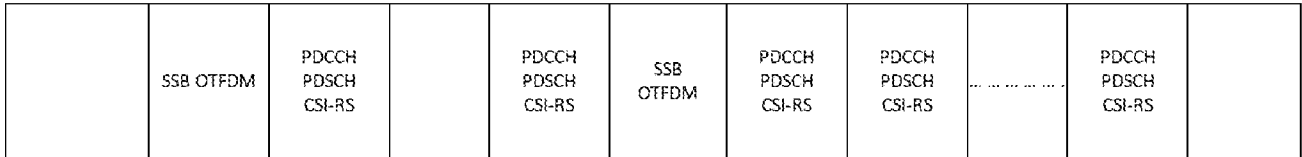
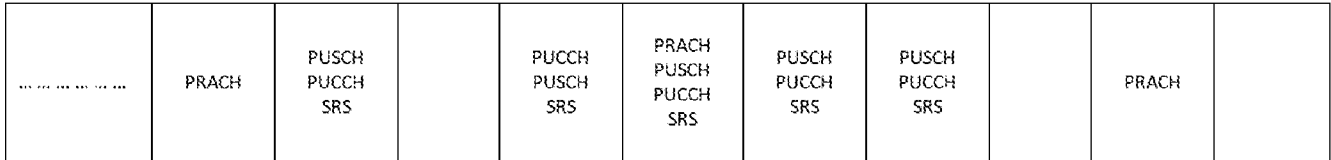


Figure 26G



FDD DL frame structure

Figure 26H



FDD UL frame structure

Figure 26I

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2024/050301

A. CLASSIFICATION OF SUBJECT MATTER

H04L27/26, H04L5/00, H04J11/00 Version=2024.01

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, H04J

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

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

PatSeer, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US20190373597A1 (APPLE CORP., INTEL CORP) 05 DECEMBER 2019 (05/12/2019) Paragraph [0045], [0059]	1-28, 30-31, 33, 37
X	EP3443704A2 (TELEFONAKTIEBOLAGET LM ERICSSON AB) 20 FEBRUARY 2019 (20/02/2019) Paragraph [0529], [0561], [0642], [0647], [0662], [0751]	29, 32, 34, 35, 36
Y	EP3443704A2 (TELEFONAKTIEBOLAGET LM ERICSSON AB) 20 FEBRUARY 2019 (20/02/2019) Paragraph [0046], [0525], [0529], [0561], [0642], [0647], [0662], [0751]	1-28, 30-31, 33, 37

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

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"&" document member of the same patent family

Date of the actual completion of the international search

29-08-2024

Date of mailing of the international search report

29-08-2024

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IN2024/050301

Citation	Pub.Date	Family	Pub.Date
US 20190373597 A1	05-12-2019	EP 3823206 A1	19-05-2021
		CN 107852321 A	27-03-2018
		WO 2017019132 A1	02-02-2017
EP 3443704 A2	20-02-2019	US 20230224059 A1	13-07-2023
		KR 20200145849 A	30-12-2020
		JP 7075897 B2	26-05-2022