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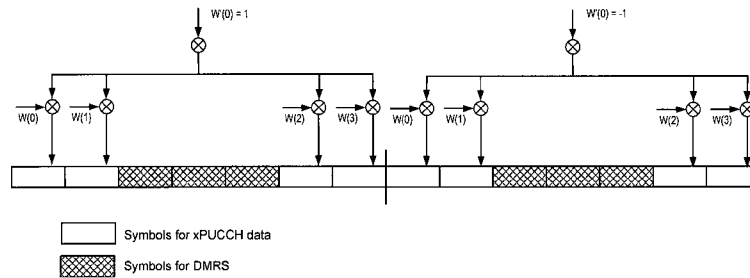


FIG. 2a

(57) Abstract: Technology described herein relates to collision avoidance for an advanced Physical Uplink Control Channel (xPUCCH) that is transmitted in non-edge portions of a frequency band. Due to the flexibility with which Physical Resource Blocks (PRBs) can be allocated for the xPUCCH of a Fifth Generation (5G) system, resource collisions with a Physical Uplink Shared Channel (PUSCH) or a Sounding Reference Signal (SRS) can potentially occur. Examples of the present disclosure provide technologies that allow such resource collisions to be avoided in pair-wise distributed and cluster-wise distributed localized PRB allocation schemes.

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COLLISION AVOIDANCE TECHNOLOGY FOR AN ENHANCED PHYSICAL UPLINK CONTROL CHANNEL

BACKGROUND

5 [0001] Wireless mobile communication technology uses various standards and protocols to transmit data between a node (e.g., a transmission station) and a wireless device (e.g., a mobile device). Some wireless devices communicate using orthogonal frequency-division multiple access (OFDMA) in a downlink (DL) transmission and single carrier frequency division multiple access (SC-FDMA) in an uplink (UL) transmission.

10 Standards and protocols that use orthogonal frequency-division multiplexing (OFDM) for signal transmission include the third generation partnership project (3GPP) long term evolution (LTE), the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard (e.g., 802.16e, 802.16m), which is commonly known to industry groups as WiMAX (Worldwide interoperability for Microwave Access), and the IEEE 802.11
15 standard, which is commonly known to industry groups as WiFi.

[0002] In 3GPP radio access network (RAN) LTE systems, the node in an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) system is referred to as an eNode B (also commonly denoted as evolved Node Bs, enhanced Node Bs, eNodeBs, or eNBs), which communicates with the wireless device, known as a user
20 equipment (UE). The downlink (DL) transmission can be a communication from the node (e.g., eNodeB) to the wireless device (e.g., UE), and the uplink (UL) transmission can be a communication from the wireless device to the node.

[0003] In LTE, data can be transmitted from the eNodeB to the UE via a physical downlink shared channel (PDSCH). A physical uplink control channel (PUCCH) can be
25 used to acknowledge that data was received. Downlink and uplink channels or transmissions can use time-division duplexing (TDD) or frequency-division duplexing (FDD).

BRIEF DESCRIPTION OF THE DRAWINGS

30 [0004] Features and advantages of the disclosure will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the disclosure; and, wherein:

- [0005] FIG. 1 is a diagram illustrating a localized xPUCCH format 1x when a normal cyclic prefix (CP) is used in accordance with an example;
- [0006] FIGs. 2a–b are diagrams of a localized xPUCCH of a first cell and a localized xPUCCH of a second cell, respectively, in accordance with an example;
- 5 [0007] FIGs. 3a–b are diagrams of a localized xPUCCH of a first cell and a localized xPUCCH of a second cell, respectively, in accordance with an example;
- [0008] FIG. 4 illustrates an example of a shortened localized xPUCCH format 2a/2b that uses a normal CP structure;
- [0009] FIG. 5 illustrates an example of a localized xPUCCH format 2a/2b that can
10 be used to support an extended CP structure;
- [0010] FIG. 6 illustrates an example of a localized xPUCCH format 3 that can be used to support up to five UEs at a time with an SRS in the same subframe;
- [0011] FIG. 7 illustrates functionality of an apparatus of a UE in accordance with an example;
- 15 [0012] FIG. 8 illustrates functionality of an apparatus of a UE in accordance with an example;
- [0013] FIG. 9 illustrates functionality of cellular base station in accordance with an example;
- [0014] FIG. 10 illustrates a diagram of radio frame resources (e.g., a resource
20 grid) for a downlink (DL) transmission including a legacy physical downlink control channel (PDCCH) in accordance with an example;
- [0015] FIG. 11 provides an example illustration of a wireless device in accordance with an example;
- [0016] FIG. 12 provides an example illustration of a user equipment (UE) device,
25 such as a wireless device, a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device; and
- [0017] FIG. 13 illustrates a diagram of a node (e.g., eNB and/or a Serving GPRS Support Node) and a wireless device (e.g., UE) in accordance with an example.
- [0018] Reference will now be made to the exemplary embodiments illustrated and
30 specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of is thereby intended.

DETAILED DESCRIPTION

[0019] Before some embodiments are disclosed and described, it is to be understood that the claimed subject matter is not limited to the particular structures, process operations, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular examples only and is not intended to be limiting. The same reference numerals in different drawings represent the same element. Numbers provided in flow charts and processes are provided for clarity in illustrating operations and do not necessarily indicate a particular order or sequence.

[0020] An initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail later. This initial summary is intended to aid readers in understanding the technology more quickly, but is not intended to identify key features or essential features of the technology nor is it intended to limit the scope of the claimed subject matter.

[0021] For Fifth-Generation (5G) Systems, Orthogonal Frequency Division Multiple Access (OFDMA) is viewed as a strong candidate to for the 5G uplink waveform. This would allow downlink (DL) and uplink (UL) transmissions for 5G to have a symmetric waveform. A symmetric waveform would be convenient for a number of wireless applications, such as the Internet of Things (IoT) and Machine-Type Communication (MTC).

[0022] In addition, in 5G systems, it is possible for an advanced Physical Uplink Control Channel (xPUCCH) to be transmitted in non-edge portions of a frequency band. Instead, 5G systems can flexibly adopt localized or distributive Physical Resource Block (PRB) allocation schemes for the xPUCCH based on channel quality considerations. In this manner, high-order diversity gain and frequency-scheduling gain can be achieved and xPUCCH performance can be improved. In scenarios where millimeter waves (mmWaves) are used, a scheduling-based xPUCCH can be supported to provide beamforming gain. This promotes deployment of a localized xPUCCH.

[0023] In a localized xPUCCH, a Demodulation Reference Signal (DMRS) can be shared between an even slot and an odd slot in the same subframe. If this type of sharing is utilized, the structure of the xPUCCH can be designed in order to increase the

xPUCCH capacity, avoid inter-cell interference, and improve the Signal-to-Interference-plus-Noise Ratio (SINR).

[0024] Due to the flexibility with which PRBs can be allocated for the xPUCCH, resource collisions with a Physical Uplink Shared Channel (PUSCH) or a Sounding

5 Reference Signal (SRS) can potentially occur. Examples of the present disclosure provide ways for such resource collisions to be avoided.

[0025] For localized xPUCCH PRB allocation, a least two different types of mapping schemes can be applied. One example scheme is pair-wise distributed PRB allocation, where a PRB allocated to the xPUCCH can have a physical resource block

10 number n'_{PRB} that satisfies:

$$[0026] \quad n'_{PRB}(m') = \begin{cases} \left\lfloor \frac{m' - 2^\alpha + 1}{2^{\alpha+1}} N_{RB}^{UL} \right\rfloor, & \text{if } \text{mod}(m', 2) = 0 \\ \left\lfloor \left(\frac{1}{2} + \frac{m' - 2^\alpha}{2^{\alpha+1}} \right) N_{RB}^{UL} \right\rfloor, & \text{if } \text{mod}(m', 2) = 1 \end{cases}$$

$$\alpha = \lfloor \log_2(m') \rfloor$$

[0027] where m' denotes a conventional integer index of the PRB, mod is a modulus operator, and N_{RB}^{UL} denotes the number of resource blocks during the whole uplink bandwidth. A physical resource block pair can be defined as the two physical

15 resource blocks in one subframe having the same physical resource block number n'_{PRB} .

[0028] Another example scheme is cluster-wise distributed PRB allocation, where a PRB allocated to the xPUCCH can have a physical resource block number n'_{PRB} that satisfies:

$$n'_{PRB} = \begin{cases} \alpha, & \text{if } \beta = 0 \\ \left\lfloor \beta \frac{N_{RB}^{UL}}{N_{block} - 1} \right\rfloor + (-1)^\alpha \left\lfloor \frac{\alpha}{2} \right\rfloor, & \text{otherwise} \\ N_{RB}^{UL} - \alpha - 1, & \text{if } \beta = N_{block} - 1 \end{cases}$$

$$\alpha = \left\lfloor \frac{m'}{N_{block}} \right\rfloor, \beta = \text{mod}(m', N_{block})$$

20 [0029] where m' denotes a conventional integer index of the PRB, mod is a modulus operator, N_{RB}^{UL} denotes the number of resource blocks in an uplink (UL) slot, and N_{block} denotes a number of cluster PRBs allocated for xPUCCH transmission.

[0030] When localized xPUCCH PRB allocation is used according to the example schemes above, a PRB allocated for the xPUCCH will have the same PRB number regardless of whether the PRB is in an even-numbered slot or an odd-numbered slot.

[0031] FIG. 1 is a diagram illustrating a localized xPUCCH format 1x when a normal cyclic prefix (CP) is used and $N_{SF}^{PUCCH} = 4$, where N_{SF}^{PUCCH} denotes a number of symbols used for the PUCCH per slot in a subframe (SF). A first slot 100a can include symbols 102a–g and a second slot 100b can include symbols 102h–n. Symbols 102c–e and symbols 102j–l can be used to transmit a Demodulation Reference Signal (DMRS). Symbols 102a–b, 102f–i, and 102m–n can be used to transmit the PUCCH.

10

Improved localized xPUCCH format 1/1a/1b design for capacity improvement

[0032] An additional orthogonal sequence $[w'(0) \ w'(1)]$ (e.g., a Walsh code of length 2) can be applied between the an even and an odd slot that are used to transmit a PUCCH according to the equation

$$z^{(p)}(k, l) = \begin{cases} w'(0)z^{(p)}(k, l), & n_s \bmod 2 = 0 \\ w'(1)z^{(p)}(k, l), & n_s \bmod 2 = 1 \end{cases}$$

15

[0033] wherein $z^{(p)}(k, l)$ is a complex-value symbol that maps to a resource element (k, l) at a frequency index k and a time-symbol index l on an antenna port number p that has an index \tilde{p} , n_s is a slot number within the radio frame for a slot in which the resource element is located, \bmod is a modulus operator, $w'(0)$ is a real or complex-valued scalar, $w'(1)$ is a real or complex-valued scalar, and $z^{(p)}(k, l)$ is a complex-value symbol that results when the additional orthogonal sequence is applied.

20

[0034] In this way, the capacity of the localized xPUCCH is doubled, since an additional dimension is provided when the additional orthogonal code is applied between the two slots of the same subframe. For $N_{SF}^{PUCCH} = 4$, for example, a maximum number of format-1 xPUCCHs that can be multiplexed on the same PRB can be increased from 36 to 72.

25

[0035] Meanwhile, the additional localized xPUCCH candidates still maintain the same orthogonality as a conventional xPUCCH. So the localized xPUCCH elements can co-exist in a same PRB pair with distributed xPUCCH elements such that legacy compatibility is maintained.

30

[0036] In one example, the orthogonal sequence sets $\{ [1 \ -1], [1 \ 1] \}$, $\{ [j \ j], [j \ -j] \}$ can be adopted for $[w'(0) \ w'(1)]$, wherein j is the imaginary unit (i.e., the solution to the equation $x^2 = -1$). In another example, an orthogonal sequence index $n_{oc}^{(\bar{p})}$ for $[w'(0) \ w'(1)]$ can be configured by Radio Resource Control (RRC) signaling or by adding a 1-bit indicator in uplink-related downlink control information (DCI). In another example, the orthogonal sequence index of $[w'(0) \ w'(1)]$ can be calculated according to the equation

$$n_{oc}^{(\bar{p})} = n_{PUCCH}^{(1,\bar{p})} \bmod 2,$$

[0037] where $n_{PUCCH}^{(1,\bar{p})}$ is a resource index for a format 1, 1a, or 1b of the xPUCCH and \bmod is a modulus operator. Previous versions of format 1, 1a, or 1b can be found in 3GPP Technical Specification (TS) 36.211 version 12.2.0 (or earlier versions of 3GPP TS 36.211).

Improved localized xPUCCH format1/1a/1b design for performance improvement

[0038] Alternatively, the additional orthogonal sequence can be configured in a cell-specific fashion in order to reduce the inter-cell interference on the localized xPUCCH.

[0039] FIGs. 2a–b are diagrams of a localized xPUCCH of a first cell and a localized xPUCCH of a second cell, respectively. As shown in FIG. 2a, the first cell adopts $[1 \ -1]$ for $[w'(0) \ w'(1)]$. As shown in FIG. 2b, the second cell 1 adopts $[1 \ 1]$. In this way, mutual interference between the first cell and the second call is avoided.

[0040] In one example, a 1-bit indicator can be added to enable the orthogonal sequence $[w'(0) \ w'(1)]$ for capacity boosting or interference avoidance. A value of 0 for the 1-bit indicator can indicate the system capacity improvement is desired, while a value of 1 for the 1-bit indicator can indicate the interference avoidance is desired. The 1-bit indicator can be configured by RRC signaling or a system information block (SIB).

[0041] In another example, the orthogonal sequence index $n_{oc}^{(\bar{p})}$ for $[w'(0) \ w'(1)]$ may be configured by RRC signaling or a SIB. Alternatively, the orthogonal sequence index may be calculated according to an index cell identifier (ID) or a virtual cell ID according to the equation

$$n_{oc}^{(\bar{p})} = n_{cell \ ID} \bmod 2,$$

[0042] Where $n_{cell\ ID}$ is a cell identifier (ID) of a cell and **mod** is a modulus operator.

Improved localized/distributed xPUCCH format1/1a/1b design

5 [0043] The performance of the xPUCCH can be further improved by extending the orthogonal sequence set. Currently, three orthogonal sequences are adopted when $N_{SF}^{PUCCH} = 4$, including $[1\ 1\ 1\ 1]$, $[1\ -1\ 1\ -1]$, and $[1\ -1\ -1\ 1]$. An additional sequence $[+1\ +1\ -1\ -1]$ can be added as an alternative candidate. Four alternative sequences can therefore be made available for three indexes. This can provide

10 orthogonality redundancy and enable different cells to choose different orthogonal sequences. As a result, inter-cell interference can be reduced. In some examples, the available orthogonal sequences of each cell can be cell specifically configured by a SIB.

[0044] FIGs. 3a–b are diagrams of a localized xPUCCH of a first cell and a localized xPUCCH of a second cell, respectively. As shown in FIG. 3a, the first cell uses

15 the orthogonal sequence $[1\ 1\ 1\ 1]$. As shown in FIG. 3b, the second cell uses the orthogonal sequence $[+1\ +1\ -1\ -1]$. In this way, mutual interference between the first cell and the second call is avoided.

Improved xPUCCH Format 2x Structure Shortened structure to avoid collision between xPUCCH and SRS

20 [0045] In conventional LTE systems, when there is a collision between a sounding reference signal (SRS) and PUCCH format 2, a UE does not transmit a type-0-triggered SRS if the type-0-triggered SRS and PUCCH format 2/2a/2b transmissions happen to coincide in the same subframe. A UE does not transmit a type-1-triggered SRS

25 whenever the type-1-triggered SRS and PUCCH format 2a/2b (or format 2 with HARQ-ACK) transmissions happen to coincide in the same subframe. A UE does not make PUCCH format 2 transmission without a Hybrid Automatic Repeat Request Acknowledgment (HARQ-ACK) whenever a type-1-triggered SRS and PUCCH format 2 (without HARQ-ACK) transmissions happen to coincide in the same subframe.

30 [0046] A shortened xPUCCH format 2x can be supported in the localized xPUCCH so that a collision between the xPUCCH and the SRS can be avoided, thereby allowing a UE to transmit the SRS and the xPUCCH format 2x concurrently.

[0047] FIG. 4 illustrates an example of a shortened localized xPUCCH format 2a/2b that uses a normal CP structure. As shown, the complex-valued symbols $d(0)$, $d(1)$, and $d(10)$ can be carried in a first slot, while the complex-valued symbols $d(8)$ and $d(9)$ can be carried in a second slot. In addition, a muted symbol can be used as shown.

5 [0048] In one example, a 1-bit indicator can be configured by downlink control information (DCI), RRC signaling, or a SIB to inform UE whether to use the shortened xPUCCH format 2x or use the collision avoidance rule of the conventional LTE systems. In another example, the shortened xPUCCH format 2x can also be applied for with an extended CP. In another example, a UE can refrain from using the shortened xPUCCH
10 format 2x if there is collision between the xPUCCH and an aperiodical SRS. For collision avoidance between the xPUCCH and a periodical SRS, the examples above may be used.

Enabling xPUCCH format 2a/2b in extended CP structure

[0049] In conventional LTE systems, format 2a/2b (e.g., as described in 3GPP TS
15 36.211 version 12.2.0) cannot be supported under the extended CP structure because the number of reference signal symbols is equal to 1.

[0050] FIG. 5 illustrates an example of a localized xPUCCH format 2a/2b that can be used to support an extended CP structure. As shown, the last complex-value symbol $d(10)$ can be carried by the DMRS in the second slot. Legacy compatibility is preserved.
20

Improved xPUCCH Format3 Structure

[0051] In the legacy shortened PUCCH format 3, in order to avoid a collision between the SRS and PUCCH format 3, only up to four UEs can be supported at a time. However, since the DMRS can be shared between two slots in the same subframe, some
25 examples of the present disclosure provide an improved shortened localized xPUCCH format 3 that allows up to five UEs to be supported at a time with an SRS in the same subframe.

[0052] FIG. 6 illustrates an example of a localized xPUCCH format 3 that can be used to support up to five UEs at a time with an SRS in the same subframe. As shown in
30 FIG. 6, a normal CP structure can be used and a muted symbol can be used.

[0053] In one example, a 1-bit indicator can be configured by DCI, RRC signaling, or a SIB to notify a UE of whether to use the improved shortened xPUCCH format 3 or use the legacy collision avoidance rule. In another example, the improved

shortened xPUCCH format3 can be used with an extended CP. In another example, a UE can refrain from using the improved shortened xPUCCH format 3 if the xPUCCH collides with an aperiodic SRS. For collision avoidance with a periodic SRS, the examples above may be used. In another example, a mapping relationship between

5 $n_{oc}^{(\beta)}$ = 5 and $n'_p(n_s) = 10$ can be added to 3GPP TS 36.211, where the expression $n'_p(n_s)$ denotes resource indices within two resource blocks in two slots of a subframe to which the xPUCCH is mapped.

Design to avoid overlap between PUSCH and xPUCCH

[0054] When flexible xPUCCH PRB allocation is used, a collision between the

10 xPUCCH and the Physical Uplink Shared Channel (PUSCH) is possible. In order to avoid prevent such a collision, the RB distribution of the xPUCCH can be broadcast to all users.

[0055] A new parameter $N_{RB}^{(0)}$ can be defined as the maximum number of PRBs that will be assigned for xPUCCH transmission. The parameter $N_{RB}^{(0)}$ can be added to *PUCCH-ConfigCommon* in 3GPP TS 36.331.

15 [0056] One additional bit can be provided by a higher layer (e.g., *flag_pairwise*). This additional bit can be a parameter that is used to indicate whether pair-wise or cluster-wise PRB allocation is adopted.

[0057] After receiving these two parameters (e.g., $N_{RB}^{(0)}$ and *flag_pairwise*), the UE can determine which RBs are reserved for xPUCCH transmission. The UE can then mute

20 those REs for the xPUCCH when transmitting the xPUSCH.

[0058] In another example, this collision between the xPUCCH and the PUSCH may be avoided by an eNodeB scheduler. A resource allocation type for the PUSCH can be used to increase the resource allocation flexibility so that the PUSCH can be scheduled over several distributed RBs or more than two sets of continuous RBs.

25 [0059] FIG. 7 illustrates functionality 700 of an apparatus of a UE in accordance with an example. The functionality 700 can be implemented as a method or the functionality can be executed as instructions on a machine (e.g., by one or more processors), where the instructions are included on at least one non-transitory or transitory computer-readable storage medium.

30 [0060] As in block 710, circuitry at the UE (e.g., comprising one or more processors and memory) can be configured to identify Uplink Control Information (UCI) for the UE.

[0061] As in block 720, the circuitry at the UE can be further configured to allocate Physical Resource Blocks (PRBs) for an advanced Physical Uplink Control Channel (xPUCCH) in a localized fashion.

[0062] As in block 730, the circuitry at the UE can be further configured to apply an additional orthogonal sequence $[w'(0) w'(1)]$ between an even-numbered slot and an odd-numbered slot within the radio frame according to a definition:

$$z^{(p)}(k,l) = \begin{cases} w'(0)z^{(p)}(k,l), n_s \bmod 2 = 0 \\ w'(1)z^{(p)}(k,l), n_s \bmod 2 = 1 \end{cases},$$

wherein $z^{(p)}(k,l)$ is a complex-value symbol that maps to a resource element at a frequency index k and a time-symbol index l on an antenna port number p that has an index \tilde{p} , n_s is a slot number within the radio frame for a slot in which the resource element is located, **mod** is a modulus operator, $w'(0)$ is a real or complex-valued scalar, $w'(1)$ is a real or complex-valued scalar, and $z^{(p)}(k,l)$ is a complex-value symbol resulting from application of the additional orthogonal sequence.

[0063] The additional orthogonal sequence $[w'(0) w'(1)]$ can be selected from an orthogonal sequence set $\{[1 -1], [1 1]\}$ or from an orthogonal sequence set $\{[j j], [j -j]\}$, wherein j is an imaginary unit (i.e., the square root of -1).

[0064] The circuitry at the UE can be further configured to receive an orthogonal sequence index $n_{oc}^{(p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ from a cellular base station via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH).

[0065] Alternatively, the circuitry at the UE can be further configured to calculate an orthogonal sequence index $n_{oc}^{(p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition

$$n_{oc}^{(p)} = n_{PUCCH}^{(1,p)} \bmod 2,$$

Or according to the definition

$$n_{oc}^{(p)} = n_{cell ID} \bmod 2$$

Wherein $n_{cell ID}$ is a cell identifier (ID) of a cell, $n_{PUCCH}^{(1,p)}$ is a resource index for a format 1, 1a, or 1b of the xPUCCH, and **mod** is a modulus operator.

[0066] The circuitry at the UE can be further configured to receive a one-bit indicator from a cellular base station via Radio Resource Control (RRC) signaling or via a System Information Block (SIB); and apply the additional orthogonal sequence $[w'(0) \ w'(1)]$ based on the one-bit indicator for interference avoidance or for capacity boosting.

[0067] As in block 740, the circuitry at the UE can be further configured to send the UCI in the xPUCCH in a radio frame.

[0068] FIG. 8 illustrates functionality 800 of an apparatus of a UE in accordance with an example. The functionality 800 can be implemented as a method or the functionality can be executed as instructions on a machine (e.g., by one or more processors), where the instructions are included on at least one non-transitory or transitory computer-readable storage medium.

[0069] As in block 810, circuitry at the UE (e.g., comprising one or more processors and memory) can be configured to identify Uplink Control Information (UCI) for the UE.

[0070] As in block 820, the circuitry at the UE can be further configured to allocate Physical Resource Blocks (PRBs) for an advanced Physical Uplink Control Channel (xPUCCH) in a localized fashion such that Control Channel Elements (CCEs) for the xPUCCH include Resource Element Groups (REGS) of two slots that are from a same PRB pair or a same PRB cluster.

[0071] As in block 830, the circuitry at the UE can be further configured to send the UCI in the xPUCCH in a radio frame.

[0072] The circuitry at the UE can be further configured to receive an orthogonal sequence index for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1], [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ from a cellular base station in a System Information Block (SIB); and apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within the radio frame.

[0073] The circuitry at the UE can be further configured to receive a one-bit indicator from a cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and send the UCI in the xPUCCH in the radio frame using a shortened xPUCCH format 2x based on the one-bit indicator.

- [0074] The circuitry at the UE can be further configured to send the UCI in the xPUCCH in the radio frame using an extended Cyclic Prefix (CP) and using the shortened xPUCCH format 2x based on the one-bit indicator.
- [0075] The circuitry at the UE can be further configured to detect a potential collision between the xPUCCH and a Sounding Reference Signal (SRS); and send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2x that is not shortened.
- [0076] The circuitry at the UE can be further configured to send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2a or 2b and using an extended Cyclic Prefix (CP); and send a last complex-value symbol $d(10)$ in a Demodulation Reference Signal (DMRS) of a second slot of a subframe of the radio frame.
- [0077] The circuitry at the UE can be further configured to send the UCI in the xPUCCH in the radio frame according to a shortened xPUCCH format 3, wherein the shortened xPUCCH format 3 specifies that: two symbols of a first slot of a subframe of the radio frame are used to transmit a Demodulation Reference Signal (DMRS) or a periodic Sounding Reference Signal (SRS); one symbol of a second slot of the subframe is used to transmit the DMRS or the periodic SRS; five symbols of the first slot and five symbols of the second slot are used to transmit xPUCCH data; and one symbol of the second slot is muted.
- [0078] The circuitry at the UE can be further configured to receive a one-bit indicator from a cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 based on the one-bit indicator.
- [0079] The circuitry at the UE can be further configured to send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 using an extended cyclic prefix (CP).
- [0080] The circuitry at the UE can be further configured to receive a parameter $N_{RB}^{(1)}$ from a cellular base station, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum number of Physical Resource Blocks (PRBs) to be allocated for the xPUCCH; receive a one-bit indicator from the cellular base station; and allocate the PRBs for the xPUCCH in

a localized fashion according to a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme based on the one-bit indicator.

[0081] FIG. 9 illustrates functionality 900 of cellular base station in accordance with an example. The functionality 900 can be implemented as a method or the
 5 functionality can be executed as instructions on a machine (e.g., by one or more processors), where the instructions are included on at least one non-transitory or transitory computer-readable storage medium.

[0082] As in block 910, circuitry at the cellular base station (e.g., comprising one or more processors and memory) can be configured to send an orthogonal sequence index
 10 $n_{oc}^{(\bar{p})}$ for an additional orthogonal sequence $[w'(0) w'(1)]$ to a User equipment (UE) via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), wherein the UE is signaled to apply the additional orthogonal sequence $[w'(0) w'(1)]$ between an even-numbered slot and an odd-numbered slot within a radio frame of an advanced Physical
 15 Uplink Control Channel (xPUCCH), and wherein $w'(0)$ is a real or complex-valued scalar and $w'(1)$ is a real or complex-valued scalar.

[0083] As in block 920, the circuitry at the cellular base station can be further configured to send a one-bit purpose indicator to the UE via RRC signaling or via a
 20 System Information Block (SIB), wherein the first one-bit purpose indicator indicates that the UE is to apply the additional orthogonal sequence $[w'(0) w'(1)]$ for interference avoidance or for capacity boosting.

[0084] As in block 930, the circuitry at the cellular base station can be further configured to receive Uplink Control Information (UCI) in the xPUCCH from the UE.

[0085] The circuitry at the cellular base station can be further configured to send a
 25 one-bit format indicator to the UE via RRC signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or the System Information Block (SIB), wherein the one-bit format indicator indicates that the UE is to use a shortened xPUCCH format 2x or a shortened xPUCCH format 3.

[0086] The circuitry at the cellular base station can be further configured to send
 30 an orthogonal sequence index for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1], [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ in the SIB to

enable the UE to apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within a radio frame of the xPUCCH.

[0087] The circuitry at the cellular base station can be further configured to send a parameter $N_{RB}^{(1)}$ to the UE, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum number of Physical Resource Blocks (PRBs) to be allocated by the UE for the xPUCCH; and send a one-bit allocation-scheme indicator to the UE, wherein the one-bit allocation-scheme indicator indicates that the UE is to apply either a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme.

[0088] FIG. 10 depicts constitutive elements, with respect to time and frequency, of the Orthogonal Frequency Division Multiplexing (OFDM) transmission scheme employed by the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standards. However, other OFDM and non-OFDM modulation schemes are possible. With respect to time in the example, a single radio frame 1002, with a duration of 10 milliseconds (ms), is depicted from a stream of frames. The single radio frame comprises a set of 10 sub-frames 1004, numbered from #1 to #10 in the expanded cutout of the radio frame. Each sub-frame has a duration of 1 ms. A sub-frame can be further subdivided into two slots (#0 1006a, #1 1006b), a slot having a duration of 0.5 ms.

[0089] The 0.5 ms duration of a slot can coincide with the temporal duration of a physical resource block (PRB) 1008a–x. A PRB, as further defined in 3GPP TS 36.211, Sections 5.2.3 and 6.2.3 for 3GPP LTE release 12 (or an earlier release), can be the smallest unit of resource allocation assigned by a transmission point scheduler unit within 3GPP LTE standards. Other standards can define analogous units, for purposes of resource assignment, with respect to time and frequency. For example, a 5G radio frame may include frames and sub-frames with significantly shorter time durations. For instance, each frame in a 5G system may have a duration of 0.5 ms, 1.0 ms, 2 ms, 5 ms, or another desired time duration.

[0090] In addition to its 0.5 ms temporal span in this example, a PRB also spans a range of frequencies. Individual PRBs have distinct frequency spans, as depicted by the ascending series of PRBs with respect to frequency in FIG. 10. More specifically, an individual PRB 1008a–x can include 12 different 15 kHz subcarriers 1010 (on the frequency axis) and 6 or 7 time symbols 1020 (on the time axis) per slot 1006, per subcarrier, depending on whether a normal Cyclic Prefix (CP), 7 time symbols, or an

extended CP, 6 time symbols, is used. The various subcarriers and time symbols with respect to frequency and time dimensions can create a grid of 84 Resource Elements (REs) 1014, where a PRB 1008k comprises 7 time symbols. In a 5G system, the PRBs may include more subcarriers, fewer subcarriers, a greater bandwidth per subcarrier, a lesser bandwidth per subcarrier, and a different CP length.

[0091] FIG. 11 provides an example illustration of a mobile device, such as a user equipment (UE), a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The mobile device can include one or more antennas configured to communicate with a node, macro node, low power node (LPN), or, transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband processing unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), or other type of wireless wide area network (WWAN) access point. The mobile device can be configured to communicate using at least one wireless communication standard such as, but not limited to, 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The mobile device can communicate using separate antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The mobile device can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN.

[0092] The mobile device can also comprise a wireless modem. The wireless modem can comprise, for example, a wireless radio transceiver and baseband circuitry (e.g., a baseband processor). The wireless modem can, in one example, modulate signals that the mobile device transmits via the one or more antennas and demodulate signals that the mobile device receives via the one or more antennas.

[0093] The mobile device can include a storage medium. In one aspect, the storage medium can be associated with and/or communication with the application processor, the graphics processor, the display, the non-volatile memory port, and/or internal memory. In one aspect, the application processor and graphics processor are storage mediums.

[0094] FIG. 11 also provides an illustration of a microphone and one or more speakers that can be used for audio input and output from the mobile device. The display screen can be a liquid crystal display (LCD) screen, or other type of display screen such as an organic light emitting diode (OLED) display. The display screen can be configured

as a touch screen. The touch screen can use capacitive, resistive, or another type of touch screen technology. An application processor and a graphics processor can be coupled to internal memory to provide processing and display capabilities. A non-volatile memory port can also be used to provide data input/output options to a user. The non-volatile
5 memory port can also be used to expand the memory capabilities of the mobile device. A keyboard can be integrated with the mobile device or wirelessly connected to the wireless device to provide additional user input. A virtual keyboard can also be provided using the touch screen.

[0095] FIG. 12 provides an example illustration of a user equipment (UE) device
10 1200, such as a wireless device, a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The UE device 1200 can include one or more antennas configured to communicate with a node or transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station
15 (RS), a radio equipment (RE), a remote radio unit (RRU), a central processing module (CPM), or other type of wireless wide area network (WWAN) access point. The UE device 1200 can be configured to communicate using at least one wireless communication standard such as, but not limited to, 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The UE device 1200 can communicate using separate
20 antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The UE device 1200 can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN.

[0096] In some embodiments, the UE device 1200 may include application
25 circuitry 1202, baseband circuitry 1204, Radio Frequency (RF) circuitry 1206, front-end module (FEM) circuitry 1208 and one or more antennas 1210, coupled together at least as shown.

[0097] The application circuitry 1202 may include one or more application
processors. For example, the application circuitry 1202 may include circuitry such as, but
30 not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage (e.g., storage medium 1212) and may be configured

to execute instructions stored in the memory/storage (e.g., storage medium 1212) to enable various applications and/or operating systems to run on the system.

[0098] The baseband circuitry 1204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1204 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1206 and to generate baseband signals for a transmit signal path of the RF circuitry 1206. Baseband processing circuitry 1204 may interface with the application circuitry 1202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1206. For example, in some embodiments, the baseband circuitry 1204 may include a second generation (2G) baseband processor 1204a, third generation (3G) baseband processor 1204b, fourth generation (4G) baseband processor 1204c, and/or other baseband processor(s) 1204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1204 (e.g., one or more of baseband processors 1204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1206. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1204 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1204 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0099] In some embodiments, the baseband circuitry 1204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 1204e of the baseband circuitry 1204 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some

embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1204f. The audio DSP(s) 1204f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1204 and the application circuitry 1202 may be implemented together such as, for example, on a system on a chip (SOC).

[00100] In some embodiments, the baseband circuitry 1204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1204 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00101] The RF circuitry 1206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1206 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1208 and provide baseband signals to the baseband circuitry 1204. RF circuitry 1206 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1204 and provide RF output signals to the FEM circuitry 1208 for transmission.

[00102] In some embodiments, the RF circuitry 1206 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1206 may include mixer circuitry 1206a, amplifier circuitry 1206b and filter circuitry 1206c. The transmit signal path of the RF circuitry 1206 may include filter circuitry 1206c and mixer circuitry 1206a. RF circuitry 1206 may also include synthesizer circuitry 1206d for synthesizing a frequency for use by the mixer circuitry 1206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1206a of the receive signal path may be configured to down-convert RF signals received from the

FEM circuitry 1208 based on the synthesized frequency provided by synthesizer circuitry 1206d. The amplifier circuitry 1206b may be configured to amplify the down-converted signals and the filter circuitry 1206c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to
5 generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1204 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although other types of baseband signals may be used in other examples. In some embodiments, mixer circuitry 1206a of the receive signal path may comprise passive mixers, although the scope of the
10 embodiments is not limited in this respect.

[00103] In some embodiments, the mixer circuitry 1206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1206d to generate RF output signals for the FEM circuitry 1208. The baseband signals may be provided by the baseband circuitry
15 1204 and may be filtered by filter circuitry 1206c. The filter circuitry 1206c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[00104] In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path may include two or more mixers
20 and may be arranged for quadrature down-conversion and/or up-conversion respectively. In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a may be
25 arranged for direct down-conversion and/or direct up-conversion, respectively. In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path may be configured for super-heterodyne operation.

[00105] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not
30 limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1206 may include analog-to-digital converter (ADC) and

digital-to-analog converter (DAC) circuitry and the baseband circuitry 1204 may include a digital baseband interface to communicate with the RF circuitry 1206.

[00106] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the
5 embodiments is not limited in this respect.

[00107] In some embodiments, the synthesizer circuitry 1206d may be a fractional-N synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1206d may be a delta-sigma synthesizer, a frequency
10 multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00108] The synthesizer circuitry 1206d may be configured to synthesize an output frequency for use by the mixer circuitry 1206a of the RF circuitry 1206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1206d may be a fractional $N/N+1$ synthesizer.

[00109] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although frequency input may also be provided by other devices in other examples. Divider control input may be provided by either the baseband circuitry 1204 or the applications processor 1202 depending on the desired output
15 frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1202.

[00110] Synthesizer circuitry 1206d of the RF circuitry 1206 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD
25 may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay
30 elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00111] In some embodiments, synthesizer circuitry 1206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the

output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output
5 frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 1206 may include an IQ/polar converter.

[00112] FEM circuitry 1208 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1210, amplify the received signals and provide the amplified versions of the received signals to
10 the RF circuitry 1206 for further processing. FEM circuitry 1208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1206 for transmission by one or more of the one or more antennas 1210.

[00113] In some embodiments, the FEM circuitry 1208 may include a TX/RX
15 switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1206). The transmit signal path of the FEM circuitry 1208 may include a power
20 amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1210).

[00114] In some embodiments, the UE device 1200 may include additional
25 elements such as, for example, memory/storage, display (e.g., touch screen), camera, antennas, keyboard, microphone, speakers, sensor, and/or input/output (I/O) interface.

[00115] FIG. 13 illustrates a diagram 1300 of a node 1310 (e.g., eNB and/or a Serving GPRS Support Node) and a wireless device 1320 (e.g., UE) in accordance with an example. The node can include a base station (BS), a Node B (NB), an evolved Node B (eNB), a baseband unit (BBU), a remote radio head (RRH), a remote radio equipment
30 (RRE), a remote radio unit (RRU), or a central processing module (CPM). In one aspect, the node can be a Serving GPRS Support Node. The node 1310 can include a node device 1312. The node device 1312 or the node 1310 can be configured to communicate with the wireless device 1320. The node device 1312 can be configured to implement

technologies described herein. The node device 1312 can include a processing module 1314 and a transceiver module 1316. In one aspect, the node device 1312 can include the transceiver module 1316 and the processing module 1314 forming a circuitry for the node 1310. In one aspect, the transceiver module 1316 and the processing module 1314 can
5 form a circuitry of the node device 1312. The processing module 1314 can include one or more processors and memory. In one embodiment, the processing module 1322 can include one or more application processors. The transceiver module 1316 can include a transceiver and one or more processors and memory. In one embodiment, the transceiver module 1316 can include a baseband processor.

10 [00116] The wireless device 1320 can include a transceiver module 1324 and a processing module 1322. The processing module 1322 can include one or more processors and memory. In one embodiment, the processing module 1322 can include one or more application processors. The transceiver module 1324 can include a transceiver and one or more processors and memory. In one embodiment, the transceiver module
15 1324 can include a baseband processor. The wireless device 1320 can be configured to implement technologies described herein. The node 1310 and the wireless devices 1320 can also include one or more storage mediums, such as the transceiver module 1316, 1324 and/or the processing module 1314, 1322.

20 **Definitions**

[00117] The following definitions are provided for the current disclosure:

[00118] OFDM: Orthogonal Frequency Division Multiplexing.

[00119] OFDMA: Orthogonal Frequency Division Multiple Access.

[00120] IoT: Internet of Things.

25 [00121] MTC: Machine-type Communication.

[00122] 5G: Fifth-Generation mobile networks or wireless systems.

[00123] PUCCH: Physical Uplink Control Channel.

[00124] xPUCCH: advanced Physical Uplink Control Channel (e.g., for 5G).

[00125] PUSCH: Physical Uplink Shared Channel.

30 [00126] xPUSCH: advanced Physical Uplink Shared Channel (e.g., for 5G).

[00127] PRB: Physical Resource Block.

[00128] RB: Resource Block.

[00129] RE: Resource Element.

- [00130] DMRS: Demodulation Reference Signal.
- [00131] SRS: Sounding Reference Signal.
- [00132] SINR: Signal-to-Interference-plus-Noise Ratio.
- [00133] CCE: Control Channel Element.
- 5 [00134] CP: Cyclic Prefix.
- [00135] Mod: Modulus or the modulus operator.
- [00136] SIB: System Information Block.
- [00137] RRC: Radio Resource Control.
- [00138] SF: Subframe.
- 10 [00139] OC: Orthogonal Code.
- [00140] HARQ-ACK: Hybrid Automatic Repeat Request Acknowledgement.
- [00141] ID: Identity, Identification, or Identifier.
- [00142] DCI: Downlink Control Information.
- [00143] DL: Downlink.
- 15 [00144] UL: Uplink.
- [00145] mmWave: Millimeter Wave.

Examples

[00146] The following examples pertain to specific embodiments and point out
 20 specific features, elements, or steps that can be used or otherwise combined in achieving such embodiments.

[00147] Example 1 includes an apparatus of a user equipment (UE), the apparatus comprising one or more processors and memory configured to: identify Uplink Control Information (UCI) for the UE; allocate Physical Resource Blocks (PRBs) for an advanced
 25 Physical Uplink Control Channel (xPUCCH) in a localized fashion; apply an additional orthogonal sequence $[w'(0) \ w'(1)]$ between an even-numbered slot and an odd-numbered slot within the radio frame according to a definition:

$$z^{(p)}(k, l) = \begin{cases} w'(0)z^{(p)}(k, l), & n_s \bmod 2 = 0 \\ w'(1)z^{(p)}(k, l), & n_s \bmod 2 = 1 \end{cases},$$

wherein $z^{(p)}(k, l)$ is a complex-value symbol that maps to a resource element at a
 30 frequency index k and a time-symbol index l on an antenna port number p that has an index \tilde{p} , n_s is a slot number within the radio frame for a slot in which the resource

element is located, **mod** is a modulus operator, $w'(0)$ is a real or complex-valued scalar, $w'(1)$ is a real or complex-valued scalar, and $z^{(p)}(k,l)$ is a complex-value symbol resulting from application of the additional orthogonal sequence; and signal transceiver circuitry at the UE to send the UCI in the xPUCCH in a radio frame to a cellular base station.

[00148] Example 2 includes the apparatus of example 1, wherein the one or more processors and memory are further configured to: select the additional orthogonal sequence $[w'(0) w'(1)]$ from an orthogonal sequence set $\{[1 -1], [1 1]\}$ or from an orthogonal sequence set $\{[j j], [j -j]\}$, wherein j is an imaginary unit (i.e., the square root of -1).

[00149] Example 3 includes the apparatus of example 1 or 2, wherein the one or more processors and memory are further configured to: identify an orthogonal sequence index $n_{\infty}^{(p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ received from the cellular base station via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH).

[00150] Example 4 includes the apparatus of example 1 or 2, wherein the one or more processors and memory are further configured to: calculate an orthogonal sequence index $n_{\infty}^{(p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition

$$n_{\infty}^{(p)} = n_{PUCCH}^{(1,p)} \bmod 2,$$

wherein $n_{PUCCH}^{(1,p)}$ is a resource index for a format 1, 1a, or 1b of the xPUCCH and **mod** is a modulus operator.

[00151] Example 5 includes the apparatus of example 1, 2, 3, or 4, wherein the one or more processors and memory are further configured to: identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling or via a System Information Block (SIB); and apply the additional orthogonal sequence $[w'(0) w'(1)]$ based on the one-bit indicator for interference avoidance or for capacity boosting.

[00152] Example 6 includes the apparatus of example 1, 2, or 5, wherein the one or more processors and memory are further configured to: calculate an orthogonal

sequence index $n_{oc}^{(\bar{p})}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition

$$n_{oc}^{(\bar{p})} = n_{cell ID} \bmod 2,$$

wherein $n_{cell ID}$ is a cell identifier (ID) of a cell and **mod** is a modulus operator.

5 **[00153]** Example 7 includes an apparatus of a user equipment (UE), the apparatus comprising one or more processors and memory configured to: identify Uplink Control Information (UCI) for the UE; allocate Physical Resource Blocks (PRBs) for an advanced Physical Uplink Control Channel (xPUCCH) in a localized fashion such that Control Channel Elements (CCEs) for the xPUCCH include Resource Element Groups (REGS) of
10 two slots that are from a same PRB pair or a same PRB cluster; and signal transceiver circuitry at the UE to send the UCI in the xPUCCH in a radio frame to a cellular base station.

[00154] Example 8 includes the apparatus of example 7, wherein the one or more processors and memory are further configured to: identify an orthogonal sequence index
15 for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1] , [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ received from the cellular base station in a System Information Block (SIB); and apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within the radio frame.

[00155] Example 9 includes the apparatus of example 7 or 8, wherein the one or
20 more processors and memory are further configured to: identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using a shortened xPUCCH format 2x
25 based on the one-bit indicator.

[00156] Example 10 includes the apparatus of example 7 or 8, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an extended Cyclic Prefix (CP) and using a shortened xPUCCH format 2x based on the one-bit indicator.

30 **[00157]** Example 11 includes the apparatus of example 7 or 8, wherein the one or more processors and memory are further configured to: detect a potential collision between the xPUCCH and a Sounding Reference Signal (SRS); and signal the transceiver

circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2x that is not shortened.

[00158] Example 12 includes the apparatus of example 7 or 8, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2a or 2b and using an extended Cyclic Prefix (CP); and send a last complex-value symbol $d(10)$ in a Demodulation Reference Signal (DMRS) of a second slot of a subframe of the radio frame.

[00159] Example 13 includes the apparatus of example 7 or 8, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame according to a shortened xPUCCH format 3, wherein the shortened xPUCCH format 3 specifies that: two symbols of a first slot of a subframe of the radio frame are used to transmit a Demodulation Reference Signal (DMRS) or a periodic Sounding Reference Signal (SRS); one symbol of a second slot of the subframe is used to transmit the DMRS or the periodic SRS; five symbols of the first slot and five symbols of the second slot are used to transmit xPUCCH data; and one symbol of the second slot is muted.

[00160] Example 14 includes the apparatus of example 13, wherein the one or more processors and memory are further configured to: identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 based on the one-bit indicator.

[00161] Example 15 includes the apparatus of example 13 or 14, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 using an extended cyclic prefix (CP).

[00162] Example 16 includes the apparatus of example 7, 8, 10, 11, 12, 13, 14, or 15, wherein the one or more processors and memory are further configured to: identify a parameter $N_{RB}^{(1)}$ received from the cellular base station, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum number of Physical Resource Blocks (PRBs) to be allocated for the

xPUCCH; receive a one-bit indicator from the cellular base station; and allocate the PRBs for the xPUCCH in a localized fashion according to a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme based on the one-bit indicator.

[00163] Example 17 includes an apparatus of a cellular base station, the apparatus comprising one or more processors and memory configured to: signal transceiver circuitry at the cellular base station to send an orthogonal sequence index $n_{oc}^{(p)}$ for an additional orthogonal sequence $[w'(0) w'(1)]$ to a User equipment (UE) via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), wherein the UE is signaled to apply the additional orthogonal sequence $[w'(0) w'(1)]$ between an even-numbered slot and an odd-numbered slot within a radio frame of an advanced Physical Uplink Control Channel (xPUCCH), and wherein $w'(0)$ is a real or complex-valued scalar and $w'(1)$ is a real or complex-valued scalar; signal the transceiver circuitry at the cellular base station to send a one-bit purpose indicator to the UE via RRC signaling or via a System Information Block (SIB), wherein the first one-bit purpose indicator indicates that the UE is to apply the additional orthogonal sequence $[w'(0) w'(1)]$ for interference avoidance or for capacity boosting; and identify Uplink Control Information (UCI) in the xPUCCH received from the UE.

[00164] Example 18 includes the apparatus of example 17, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the cellular base station to send a one-bit format indicator to the UE via RRC signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or the System Information Block (SIB), wherein the one-bit format indicator indicates that the UE is to use a shortened xPUCCH format 2x or a shortened xPUCCH format 3.

[00165] Example 19 includes the apparatus of example 17 or 18, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the cellular base station to send an orthogonal sequence index for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1], [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ in the SIB to enable the UE to apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within a radio frame of the xPUCCH.

[00166] Example 20 includes the apparatus of example 17, 18, or 19, wherein the one or more processors and memory are further configured to: signal the transceiver circuitry at the cellular base station to send a parameter $N_{RB}^{(1)}$ to the UE, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum number of Physical Resource Blocks (PRBs) to be allocated by the UE for the xPUCCH; and send a one-bit allocation-scheme indicator to the UE, wherein the one-bit allocation-scheme indicator indicates that the UE is to apply either a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme.

[00167] Example 21 includes an apparatus of a user equipment (UE), the apparatus comprising one or more processors and memory configured to: identify Uplink Control Information (UCI) for the UE; allocate Physical Resource Blocks (PRBs) for an advanced Physical Uplink Control Channel (xPUCCH) in a localized fashion; select an additional orthogonal sequence $[w'(0) w'(1)]$ from an orthogonal sequence set $\{[1 -1], [1 1]\}$ or from an orthogonal sequence set $\{[j j], [j -j]\}$, wherein j is an imaginary unit (i.e., the square root of -1); apply the additional orthogonal sequence $[w'(0) w'(1)]$ between an even-numbered slot and an odd-numbered slot within the radio frame according to a definition:

$$z^{(p)}(k,l) = \begin{cases} w'(0)z^{(p)}(k,l), n_s \bmod 2 = 0 \\ w'(1)z^{(p)}(k,l), n_s \bmod 2 = 1 \end{cases}$$

wherein $z^{(p)}(k,l)$ is a complex-value symbol that maps to a resource element at a frequency index k and a time-symbol index l on an antenna port number p that has an index \tilde{p} , n_s is a slot number within the radio frame for a slot in which the resource element is located, **mod** is a modulus operator, $w'(0)$ is a real or complex-valued scalar, $w'(1)$ is a real or complex-valued scalar, and $z^{(p)}(k,l)$ is a complex-value symbol resulting from application of the additional orthogonal sequence; and signal transceiver circuitry at the UE to send the UCI in the xPUCCH in a radio frame to a cellular base station.

[00168] Example 22 includes the apparatus of example 21, wherein the one or more processors and memory are further configured to: identify an orthogonal sequence index $n_{oc}^{(p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ received from the cellular base station via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel

(PDCCH); or calculate the orthogonal sequence index $n_{oc}^{(i,p)}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition $n_{oc}^{(i,p)} = n_{PUCCH}^{(i,p)} \bmod 2$ or according to a definition $n_{oc}^{(i,p)} = n_{cell ID} \bmod 2$, wherein $n_{cell ID}$ is a cell identifier (ID) of a cell, $n_{PUCCH}^{(i,p)}$ is a resource index for a format 1, 1a, or 1b of the xPUCCH, and **mod** is a modulus operator.

[00169] Example 23 includes the apparatus of example 21 or 22, wherein the one or more processors and memory are further configured to: identify a one-bit indicator from the cellular base station via Radio Resource Control (RRC) signaling or via a System Information Block (SIB); and apply the additional orthogonal sequence $[w'(0) w'(1)]$ based on the one-bit indicator for interference avoidance or for capacity boosting.

[00170] Example 26 includes the apparatus of example 7 or 8, wherein the one or more processors and memory are further configured to: identify a one-bit indicator received from a cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and signal transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an extended Cyclic Prefix (CP) and a shortened xPUCCH format 2x based on the one-bit indicator.

[00171] Example 27 includes the apparatus of example 13, wherein the one or more processors and memory are further configured to: identify a one-bit indicator received from a cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and signal transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an extended cyclic prefix (CP) and the shortened xPUCCH format 3 based on the one-bit indicator.

[00172] Various techniques, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, compact disc-read-only memory (CD-ROMs), hard drives, non-transitory computer readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the various techniques. A non-transitory computer readable storage medium can be a computer readable storage

medium that does not include signal. In the case of program code execution on programmable computers, the computing device may include a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. The volatile and non-volatile memory and/or storage elements may be a random-access memory (RAM), erasable programmable read only memory (EPROM), flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). One or more programs that may implement or utilize the various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[00173] As used herein, the term “circuitry” may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[00174] While the flowcharts presented for this technology may imply a specific order of execution, the order of execution may differ from what is illustrated. For example, the order of two more blocks may be rearranged relative to the order shown. Further, two or more blocks shown in succession may be executed in parallel or with partial parallelization. In some configurations, one or more blocks shown in the flow chart may be omitted or skipped. Any number of counters, state variables, warning semaphores, or messages may be added to the logical flow for enhanced utility, accounting, performance, measurement, troubleshooting, or other purposes.

[00175] As used herein, the word “or” indicates an inclusive disjunction. For example, as used herein, the phrase “A or B” represents an inclusive disjunction of exemplary conditions A and B. Hence, “A or B” is false only if both condition A is false and condition B is false. When condition A is true and condition B is also true, “A or B” is also true. When condition A is true and condition B is false, “A or B” is true. When condition B is true and condition A is false, “A or B” is true. In other words, the term “or,” as used herein, should not be construed as an exclusive disjunction. The term “xor” is used where an exclusive disjunction is intended.

[00176] As used herein, the term processor can include general-purpose processors, specialized processors such as VLSI, FPGAs, and other types of specialized processors, as well as base-band processors used in transceivers to send, receive, and process wireless communications.

[00177] It should be understood that many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module can be implemented as a hardware circuit (e.g., an application-specific integrated circuit (ASIC)) comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module can also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00178] Modules can also be implemented in software for execution by various types of processors. An identified module of executable code can, for instance, comprise one or more physical or logical blocks of computer instructions, which can, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module do not have to be physically located together, but can comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

[00179] Indeed, a module of executable code can be a single instruction, or many instructions, and can even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data can be identified and illustrated herein within modules, and can be embodied in any suitable form and organized within any suitable type of data structure. The operational data can be collected as a single data set, or can be distributed over different locations including over

different storage devices, and can exist, at least partially, merely as electronic signals on a system or network. The modules can be passive or active, including agents operable to perform desired functions.

[00180] As used herein, the term “processor” can include general purpose processors, specialized processors such as VLSI, FPGAs, and other types of specialized processors, as well as base band processors used in transceivers to send, receive, and process wireless communications.

[00181] Reference throughout this specification to “an example” means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment. Thus, appearances of the phrases “in an example” in various places throughout this specification are not necessarily all referring to the same embodiment.

[00182] As used herein, a plurality of items, structural elements, compositional elements, and/or materials can be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and examples can be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as de facto equivalents of one another, but are to be considered as separate and autonomous.

[00183] Furthermore, the described features, structures, or characteristics can be combined in any suitable manner in one or more embodiments. In the foregoing description, numerous specific details are provided, such as examples of layouts, distances, network examples, etc., to provide a thorough understanding of some embodiments. One skilled in the relevant art will recognize, however, that the some embodiments can be practiced without one or more of the specific details, or with other methods, components, layouts, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of different embodiments.

[00184] While the forgoing examples are illustrative of the principles used in various embodiments in one or more particular applications, it will be apparent to those of

ordinary skill in the art that numerous modifications in form, usage and details of implementation can be made without the exercise of inventive faculty, and without departing from the principles and concepts of the embodiments. Accordingly, it is not intended that the claimed matter be limited, except as by the claims set forth below.

5

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE), the apparatus comprising one or more
 5 processors and memory configured to:
 identify Uplink Control Information (UCI) for the UE;
 allocate Physical Resource Blocks (PRBs) for an advanced Physical
 Uplink Control Channel (xPUCCH) in a localized fashion;
 apply an additional orthogonal sequence $[w'(0) \ w'(1)]$ between an even-
 10 numbered slot and an odd-numbered slot within the radio frame according to a
 definition:

$$z^{(p)}(k,l) = \begin{cases} w'(0)z^{(p)}(k,l), n_s \bmod 2 = 0 \\ w'(1)z^{(p)}(k,l), n_s \bmod 2 = 1 \end{cases}$$

- wherein $z^{(p)}(k,l)$ is a complex-value symbol that maps to a resource
 element at a frequency index k and a time-symbol index l on an antenna port
 15 number p that has an index \tilde{p} , n_s is a slot number within the radio frame for a slot
 in which the resource element is located, **mod** is a modulus operator, $w'(0)$ is a
 real or complex-valued scalar, $w'(1)$ is a real or complex-valued scalar, and
 $z^{(p)}(k,l)$ is a complex-value symbol resulting from application of the additional
 orthogonal sequence; and
 20 signal transceiver circuitry at the UE to send the UCI in the xPUCCH in a
 radio frame to a cellular base station.

2. The apparatus of claim 1, wherein the one or more processors and memory are further
 configured to:
 25 select the additional orthogonal sequence $[w'(0) \ w'(1)]$ from an
 orthogonal sequence set $\{[1 \ -1], [1 \ 1]\}$ or from an orthogonal sequence set $\{[j \ j], [j \ -j]\}$,
 wherein j is an imaginary unit.

3. The apparatus of claim 1 or 2, wherein the one or more processors and memory are
 30 further configured to:

5 identify an orthogonal sequence index $n_{\infty}^{(\tilde{p})}$ for the additional orthogonal sequence $[w'(0) w'(1)]$, wherein the orthogonal sequence index $n_{\infty}^{(\tilde{p})}$ is received from the cellular base station via Radio Resource Control (RRC) signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH).

4. The apparatus of claim 1 or 2, wherein the one or more processors and memory are further configured to:

10 calculate an orthogonal sequence index $n_{\infty}^{(\tilde{p})}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition:

$$n_{\infty}^{(\tilde{p})} = n_{PUCCH}^{(1,\tilde{p})} \bmod 2,$$

wherein $n_{PUCCH}^{(1,\tilde{p})}$ is a resource index for a format 1, 1a, or 1b of the xPUCCH and **mod** is a modulus operator.

15 5. The apparatus of claim 1, 2, 3, or 4, wherein the one or more processors and memory are further configured to:

identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling or via a System Information Block (SIB); and

20 apply the additional orthogonal sequence $[w'(0) w'(1)]$ based on the one-bit indicator for interference avoidance or for capacity boosting.

6. The apparatus of claim 1, 2, or 5, wherein the one or more processors and memory are further configured to:

25 calculate an orthogonal sequence index $n_{\infty}^{(\tilde{p})}$ for the additional orthogonal sequence $[w'(0) w'(1)]$ according to a definition:

$$n_{\infty}^{(\tilde{p})} = n_{cell ID} \bmod 2,$$

wherein $n_{cell ID}$ is a cell identifier (ID) of a cell and **mod** is a modulus operator.

30 7. An apparatus of a user equipment (UE), the apparatus comprising one or more processors and memory configured to:

- identify Uplink Control Information (UCI) for the UE;
allocate Physical Resource Blocks (PRBs) for an advanced Physical Uplink Control Channel (xPUCCH) in a localized fashion such that Control Channel Elements (CCEs) for the xPUCCH include Resource Element Groups (REGS) of two slots that are from a same PRB pair or a same PRB cluster; and
5 signal transceiver circuitry at the UE to send the UCI to a cellular base station in the xPUCCH in a radio frame.
8. The apparatus of claim 7, wherein the one or more processors and memory are further
10 configured to:
identify an orthogonal sequence index for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1], [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ received from the cellular base station in a System Information Block (SIB); and
15 apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within the radio frame.
9. The apparatus of claim 7 or 8, wherein the one or more processors and memory are further configured to:
20 identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and
signal the transceiver circuitry at the UE to send the UCI in the xPUCCH
25 in the radio frame using a shortened xPUCCH format 2x based on the one-bit indicator.
10. The apparatus of claim 7 or 8, wherein the one or more processors and memory are further configured to:
30 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an extended Cyclic Prefix (CP) and using a shortened xPUCCH format 2x based on the one-bit indicator.

11. The apparatus of claim 7 or 8, wherein the one or more processors and memory are further configured to:

- 5 detect a potential collision between the xPUCCH and a Sounding Reference Signal (SRS); and
 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2x that is not shortened.

12. The apparatus of claim 7 or 8, wherein the one or more processors and memory are further configured to:

- 10 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using an xPUCCH format 2a or 2b and using an extended Cyclic Prefix (CP); and
 signal the transceiver circuitry at the UE to send a last complex-value
15 symbol $d(10)$ in a Demodulation Reference Signal (DMRS) of a second slot of a subframe of the radio frame.

13. The apparatus of claim 7 or 8, wherein the one or more processors and memory are further configured to:

- 20 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame according to a shortened xPUCCH format 3, wherein the shortened xPUCCH format 3 specifies that:

 two symbols of a first slot of a subframe of the radio frame are used to transmit a Demodulation Reference Signal (DMRS) or a periodic Sounding Reference Signal (SRS);

25 one symbol of a second slot of the subframe is used to transmit the DMRS or the periodic SRS;

 five symbols of the first slot and five symbols of the second slot are used to transmit xPUCCH data; and

30 one symbol of the second slot is muted.

14. The apparatus of claim 13, wherein the one or more processors and memory are further configured to:

identify a one-bit indicator received from the cellular base station via Radio Resource Control (RRC) signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or a System Information Block (SIB); and

5 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 based on the one-bit indicator.

15. The apparatus of claim 13 or 14, wherein the one or more processors and memory are

10 further configured to:

 signal the transceiver circuitry at the UE to send the UCI in the xPUCCH in the radio frame using the shortened xPUCCH format 3 using an extended cyclic prefix (CP).

15 16. The apparatus of claim 7, 8, 10, 11, 12, 13, 14, or 15, wherein the one or more processors and memory are further configured to:

 identify a parameter $N_{RB}^{(1)}$ received from the cellular base station, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum number of Physical Resource Blocks (PRBs) to be allocated for the xPUCCH;

20 identify a one-bit indicator received from the cellular base station; and

 allocate the PRBs for the xPUCCH in a localized fashion according to a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme based on the one-bit indicator.

25 17. An apparatus of a cellular base station, the apparatus comprising one or more processors and memory configured to:

 signal transceiver circuitry at the cellular base station to send an orthogonal sequence index $n_{oc}^{(p)}$ for an additional orthogonal sequence $[w'(0) w'(1)]$ to a User equipment (UE) via Radio Resource Control (RRC)

30 signaling or via a bit in uplink-related Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), wherein the UE is signaled to apply the additional orthogonal sequence $[w'(0) w'(1)]$ between an even-

numbered slot and an odd-numbered slot within a radio frame of an advanced Physical Uplink Control Channel (xPUCCH), and wherein $w'(0)$ is a real or complex-valued scalar and $w'(1)$ is a real or complex-valued scalar;

5 signal the transceiver circuitry at the cellular base station to send a one-bit purpose indicator to the UE via RRC signaling or via a System Information Block (SIB), wherein the first one-bit purpose indicator indicates that the UE is to apply the additional orthogonal sequence $[w'(0) \ w'(1)]$ for interference avoidance or for capacity boosting; and

10 identify Uplink Control Information (UCI) in the xPUCCH received from the UE.

18. The apparatus of claim 17, wherein the one or more processors and memory are further configured to:

15 signal the transceiver circuitry at the cellular base station to send a one-bit format indicator to the UE via RRC signaling, Downlink Control Information (DCI) in a Physical Downlink Control Channel (PDCCH), or the System Information Block (SIB), wherein the one-bit format indicator indicates that the UE is to use a shortened xPUCCH format 2x or a shortened xPUCCH format 3.

20 19. The apparatus of claim 17 or 18, wherein the one or more processors and memory are further configured to:

25 signal the transceiver circuitry at the cellular base station to send an orthogonal sequence index for an orthogonal sequence selected from an orthogonal sequence set $\{ [1 \ 1 \ 1 \ 1] , [1 \ -1 \ 1 \ -1], [1 \ -1 \ -1 \ 1], [+1 \ +1 \ -1 \ -1] \}$ in the SIB to enable the UE to apply the orthogonal sequence between an even-numbered slot and an odd-numbered slot within a radio frame of the xPUCCH.

20. The apparatus of claim 17, 18, or 19, wherein the one or more processors and memory are further configured to:

30 signal the transceiver circuitry at the cellular base station to send a parameter $N_{RB}^{(1)}$ to the UE, wherein the parameter $N_{RB}^{(1)}$ specifies a maximum

number of Physical Resource Blocks (PRBs) to be allocated by the UE for the xPUCCH; and

- 5 signal the transceiver circuitry at the cellular base station to send a one-bit allocation-scheme indicator to the UE, wherein the one-bit allocation-scheme indicator indicates that the UE is to apply either a pair-wise PRB allocation scheme or a cluster-wise PRB allocation scheme.

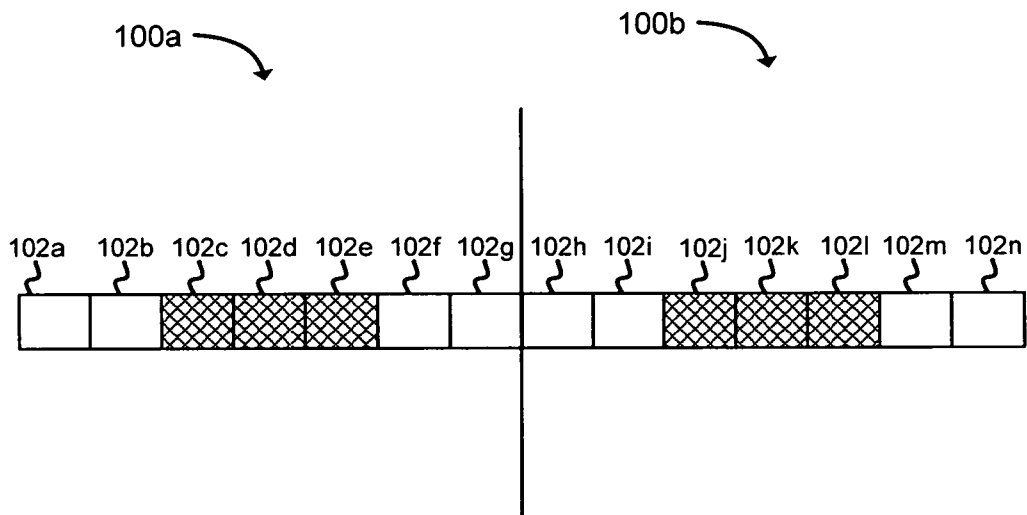


FIG. 1

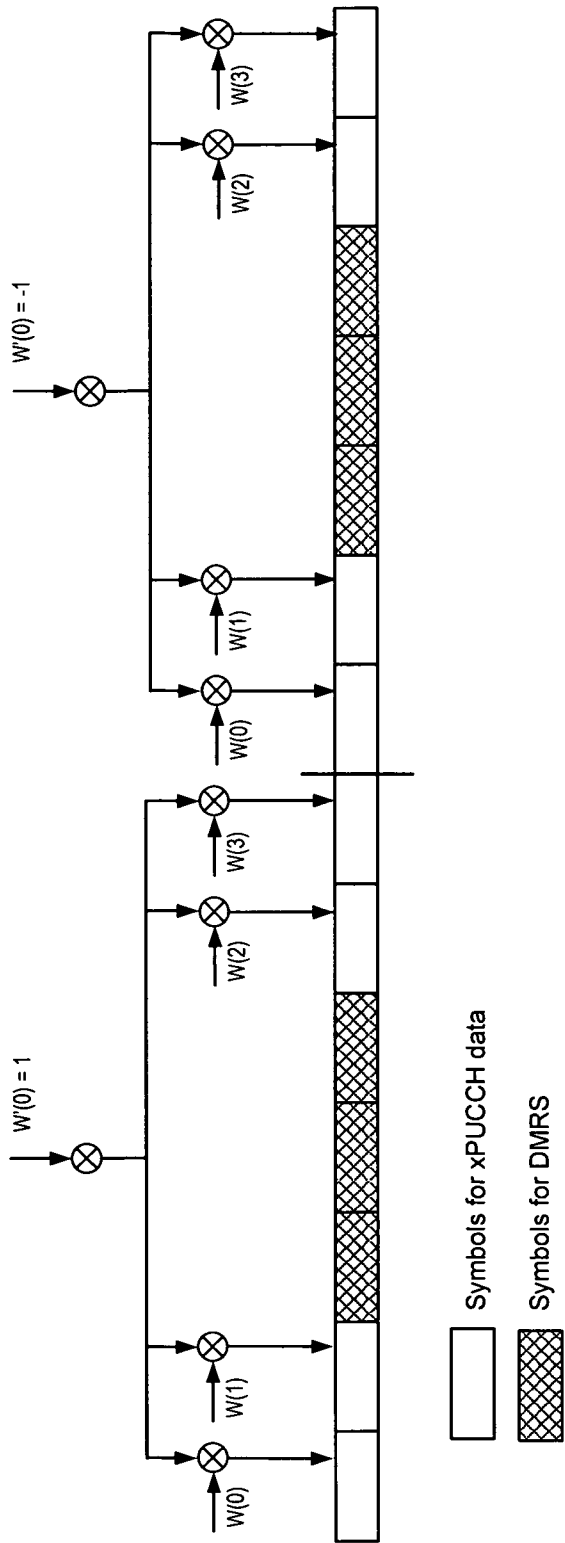


FIG. 2a

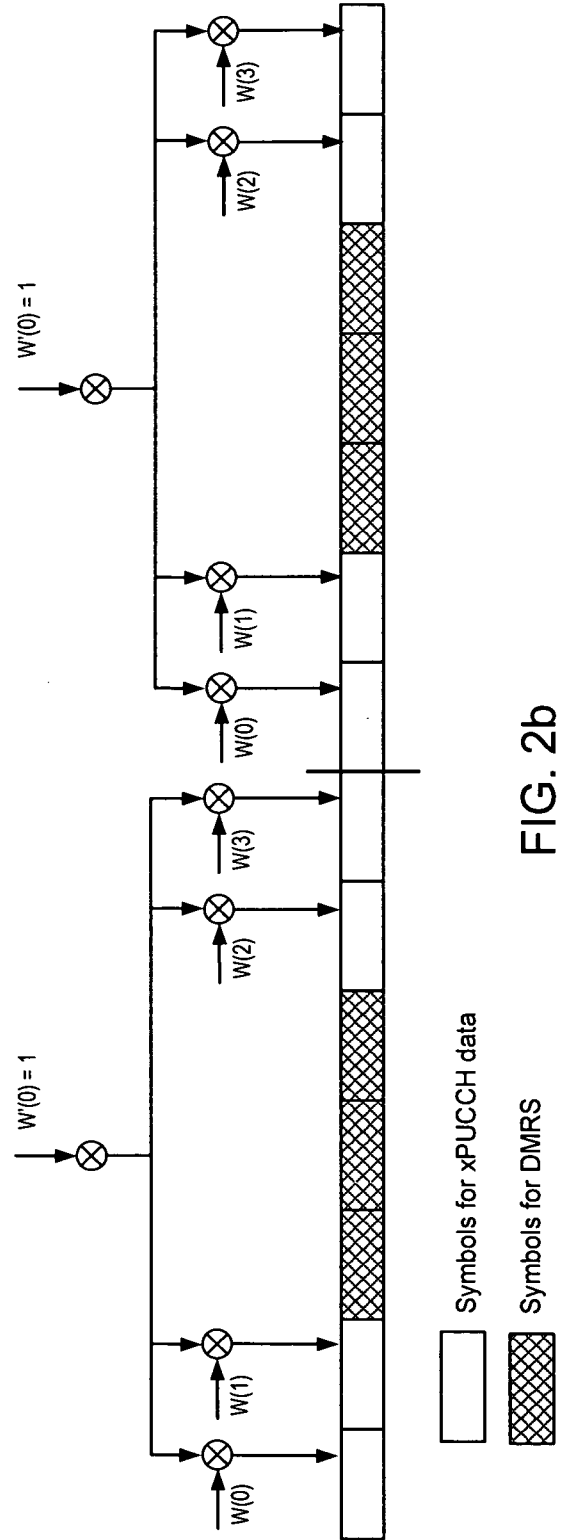


FIG. 2b

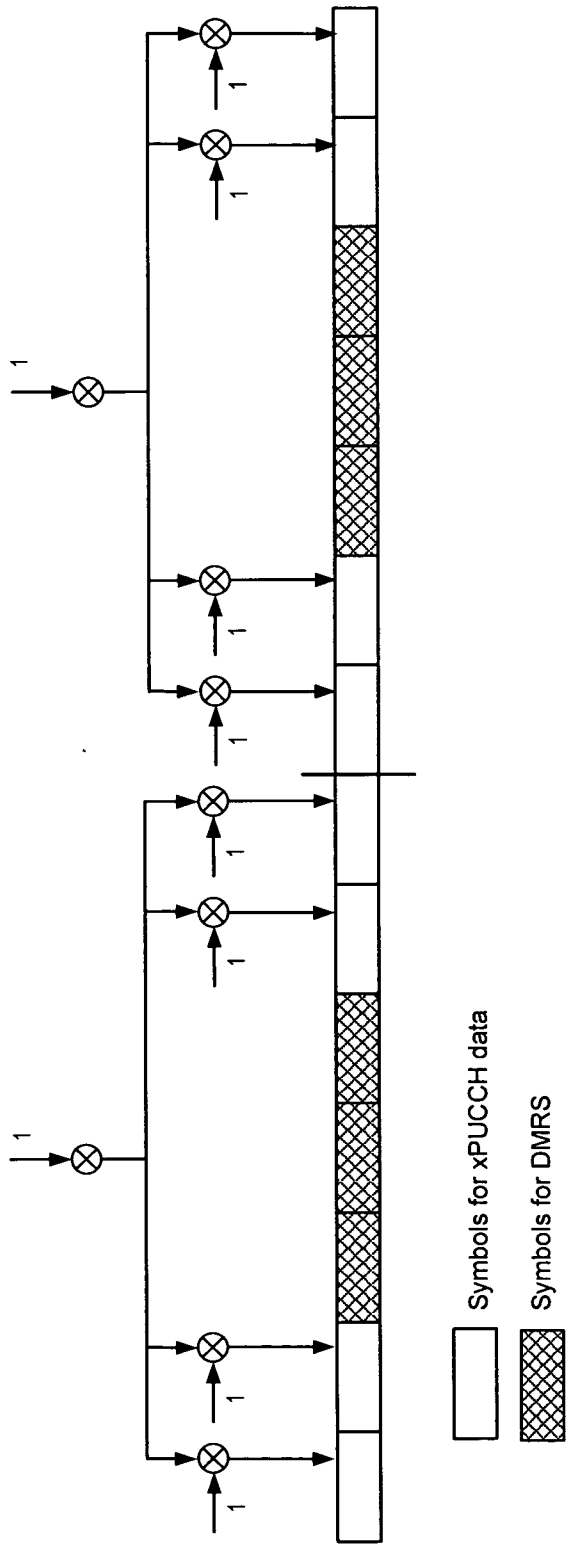


FIG. 3a

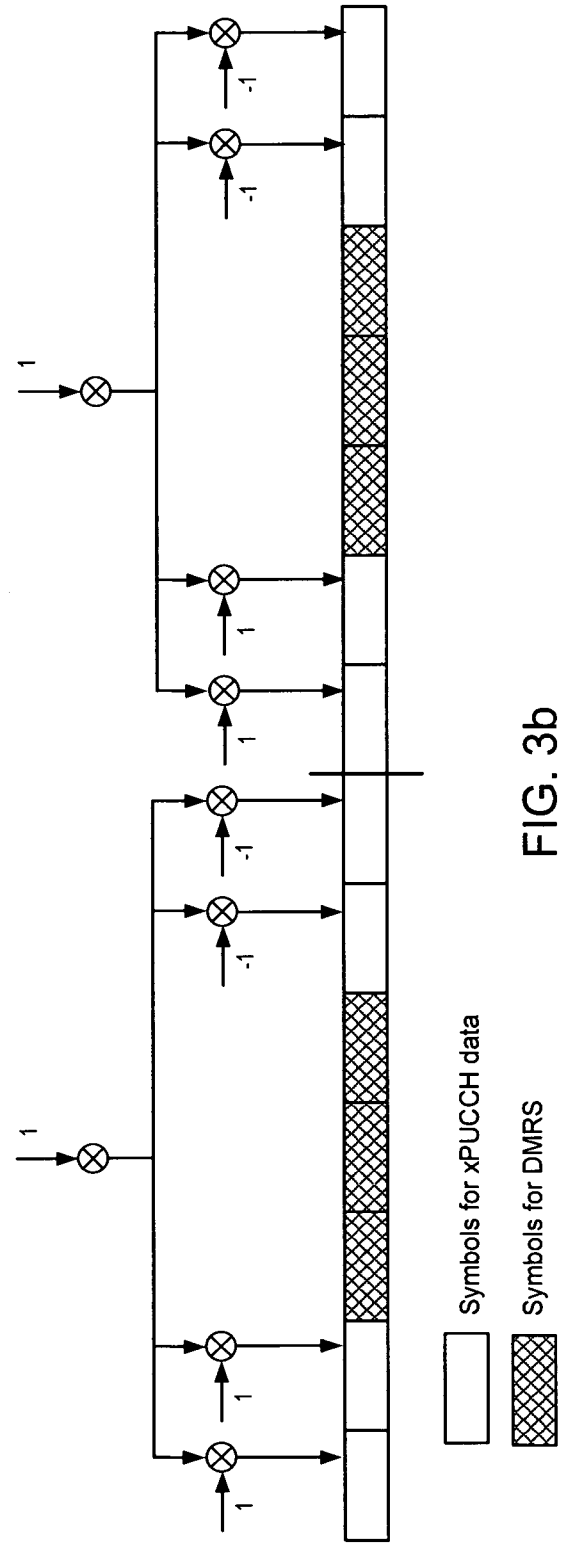


FIG. 3b

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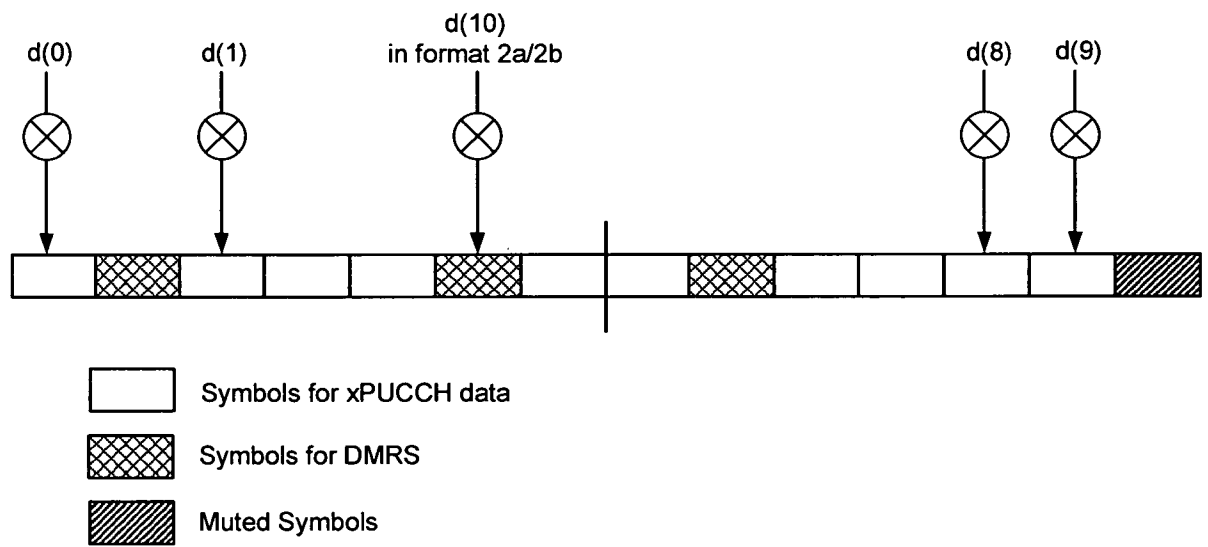


FIG. 4

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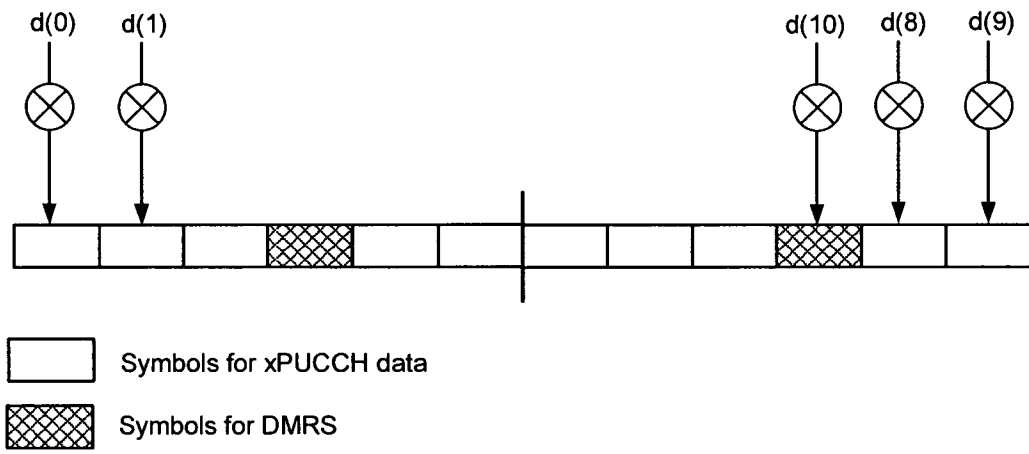


FIG. 5

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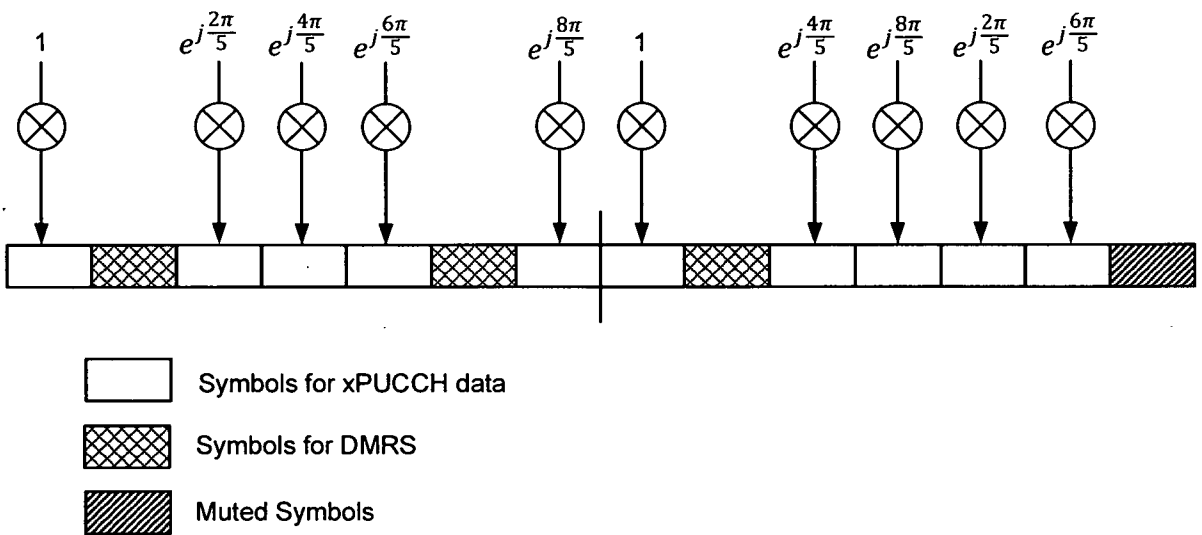


FIG. 6

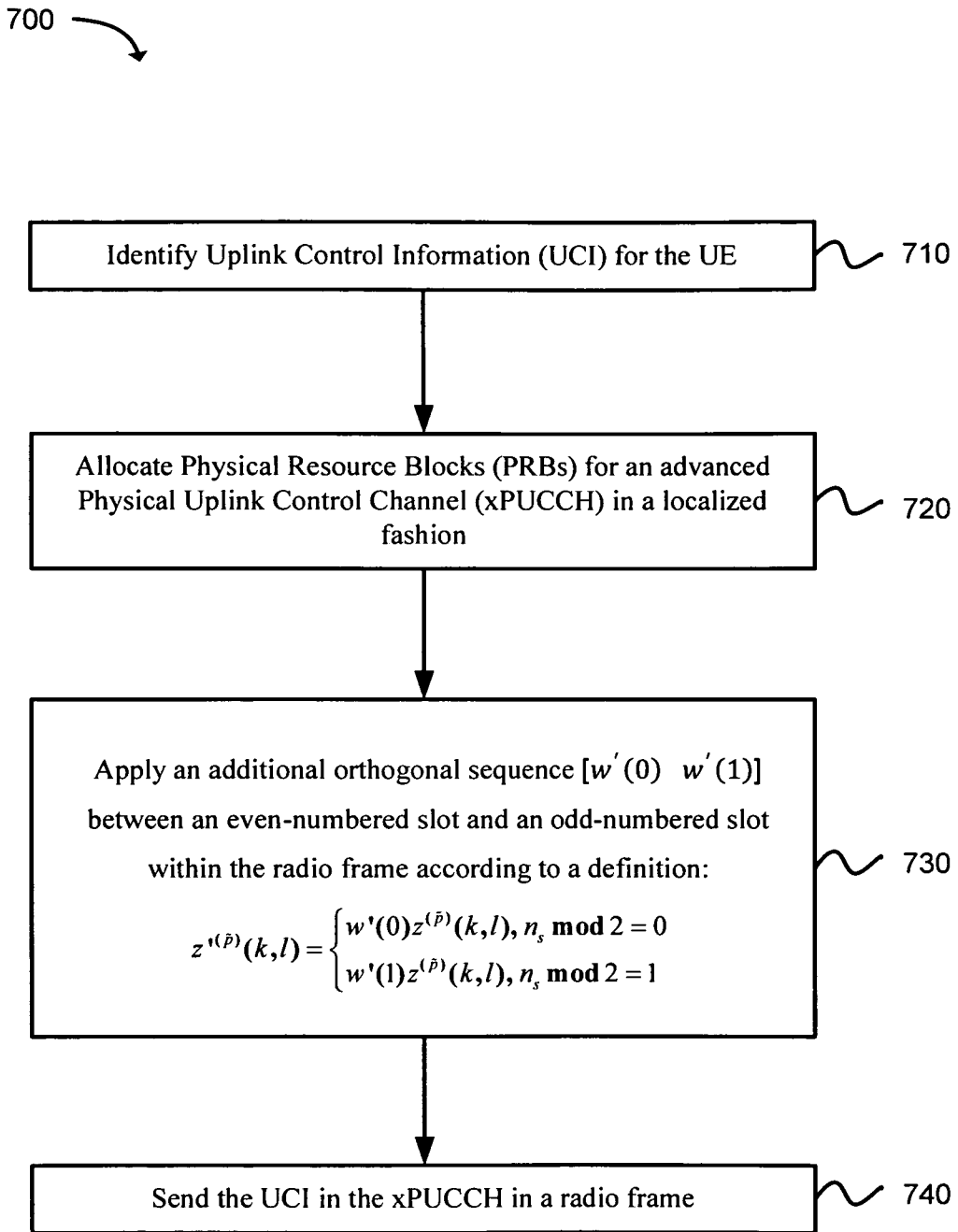


FIG. 7

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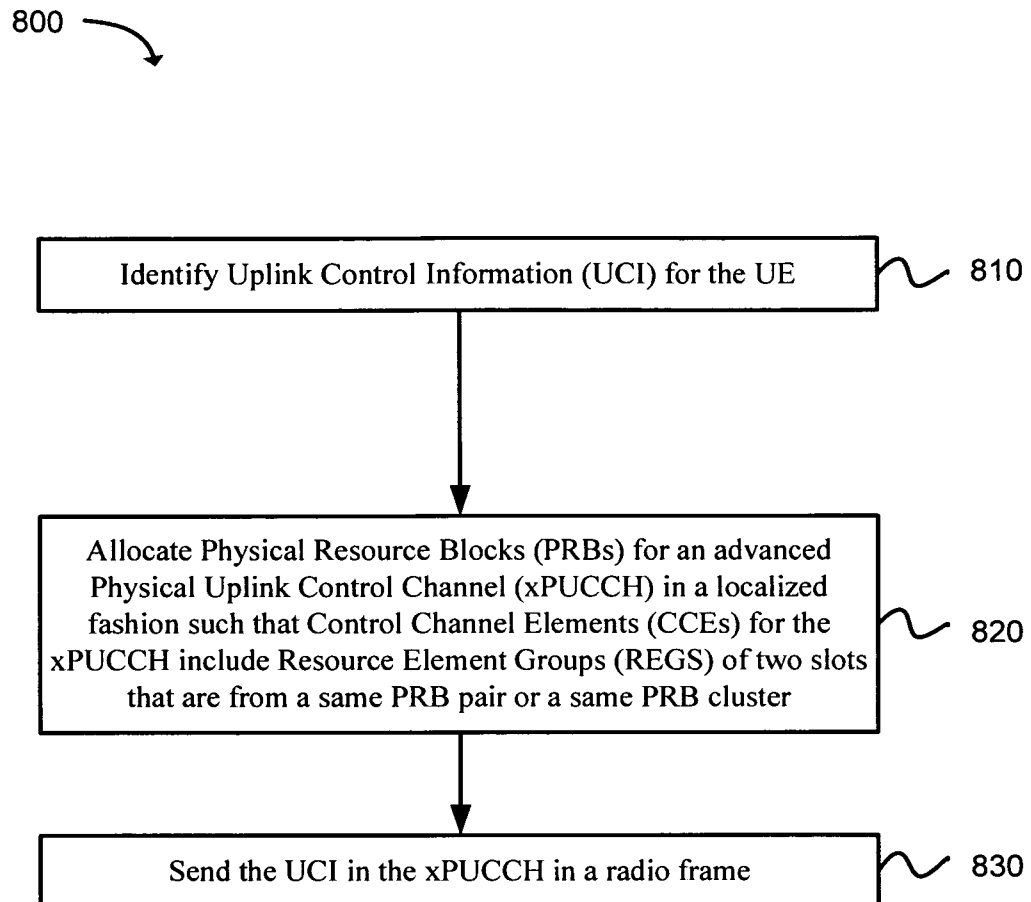


FIG. 8

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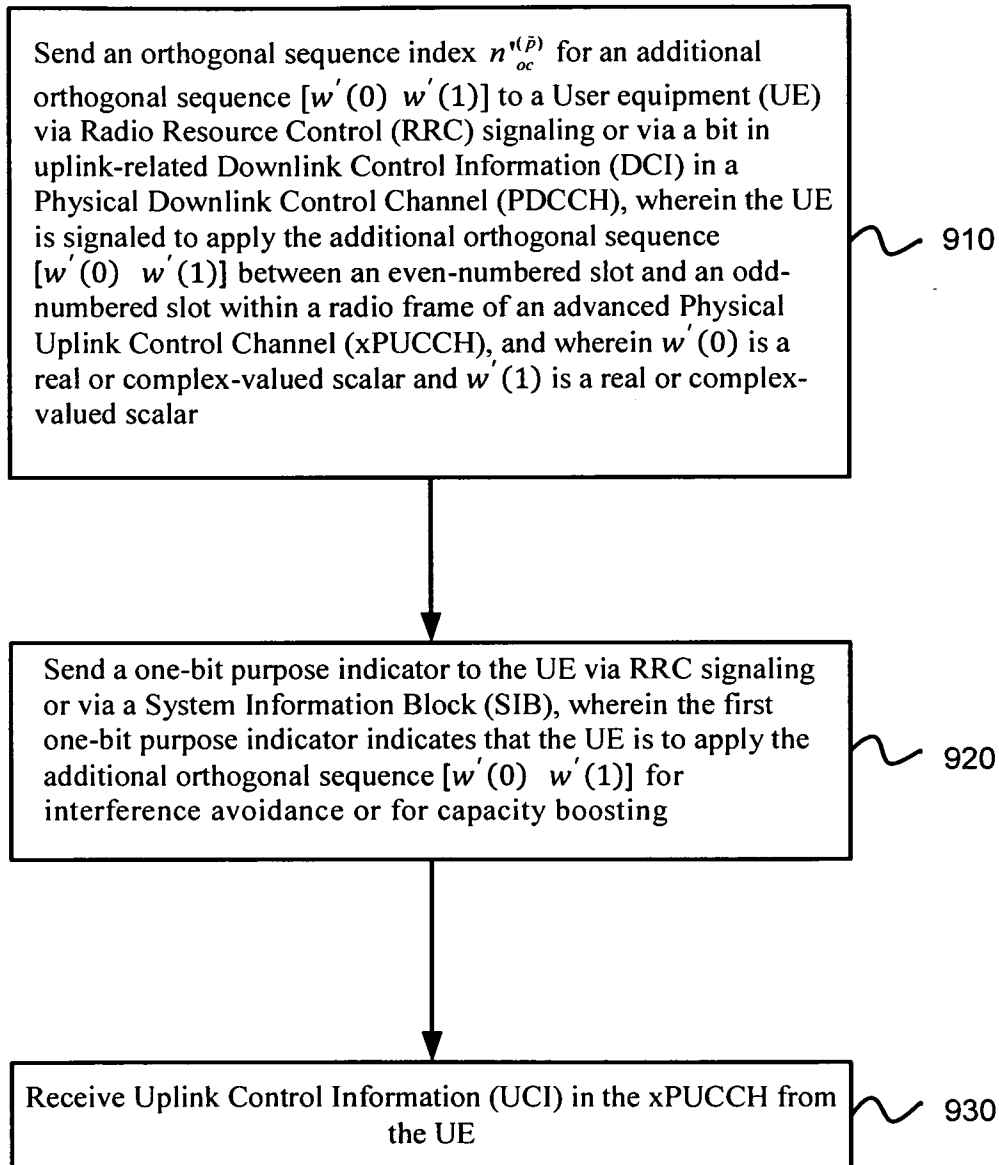

900 

FIG. 9

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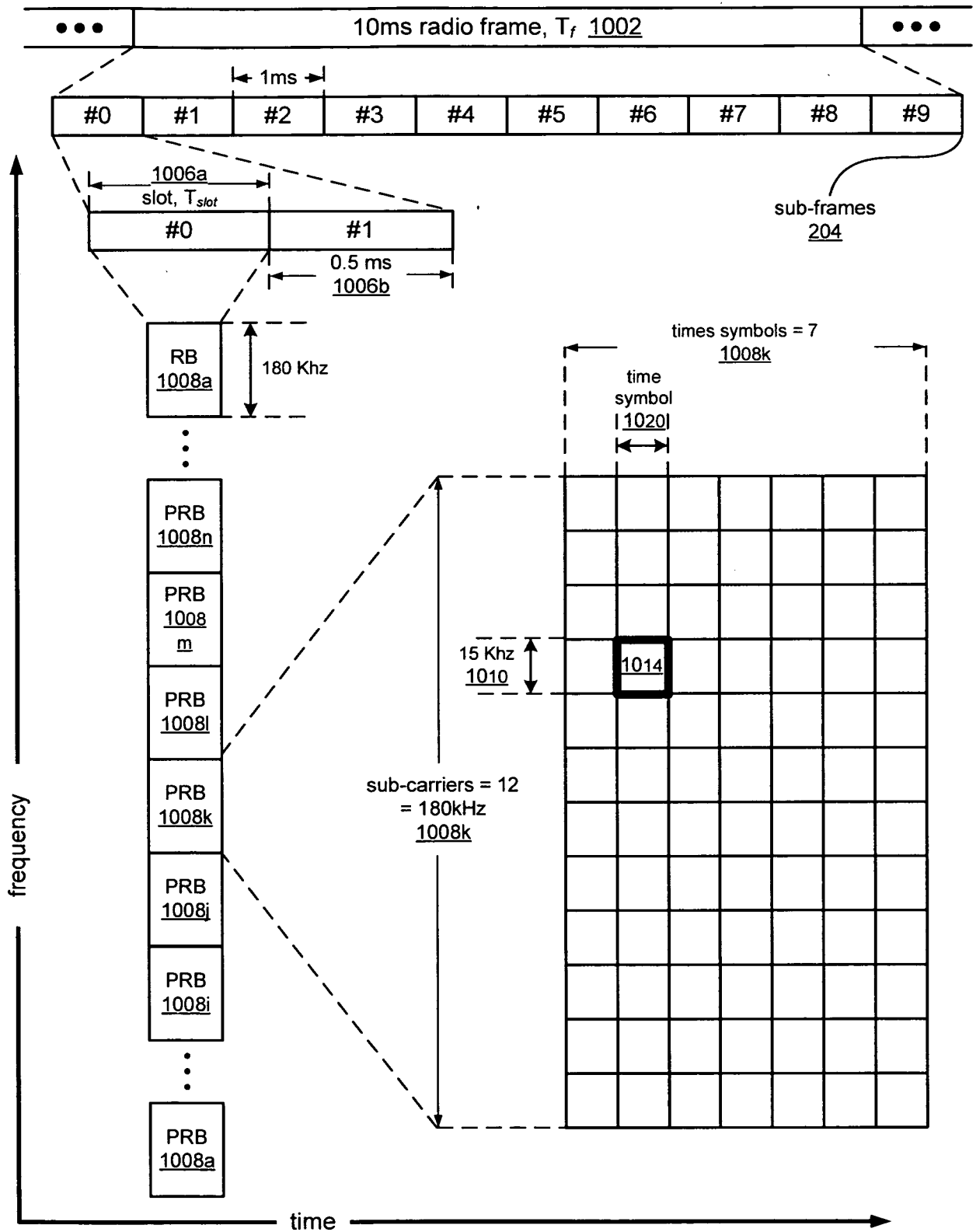


FIG. 10

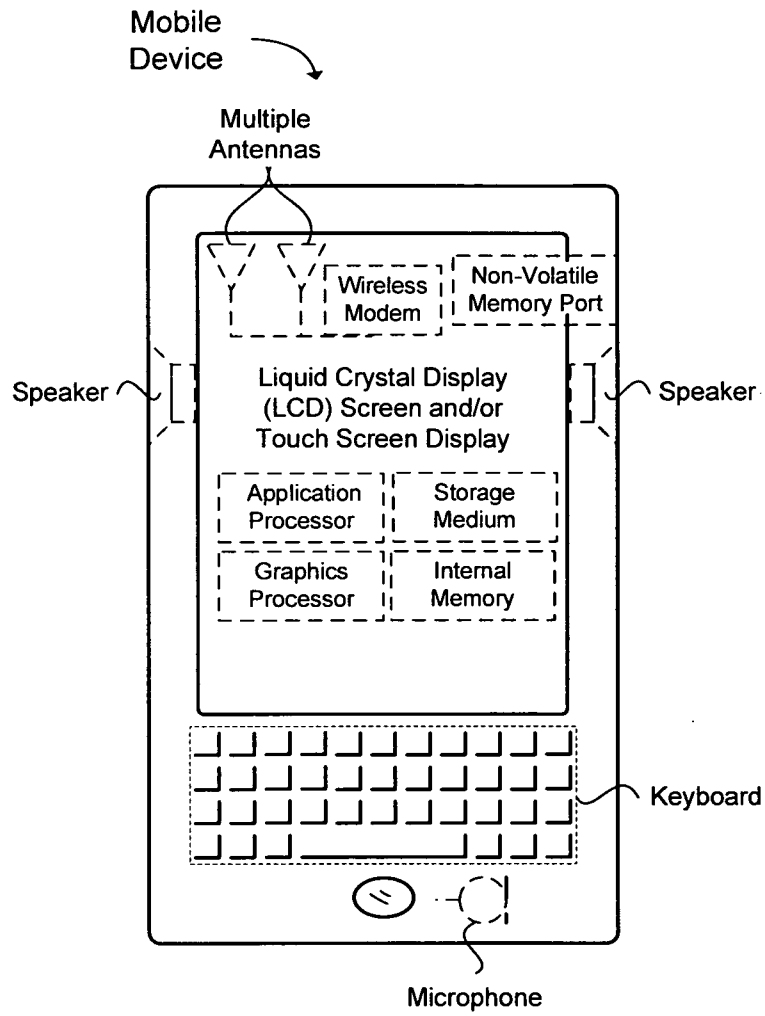


FIG. 11

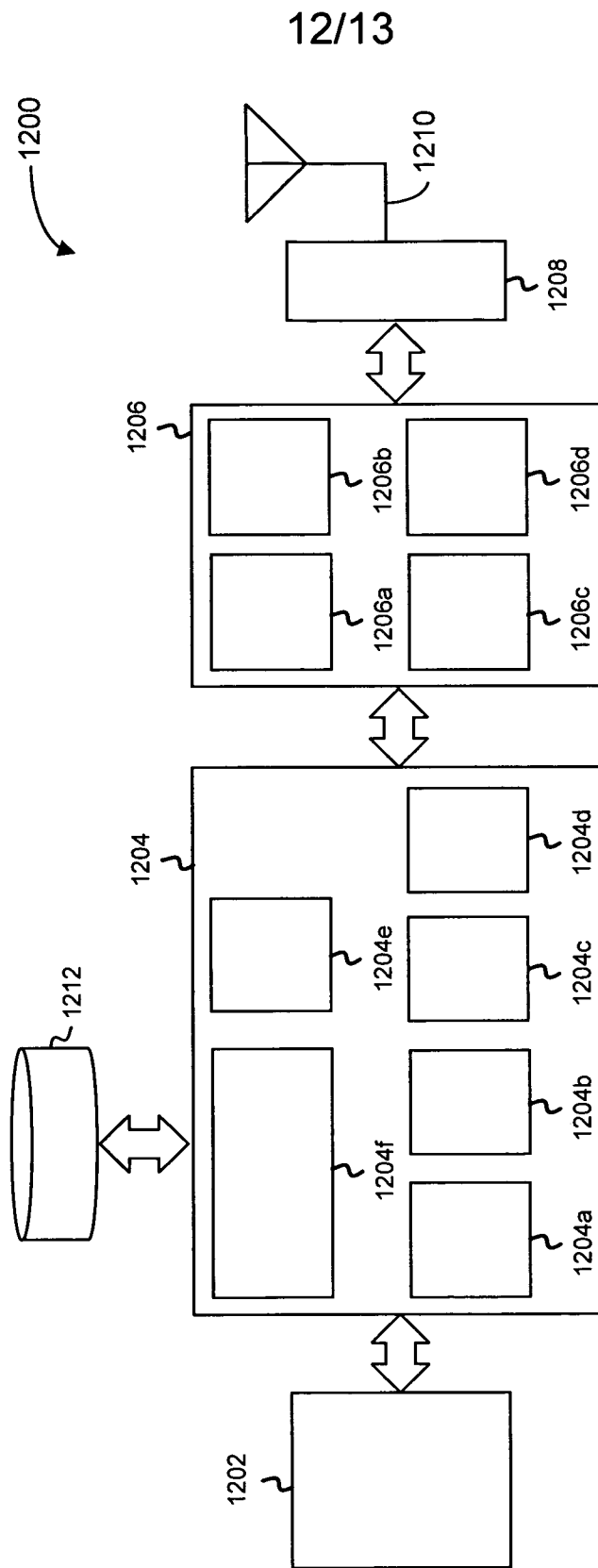


FIG. 12

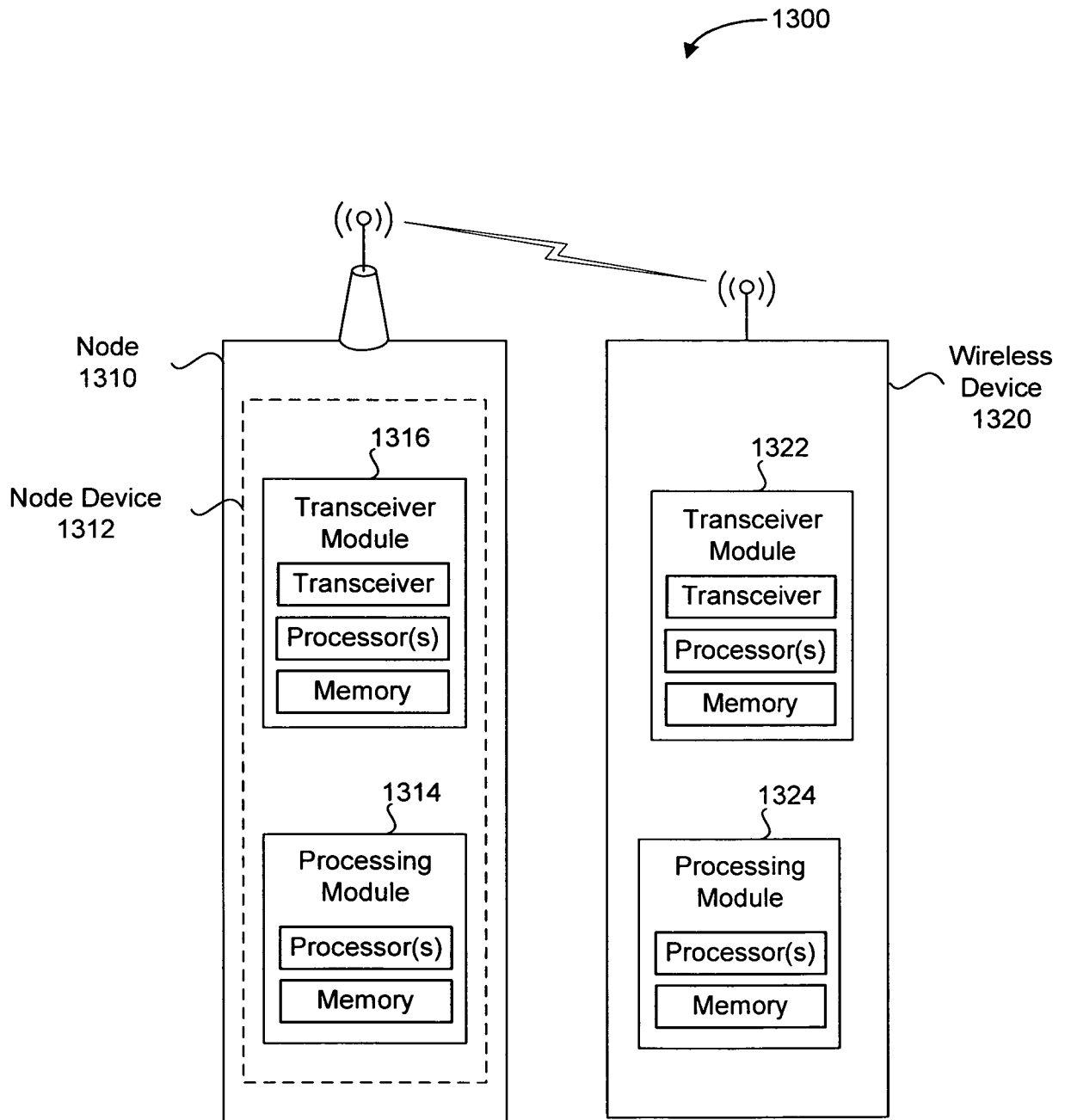


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/000356

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H04L5/00
 ADD.
 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
 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal, WPI Data, INSPEC, COMPENDEX

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 530 896 A2 (LG ELECTRONICS INC [KR]) 5 December 2012 (2012-12-05) paragraphs [0008], [0086] - [0091], [0243] - [0254] figures 26-28	1-20
A	----- EP 2 768 265 A1 (ZTE CORP [CN]) 20 August 2014 (2014-08-20) paragraphs [0017] - [0047]	1-20
A	----- US 2015/131562 A1 (KIM HAKSEONG [KR] ET AL) 14 May 2015 (2015-05-14) paragraphs [0147] - [0158] figures 9-10 -----	1-20

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 11 August 2016	Date of mailing of the international search report 19/08/2016
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Barrientos Lezcano
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Information on patent family members

International application No

PCT/US2015/000356

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