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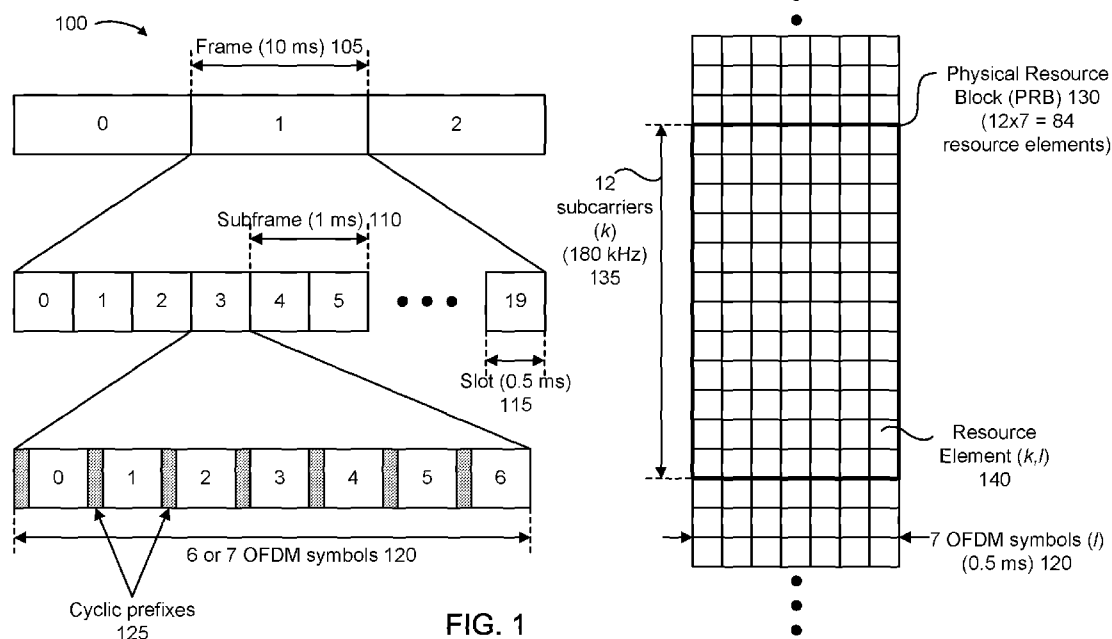


FIG. 1

(57) **Abstract:** Systems, methods, and devices for Sidelink communication are described. A symbol index (m) is determined from a plurality of symbol indices where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) Sidelink physical channel. Furthermore, the plurality of symbol indices includes at least three symbol indices (m). A plurality of elements of an orthogonal sequence ($w^{(\lambda)}(m)$) are also determined where each element in the orthogonal sequence ($w^{(\lambda)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices. A plurality of demodulation reference signals (DMRSs) are generated based on the plurality of elements of the orthogonal sequence ($w^{(\lambda)}(m)$). Each DMRS of the plurality of DMRSs is mapped to its corresponding symbol (l) of the subframe.



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DESIGN OF SIDELINK DEMODULATION REFERENCE SIGNALS

Related Applications

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/373,051, filed August 10, 2016, which is hereby incorporated by reference herein in its entirety.

Technical Field

[0002] The present disclosure generally relates to vehicular communication services, such as vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to-infrastructure/network (V2I/N), which are sometimes referred to individually and collectively as vehicle-to-anything or vehicular communication (V2X). In particular, the present disclosure relates to how long-term evolution (LTE) may be utilized for V2X (i.e., to provide the vehicles with wireless connections among each other and to the Internet (i.e., to realize the concept of “connected cars”).

Background

[0003] Wireless mobile communication technology enables communication of mobile user equipment devices, such as smartphones, tablet computing devices, laptop computers, and the like. Mobile communication technology may enable connectivity of various types of devices, supporting the “Internet of Things.” Vehicles are one example of mobile user equipment that may benefit from connectivity over wireless mobile communication technology.

[0004] Wireless mobile communication technology uses various standards and protocols to transmit data between a base station and a wireless communication device. One of these standards and protocols is the 3rd Generation Partnership Project (3GPP) long-term evolution (LTE). LTE defines various air interfaces including the Uu interface (e.g., interface between a user equipment (UE) and an evolved Node B (eNB)) and the PC5 interface (e.g., interface between two devices, i.e., Sidelink interface, proximity services (ProSe) direct communication, device-to-device (D2D) communication, etc.). It is proposed that the LTE PC5 interface (e.g., PC5 transport channels, Sidelink, D2D physical channels) be used to enable direct V2V/V2P/V2I/N communication.

Brief Description of the Drawings

[0005] FIG. 1 is a block diagram illustrating the structure of a long term evolution (LTE) communication frame.

[0006] FIG. 2 is a block diagram illustrating one example of how DMRS may be mapped to the PSSCH.

[0007] FIG. 3 is a block diagram illustrating one example of how DMRS may be mapped to the PSCCH.

[0008] FIG. 4 is a block diagram illustrating one example of how DMRS 210 may be mapped to the PSBCH.

[0009] FIG. 5 is a flow diagram of a method for enabling V2X communication.

[0010] FIG. 6 is a flow diagram of a method for enabling V2X communication.

[0011] FIG. 7 is a flow diagram of a method for enabling V2X communication.

[0012] FIG. 8 is a block diagram illustrating electronic device circuitry that may be eNB circuitry, UE circuitry, network node circuitry, or some other type of circuitry in accordance with various embodiments.

[0013] FIG. 9 is a block diagram illustrating, for one embodiment, example components of a V2X user equipment (UE), UE, mobile station (MS) device, or evolved Node B (eNB).

Detailed Description

[0014] The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail.

[0015] Long-term evolution (LTE), which is widely used for communications systems, may also be utilized to realize the concept of “connected cars.” In other words, LTE may be used to provide vehicles with wireless connections among each other and to the Internet (e.g., V2X). In particular, the LTE PC5 interface (e.g., PC5 transport channels, Sidelink, D2D physical channels) may be used to enable direct V2X communication. As noted previously, vehicle-to-device V2X communication may include vehicle-to-vehicle (V2V), vehicle-to-infrastructure/network (V2I/N),

and/or vehicle-to-pedestrian (V2P) communication. Although it is anticipated that the PC5 transport channels will be primarily used for V2V communication, it is appreciated that PC5 transport channels may also be used for V2I/N and/or V2P communication. Accordingly, the term V2X will be used in the following description.

[0016] It has been proposed that V2X communication over the PC5 transport channels may operate at up to the 6 gigahertz (GHz) carrier frequency and may support high speed scenarios with up to 500 kilometers per hour (km/h) relative vehicles speeds. So the physical layer design for the PC5 interface needs to be robust enough to provide reliable performance (for V2X communication) under such conditions.

[0017] The LTE PC5 interface includes multiple physical layer transport channels (i.e., Sidelink, device-to-device (D2D) physical channels). These PC5 transport channels include a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Control Channel (PSCCH), and a Physical Sidelink Broadcast Channel (PSBCH). Current PC5 transport channels (e.g., ProSe legacy D2D PSSCH, legacy D2D PSCCH, and legacy D2D PSBCH) utilize two demodulation reference signal (DMRS) symbols per 1 millisecond (ms) transmission time interval (TTI) (i.e., subframe).

[0018] The present systems and methods relate to enhanced PC5 transport channels (i.e., Sidelink, device-to-device (D2D) physical channels) which may be used to enable direct V2X operation using LTE technology. In particular, the present systems and methods relate to an enhanced PSSCH and an enhanced PSCCH that uses four DMRS symbols per 1 millisecond (ms) transmission time interval (TTI) (i.e., subframe) instead of the two DMRS symbols for the legacy PSSCH channel and the legacy PSCCH channel. Additionally, the present systems and methods relate to an enhanced PSBCH that uses three DMRS symbols per 1 ms TTI (i.e., subframe) instead of the two DMRS symbols for the legacy PSBCH channel. As used herein, these enhanced PC5 transport channels are referred to as V2X PSSCH, V2X PSCCH, and V2X PSBCH. Although these designations are used, it is appreciated that these enhanced PC5 transport channels may be used for any Sidelink communications, including for example V2X, D2D, and ProSe communications, etc.

[0019] In particular, the present systems and methods relate to multiple embodiments of sequence generation for these enhanced PC5 transport channels (e.g., V2X PSSCH, V2X PSCCH, and V2X PSBCH). For example, the present systems and methods describe multiple embodiments of procedures to support

DMRS sequence generation for enhanced PC5 transport channels (e.g., V2X systems). These multiple embodiments include DMRS orthogonal sequence generation for DMRS containing 3 or 4 symbols. In addition, the multiple embodiments of procedures to support DMRS sequence generation include the enablement of per-symbol DMRS sequence variation based on per-symbol CS index variation and/or the enablement of per-symbol DMRS sequence variation based on group hopping procedure.

[0020] It is appreciated that the procedures for the Sidelink (SL) DMRS generation for the legacy release 12 (Rel-12) and release 13 (Rel-13) D2D (ProSe) physical channels are defined in the 3GPP technical specification (TS) 36.211 Section 9.8 and is based on the uplink (UL) physical uplink shared channel (PUSCH) DMRS design principles with a number of exceptions. The present systems and methods describe procedures for enhanced PC5 physical channel (e.g., V2X PSSCH, V2X PSCCH, and V2X PSBCH) DMRS sequence generation. It is appreciated that the described procedures are based on the legacy PC5 physical channels with a number of modifications.

[0021] These modifications include the support of an increased number of DMRS symbols. For example, four DMRS symbols per subframe may be used for both V2X PSSCH and V2X PSCCH and three DMRS symbols per subframe may be used for V2X PSBCH. This is in contrast to the two DMRS symbols per subframe for each of legacy PSSCH, legacy PSCCH, and legacy PSBCH.

[0022] The general form of the DMRS sequence is described in 3GPP TS 36.211 Section 5.5.2.1.1 and provided herein as Equation 1.

$$r_{PSXCH}^{(\lambda)}(m \cdot M_{sc}^{RS} + n) = w^{(\lambda)}(m)r_{u,v}^{(\alpha\lambda)}(n)$$

Equation 1

In Equation 1, the DMRS sequence $r_{PSXCH}^{(\lambda)}(m \cdot M_{sc}^{RS} + n)$ is a function of symbol index (m) and subcarrier index (n), where (n) has a range of 0 to $M_{sc}^{RS}-1$ and M_{sc}^{RS} is the total number of reference signal subcarriers in a subframe in the frequency domain. The variable $M_{sc}^{RS} = M_{RB}^{PSXCH} * N_{sc}^{RB}$, where M_{RB}^{PSXCH} is the number of resource blocks (RBs) allocated for PSXCH transmission and number of subcarriers per RB $N_{sc}^{RB} = 12$. As illustrated in Equation 1, the DMRS sequence $r_{PSXCH}^{(\lambda)}(m \cdot M_{sc}^{RS} + n)$ is formed by

applying an element of an orthogonal sequence $w^{(\lambda)}$ depending on the symbol index (m) to a reference signal sequence $r_{u,v}^{(\alpha\lambda)}(n)$. The reference signal sequence $r_{u,v}^{(\alpha\lambda)}(n)$ is formed by applying a cyclic shift α to a base sequence $\bar{r}_{u,v}(n)$, which is based on sequence-group number (u), layer (v), and subcarrier index (n). The DMRS sequence $r_{PSXCH}^{(\lambda)}(m \cdot M_{sc}^{RS} + n)$ is further based on a given lambda (λ). It is noted that in both legacy PC5 physical channels and enhanced PC5 physical channels, the layer (v) may be considered to be a single layer and λ may be considered to be zero (e.g., 0). As used herein, PSXCH is used to denote any or different V2X Sidelink channels (e.g., V2X PSCCH, V2X PSSCH, V2X PSBCH).

[0023] Legacy PC5 physical channels (e.g., D2D PSSCH, D2D PSCCH, D2D PSBCH) are only defined for symbol index (m) values of 0 and 1. This limitation to two symbol indexes (m) was appropriate for legacy PC5 physical channels which only used two DMRS per subframe. However, as noted above, more than two DMRS per subframe are needed to support the performance requirements of enhanced PC5 physical channels (e.g., V2X PSSCH, V2X PSCCH, V2X PSBCH).

[0024] Enhanced PC5 physical channels may use four DMRS per subframe for V2X PSSCH and V2X PSCCH and three DMRS per subframe for V2X PSBCH. So instead of symbol index (m) values of 0 and 1, for D2D PSSCH, D2D PSCCH, and D2D PSBCH, V2X PSSCH and V2X PSCCH may have symbol index (m) values of 0, 1, 2, and 3 (e.g., four symbol index (m) values) and V2X PSBCH may have symbol index values of 0, 1, and 2 (e.g., three symbol index (m) values).

[0025] It is appreciated that one or more aspects of the sequence generation parameters in Equation 1 may need to be modified to accommodate an increased number of DMRS symbols (e.g., greater than two symbol indexes (m)). For example, the orthogonal sequence $w^{(\lambda)}$ parameter may be modified in order to accommodate the increased number of DMRS symbols (e.g., symbol indexes (m) 2 and/or 3). Additionally or alternatively, the DMRS sequence may be varied on a per-symbol basis to accommodate the increased number of DMRS symbols.

[0026] As set forth in Equation 1, the DMRS sequence is generated by applying an element $w^{(\lambda)}(m)$ of an orthogonal sequence $w^{(\lambda)}$ to a reference signal sequence $r_{u,v}^{(\alpha\lambda)}(n)$. In legacy PC5 physical channels the orthogonal sequence $w^{(\lambda)}$ which is only defined for symbol indexes (m) 0 and 1 has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1)]$. For

legacy D2D PSSCH the orthogonal sequence $w^{(\lambda)}$ is defined to be $[+1 + 1]$ if $n_{ID}^{SA} \bmod 2 = 0$ and is defined to be $[+1 - 1]$ if $n_{ID}^{SA} \bmod 2 = 1$, wherein n_{ID}^{SA} is the Sidelink group destination identity. For legacy D2D PSCCH the orthogonal sequence $w^{(\lambda)}$ is defined to be $[+1 + 1]$. For legacy D2D PSBCH the orthogonal sequence $w^{(\lambda)}$ is defined to be $[+1 + 1]$ if $N_{ID}^{SL} \bmod 2 = 0$ and is defined to be $[+1 - 1]$ if $N_{ID}^{SL} \bmod 2 = 1$, wherein N_{ID}^{SL} is the physical layer Sidelink synchronization identity. So as defined, the orthogonal sequences $w^{(\lambda)}$ for legacy PC5 physical channels do not accommodate more than two DMRS in a subframe (i.e., do not accommodate more than two symbol indices (m)).

[0027] As a result, new orthogonal sequences $w^{(\lambda)}$ are needed to accommodate additional DMRS in the subframe (i.e., more than two symbol indices (m)). As described, the enhanced PC5 physical channels (e.g., V2X PSSCH, V2X PSCCH, V2X PSBCH) may define new orthogonal sequences $w^{(\lambda)}$ to accommodate additional DMRS in the subframe.

[0028] As noted above, the V2X PSBCH includes three (3) DMRS per subframe rather than the two (2) DMRS per subframe as used in D2D PSBCH. So the orthogonal sequence $w^{(\lambda)}$ which is defined for symbol indexes (m) 0, 1, and 2 has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2)]$. In some embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSBCH is defined to be $[+1 + 1 + 1]$ (e.g., a first sequence) if $n_{ID}^{SL} \bmod 2 = 0$ and is defined to be $[+1 - 1 + 1]$ (e.g., a second sequence) if $N_{ID}^{SL} \bmod 2 = 1$, wherein N_{ID}^{SL} is the physical layer Sidelink synchronization identity. In other embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSBCH is defined to be $[+1 + 1 + 1]$ (e.g., a first sequence) if $N_{ID}^{SL} \bmod 2 = 0$ and is defined to be $[-1 + 1 - 1]$ (e.g., a second sequence) if $N_{ID}^{SL} \bmod 2 = 1$, wherein N_{ID}^{SL} is the physical layer Sidelink synchronization identity. In yet other embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSBCH may be defined to be $[+1 + 1 + 1]$ (e.g., a single sequence). It is noted that the selection rule may be inversed without departing from the scope of the description.

[0029] As noted above, the V2X PSSCH includes four (4) DMRS per subframe rather than the two (2) DMRS per subframe as used in D2D PSSCH. So the orthogonal sequence $w^{(\lambda)}$ which is defined for symbol indexes (m) 0, 1, 2, and 3 has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2) w^{(\lambda)}(3)]$. In some embodiments, the orthogonal

sequence $w^{(\lambda)}$ for V2X PSSCH is defined to be $[+1 +1 +1 +1]$ (e.g., a first sequence) if $n_{ID} \bmod 2 = 0$ and is defined to be $[+1 -1 +1 -1]$ (e.g., a second sequence) if $n_{ID} \bmod 2 = 1$, wherein n_{ID} is the Sidelink identifier. In other embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSSCH is defined to be $[+1 +1 +1 +1]$ (e.g., a first sequence) if $n_{ID} \bmod 2 = 0$ and is defined to be $[-1 +1 -1 +1]$ (e.g., a second sequence) if $n_{ID} \bmod 2 = 1$, wherein n_{ID} is the Sidelink identifier. In yet other embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSSCH may be defined to be $[+1 +1 +1 +1]$ (e.g., a single sequence). In yet another embodiment, the orthogonal sequence $w^{(\lambda)}$ for V2X PSSCH is defined to be $[+1 +1 +1 +1]$ (e.g., a first sequence) if $n_{ID} \bmod 4 = 0$, is defined to be $[+1 -1 +1 -1]$ (e.g., a second sequence) if $n_{ID} \bmod 4 = 1$, is defined to be $[+1 +1 -1 -1]$ (e.g., a third sequence) if $n_{ID} \bmod 4 = 2$, and is defined to be $[+1 -1 -1 +1]$ (e.g., a fourth sequence) if $n_{ID} \bmod 4 = 3$, wherein n_{ID} is the Sidelink identifier. It is noted that the selection rule may be reordered without departing from the scope of the description (in other words, the sequence ordering may vary).

[0030] As noted above, the V2X PSCCH includes four (4) DMRS per subframe rather than the two (2) DMRS per subframe as used in D2D PSCCH. So the orthogonal sequence $w^{(\lambda)}$ which is defined for symbol indexes (m) 0, 1, 2, and 3 has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2) w^{(\lambda)}(3)]$. In some embodiments, the orthogonal sequence $w^{(\lambda)}$ for V2X PSCCH is defined to be $[+1 +1 +1 +1]$.

[0031] In some embodiments, the DMRS sequence may vary on a per-symbol basis. In other words, one or more of the enhanced PC5 physical channels (e.g., V2X PSSCH, V2X PSCCH, V2X PSBCH) may have different DMRS sequences in different symbols of one subframe. With reference to Equation 1, per symbol sequence variation may be the result of modifying the reference signal sequence $r_{u,v}^{(\alpha_\lambda)}(n)$. This is in contrast to legacy D2D procedures which do not provide for DMRS sequence variation. As described herein, there are several (e.g., additional and/or alternative) approaches for providing per symbol DMRS sequence variation.

[0032] In some embodiments, different cyclic shifts (α_λ) are used for different symbols in the subframe. As set forth in Equation 2 below, the cyclic shift (α_λ) in a slot (n_s) is based on a cyclic shift index parameter ($n_{cs,\lambda}$).

$$\alpha_\lambda = 2\pi n_{cs,\lambda}/12$$

Equation 2

[0033] In legacy UL physical channels the cyclic shift index parameter $n_{cs,\lambda}$ = $(n_{\text{DMRS}}^{(1)} + n_{\text{DMRS},\lambda}^{(2)} + n_{\text{PN}}(n_s))$. For the legacy PC5 D2D physical channels the cyclic shift index $n_{cs,\lambda}$ is defined to be $\lfloor n_{\text{ID}}^{\text{SA}}/2 \rfloor \bmod 8$ for D2D PSSCH, $\lfloor n_{\text{ID}}^{\text{SL}}/2 \rfloor \bmod 8$ for D2D PSBCH, and 0 for D2D PSCCH and PSDCH. As described herein, the $n_{cs,\lambda}$ parameter may be modified in a way to change the cyclic shift α_λ from one DMRS symbol to another DMRS symbol in order to ensure different DMRS sequences with different cyclic shifts in different symbols.

[0034] As described herein, the cyclic shift index parameter $n_{cs,\lambda}$ may be modified to be defined as a function of the symbol index (m) (e.g., $n_{cs,\lambda} = n_{cs,\lambda}(m)$). In particular, the cyclic shift index parameter $n_{cs,\lambda}$ may be defined as set forth in Equation 3.

$$n_{cs,\lambda}(m) = (A + B \times m) \bmod C$$

Equation 3

[0035] In Equation 3, the parameter A may depend on the Sidelink identifier n_{ID} for V2X PSSCH and may be defined as $A = \lfloor n_{\text{ID}}/2 \rfloor$. In Equation 3, the parameter A may depend on the physical layer Sidelink synchronization identity $n_{\text{ID}}^{\text{SL}}$ for V2X PSBCH and may be defined as $A = \lfloor N_{\text{ID}}^{\text{SL}}/2 \rfloor$. In Equation 3, the parameter A may be zero (e.g., $A = 0$) for V2X PSCCH. In Equation 3, the parameter B may be defined as 1 (e.g., $B = 1$) as a baseline case, or 2 (e.g., $B = 2$), or 3 (e.g., $B = 3$). In Equation 3, the parameter C may be less than or equal to 12 (e.g., $C \leq 12$). For example, C may equal 8 as a baseline or may equal 12.

[0036] In other embodiments, the group hopping procedure may be modified to provide DMRS sequence variation on a per-symbol basis. As set forth in 3GPP TS 36.211 Section 5.5.1.3 Version 13.3.0, for UL the sequence-group number u in slot n_s is defined by a group-hopping pattern $f_{\text{gh}}(n_s)$ and a sequence-shift pattern f_{ss} according to Equation 4.

$$u = (f_{\text{gh}}(n_s) + f_{\text{ss}}) \bmod 30$$

Equation 4

[0037] The group hopping pattern $f_{gh}(n_s)$ for different UL transmissions may be different for PUSCH, PUCCH, and sounding reference signals (SRS) and is given by Equation 5.

$$f_{gh}(n_s) = \begin{cases} 0 & \text{if group hopping is disabled} \\ \left(\sum_{i=0}^7 c(8n_s + i) \cdot 2^i \right) \bmod 30 & \text{if group hopping is enabled} \end{cases}$$

Equation 5

[0038] In Equation 5, the pseudo-random sequence $c(i)$ is defined by 3GPP TS 36.211 Section 7.2 Version 13.3.0. The pseudo-random sequence generator shall be initialized with $c_{init} = \left\lfloor \frac{n_{ID}^{RS}}{30} \right\rfloor$ at the beginning of each radio frame, where n_{ID}^{RS} is given by 3GPP TS 36.211 Section 5.5.1.5 Version 13.3.0.

[0039] For the legacy PC5 D2D physical channels the UL DMRS design principles described above are reused with certain modifications. For the legacy PC5 D2D PSSCH physical channel, group hopping is enabled with $n_{RS}^{ID} = n_{SA}^{ID}$, $n_s = n_{SS}^{PSSCH}$ and $f_{ss} = n_{SA}^{ID} \bmod 30$. For the legacy PC5 D2D PSCCH physical channel group hopping is disabled with $f_{gh}(n_s) = 0$ and $f_{ss} = 0$. For the legacy PC5 D2D PSBCH physical channel group hopping is disabled with $f_{gh}(n_s) = 0$ and $f_{ss} = \left\lfloor N_{ID}^{SL} / 16 \right\rfloor \bmod 30$.

[0040] As described herein the group hopping procedure may be modified for V2V physical channels to ensure that the DMRS sequence is changed on a per DMRS symbol basis $u = u(m)$, where m is the symbol index. In some embodiments, the sequence shift pattern f_{ss} may be modified to change on a per-DMRS symbols basis (e.g., $f_{ss} = f_{ss}(m)$). For instance, the sequence shift pattern may be defined as set forth in Equation 6.

$$f_{ss} = (A + B \times m) \bmod C$$

Equation 6

[0041] In Equation 6, the parameter A may depend on the Sidelink identifier n_{ID} for V2X PSSCH and may be defined as $A = n_{ID}$. In Equation 6, the parameter A may depend on the physical layer Sidelink synchronization identity n_{ID}^{SL} for V2X PSBCH and may be defined as $A = \lfloor N_{ID}^{SL}/16 \rfloor$. In Equation 6, the parameter A may be zero (e.g., $A = 0$) for V2X PSCCH. In Equation 6, the parameter B may be an integer value (e.g., 1, 2, 3, ...), such as 1 (e.g., $B = 1$) as a baseline case, or 2 (e.g., $B = 2$), or 3 (e.g., $B = 3$). In Equation 6, the parameter C may be equal to 30 (e.g., $C = 30$). In some cases, the sequence shift pattern f_{ss} may be modified to change on a per-DMRS symbols basis regardless of the state (e.g., enabled or disabled) of the group hopping procedure.

[0042] As described herein, the group hopping pattern $f_{gh}(n_s)$ may be modified for V2X (e.g., V2V) physical channels to ensure that the DMRS sequence is changed on a per DMRS symbol basis $u = u(m)$, where m is the symbol index. In some embodiments, the group hopping pattern $f_{gh}(n_s)$ may be modified to change on a per-DMRS symbols basis (e.g., $f_{gh} = f_{gh}(m)$). For instance, the group hopping pattern $f_{gh}(m)$ may be defined as set forth in Equation 7.

$$f_{gh}(m) = \begin{cases} 0 & \text{if group hopping is disabled} \\ \left(\sum_{i=0}^7 c(8A(m) + i) \cdot 2^i \right) \bmod 30 & \text{if group hopping is enabled} \end{cases}$$

Equation 7

[0043] In Equation 7, the parameter $A(m)$ may be defined as a function of symbol index (m). In some embodiments, the parameter A can be defined as a function of the DMRS symbol index in the Sidelink subframe pool as set forth in Equation 8.

$$A = Bn_{ssf} + m$$

Equation 8

[0044] In Equation 8 and as used herein, symbol index (m) is the index of the current DMRS symbol within the current Sidelink subframe. In Equation 8, the parameter B may be defined as the number of DMRS symbols per subframe (e.g., $B=4$ for V2X PSSCH and V2X PSCCH, $B=3$ for V2X PSBCH). In Equation 8, the

parameter n_{ssf} may be the Sidelink subframe index in the pool (e.g., $n_{ssf} = n_{ssf}^{PSSCH}$). It is appreciated that the use of the modified group hopping pattern $f_{gh}(m)$ requires that group hopping be enabled. In addition to the use of the modified group hopping pattern $f_{gh}(m)$ as set forth in Equation 7, to enable group hopping additional parameters may need to be specified for V2X PSCCH and V2X PSBCH. In some embodiments, the group hopping parameter $n_{RS}^{ID} = 0$ is used for V2X PSCCH. In some embodiments, the group hopping parameter $n_{RS}^{ID} = \lfloor N_{ID}^{SL}/M \rfloor$ is used for V2X PSBCH, where N_{ID}^{SL} is the physical layer Sidelink synchronization identity and where M can be equal to 2, 4, 8, 16, ..., etc.

[0045] It is appreciated that many of the embodiments herein may be described with respect to V2X PSSCH, V2X PSCCH and V2X PSBCH physical channels and provided under assumption that 3GPP Release 14 V2X physical channels will have the same notations as 3GPP Release 12 Sidelink physical channels. The 3GPP Release 14 notations may be different and in this case the described embodiments may be applicable to the corresponding V2X physical channels. In some cases, legacy D2D physical channels (e.g., D2D PSSCH, D2D PSCCH, D2D PSBCH) may be referred to as Sidelink transmission modes 1 and 2 while the described V2X physical channels (e.g., V2X PSSCH, V2X PSCCH, V2X PSBCH) may be referred to as Sidelink transmission modes 3 and 4.

[0046] In some cases, the described systems and methods may be expressed in Tables 9.8-1, 9.8-2, and 9.8-3 of 3GPP TS 36.211 V14.0.0, where Table 9.8-1 provides the reference signal parameters for PSSCH, Table 9.8-2 provides the reference signal parameters for PSCCH, and Table 9.8-3 provides the reference signal parameters for PSDCH and PSBCH.

[0047] Turning now to the figures, FIG. 1 is a block diagram 100 illustrating the structure of a long term evolution (LTE) communication frame 105. A frame 105 has a duration of 10 milliseconds (ms). The frame 105 includes 10 subframes 110, each having a duration of 1 ms. Each subframe 110 (or transmission time interval) includes two slots 115, each having a duration of 0.5 ms. Therefore, the frame 105 includes 20 slots 115.

[0048] Each slot 115 includes six or seven orthogonal frequency-division multiplexing (OFDM) symbols 120. The number of OFDM symbols 120 in each slot 115 is based on the size of the cyclic prefixes (CP) 125. For example, the number of

OFDM symbols 120 in the slot 115 is seven while in normal mode CP and six in extended mode CP.

[0049] The smallest allocable unit for transmission is a resource block (RB) 130 (i.e., physical resource block (PRB) 130). Transmissions are scheduled by PRB 130 pairs (i.e., two consecutive PRBs 130 in one subframe). A PRB 130 consists of 12 consecutive subcarriers (k) 135, or 180 kHz, for the duration of one slot 115 (0.5 ms). A resource element (k, l) 140, which is the smallest defined unit, consists of one OFDM subcarrier (k) during one OFDM symbol interval (l). In the case of normal mode CP, each PRB 130 consists of $12 \times 7 = 84$ resource elements 140. Each PRB 130 consists of 72 resource elements 140 in the case of extended mode CP.

[0050] As discussed above, each DMRS is mapped to an OFDM symbol interval (l) 120. For example, a DMRS sequence is mapped to a plurality of resource elements 140 in an OFDM symbol interval (l) 120. Since the mapping of DMRS to OFDM symbol intervals (l) 120 is physical channel dependent, each will be discussed in turn below. Although the following figures illustrate the case of normal CP (e.g., 7 OFDM symbols (l) 120 per slot 115), it is understood that the same systems and methods may be used in the case of extended CP.

[0051] FIG. 2 is a block diagram illustrating one example of how DMRS 210 may be mapped to the PSSCH. As illustrated, the mapping pattern of DMRS 210 to the PSSCH is a 12 subcarrier pattern (k) that is one subframe 110 (e.g., two slots 115) in length. In the case of normal CP, the mapping pattern of DMRS 210 to the PSSCH is 14 OFDM symbols (l) 120 in length. For convenience in identifying the OFDM symbol intervals (l) 120 in the different slots 115, the OFDM symbol intervals (l) 120 in the first slot 115-a are number 0-6 and the OFDM symbol intervals (l) 120 in the second slot 115-b are numbered 7-13.

[0052] As discussed previously, the PSSCH includes four DMRS symbols per 1 ms TTI (e.g., subframe 110). Each DMRS is mapped to an OFDM symbol index (l) such that a first DMRS symbol 210 is mapped to a first OFDM symbol index (l) 120 (e.g., $l=2$), a second DMRS symbol 210 is mapped to a second OFDM symbol index (l) 120 (e.g., $l=5$), a third DMRS symbol 210 is mapped to a third OFDM symbol index (l) 120 (e.g., $l=8$), and a fourth DMRS symbol 210 is mapped to a fourth OFDM symbol index (l) 120 (e.g., $l=11$). It is appreciated that the symbol index (m) discussed above, which has indices of $m=0, 1, 2$, and 3 for PSSCH corresponds to the respective mapped OFDM symbol indices (l) 120 such that the first symbol index

(m) (e.g., $m=0$) maps to the first mapped OFDM symbol indices (l) 120 (e.g., $l=2$), the second symbol index (m) (e.g., $m=1$) maps to the second mapped OFDM symbol indices (l) 120 (e.g., $l=5$), the third symbol index (m) (e.g., $m=2$) maps to the third mapped OFDM symbol indices (l) 120 (e.g., $l=8$), and the fourth symbol index (m) (e.g., $m=3$) maps to the fourth mapped OFDM symbol indices (l) 120 (e.g., $l=11$).

[0053] In the case of the PSSCH, the four DMRSs are mapped to each of the 12 subcarriers (k) 135, so that in the 12 subcarrier pattern, there are 12 resource elements (k,l) 140 that include the DMRS for each of $l=2, 5, 8$, and 11 . The remaining resource elements (k,l) 140 in the 12 subcarrier pattern may be devoted to PSSCH 205 except for the resource elements (k,l) 140 with $l=13$ which may be devoted to guard symbols 215 (as shown).

[0054] FIG. 3 is a block diagram illustrating one example of how DMRS 210 may be mapped to the PSCCH. As illustrated, the mapping pattern of DMRS 210 to the PSCCH is a 12 subcarrier pattern (k) that is one subframe 110 (e.g., two slots 115) in length. In the case of normal CP, the mapping pattern of DMRS 210 to the PSSCH is 14 OFDM symbols (l) 120 in length. For convenience in identifying the OFDM symbol intervals (l) in the different slots 115, the OFDM symbol intervals (l) 120 in the first slot 115-a are numbered 0-6 and the OFDM symbol intervals (l) 120 in the second slot 115-b are numbered 7-13.

[0055] As discussed previously, the PSCCH includes four DMRS symbols per 1 ms TTI (e.g., subframe 110). Each DMRS is mapped to an OFDM symbol index (l) such that a first DMRS symbol 210 is mapped to a first OFDM symbol index (l) 120 (e.g., $l=2$), a second DMRS symbol 210 is mapped to a second OFDM symbol index (l) 120 (e.g., $l=5$), a third DMRS symbol 210 is mapped to a third OFDM symbol index (l) 120 (e.g., $l=8$), and a fourth DMRS symbol 210 is mapped to a fourth OFDM symbol index (l) 120 (e.g., $l=11$). It is appreciated that the symbol index (m) discussed above, which has indices of $m=0, 1, 2$, and 3 for PSCCH corresponds to the respective mapped OFDM symbol indices (l) 120 such that the first symbol index (m) (e.g., $m=0$) maps to the first mapped OFDM symbol indices (l) 120 (e.g., $l=2$), the second symbol index (m) (e.g., $m=1$) maps to the second mapped OFDM symbol indices (l) 120 (e.g., $l=5$), the third symbol index (m) (e.g., $m=2$) maps to the third mapped OFDM symbol indices (l) 120 (e.g., $l=8$), and the fourth symbol index (m) (e.g., $m=3$) maps to the fourth mapped OFDM symbol indices (l) 120 (e.g., $l=11$).

[0056] In the case of the PSCCH, the four DMRS are mapped to each of the 12 subcarriers (k) 135, so that in the 12 subcarrier pattern, there are 12 resource elements (k, l) 140 that include the DMRS for each of $l=2, 5, 8$, and 11. The remaining resource elements (k, l) 140 in the 12 subcarrier pattern may be devoted to PSCCH 305 except for the resource elements (k, l) 140 with $l=13$ which may be devoted to guard symbols 215 (as shown).

[0057] FIG. 4 is a block diagram illustrating one example of how DMRS 210 may be mapped to the PSBCH. As illustrated, the mapping pattern of DMRS 210 to the PSBCH is a 72 subcarrier pattern (k) (e.g., 1.08 MHz) 425 that is one subframe 110 (e.g., two slots 115) in length. In the case of normal CP, the mapping pattern of DMRS 210 to the PSBCH is 14 OFDM symbols (l) 120 in length. For convenience in identifying the OFDM symbol intervals (l) in the different slots 115, the OFDM symbol intervals (l) 120 in the first slot 115-a are numbered 0-6 and the OFDM symbol intervals (l) 120 in the second slot 115-b are numbered 7-13.

[0058] As discussed previously, the PSBCH includes three DMRS symbols per 1 ms TTI (e.g., subframe 110). Each DMRS is mapped to an OFDM symbol index (l) such that a first DMRS symbol 210 is mapped to a first OFDM symbol index (l) 120 (e.g., $l=4$), a second DMRS symbol 210 is mapped to a second OFDM symbol index (l) 120 (e.g., $l=6$), and a third DMRS symbol 210 is mapped to a third OFDM symbol index (l) 120 (e.g., $l=9$). It is appreciated that the symbol index (m) discussed above, which has indices of $m=0, 1$, and 2 for PSBCH corresponds to the respective mapped OFDM symbol indices (l) 120 such that the first symbol index (m) (e.g., $m=0$) maps to the first mapped OFDM symbol indices (l) 120 (e.g., $l=4$), the second symbol index (m) (e.g., $m=1$) maps to the second mapped OFDM symbol indices (l) 120 (e.g., $l=6$), and the third symbol index (m) (e.g., $m=2$) maps to the third mapped OFDM symbol indices (l) 120 (e.g., $l=9$).

[0059] In the case of the PSBCH, the three DMRSs are mapped to each of the 72 subcarriers (k) (e.g., 1.08 MHz) 425, so that in the 72 subcarrier pattern, there are 72 resource elements (k, l) 140 that include the DMRS for each of $l=4, 6$, and 9. The remaining resource elements (k, l) 140 for OFDM symbol intervals $l=0, 3, 5, 7, 8$, and 10 may be devoted to PSBCH 405. In the PSBCH 72 subcarrier pattern, 62 subcarriers (k) (e.g., 930 kHz) 430 in OFDM symbol intervals $l=1$ and 2 are devoted to primary sidelink synchronization signals (PSSS) 410 and 62 subcarriers (k) (e.g., 930 kHz) 430 in OFDM symbol intervals $l=11$ and 12 are devoted to secondary

sidelink synchronization signals (SSSS) 415. The resource elements (k,l) 140 with $l=13$ may be devoted to guard symbols 215. This may leave some of the resource elements (k,l) 140 unused 420 (as shown).

[0060] FIG. 5 is a flow diagram of a method 500 for enabling V2X communication. The method 500 is performed by a device, such as a user equipment (UE), V2X UE, or the like. In particular, the method 500 may be performed by a processor (e.g., a baseband processor) within the device. Although the operations of method 500 are illustrated as being performed in a particular order, it is understood that the operations of method 500 may be reordered without departing from the scope of the method.

[0061] At 505, a symbol index (m) is determined from a plurality of symbol indices. Each symbol index (m) corresponds to an OFDM symbol (l) of a subframe of a long-term evolution (LTE) Sidelink physical channel. The plurality of symbol indices includes at least three symbol indices (m) . At 510, a plurality of elements of an orthogonal sequence $(w^{(l)}(m))$ are determined where each element in the orthogonal sequence $(w^{(l)}(m))$ corresponds to one of the symbol indices (m) in the plurality of symbol indices. At 515, a plurality of demodulation reference signals (DMRSs) are generated based on the plurality of elements of the orthogonal sequence $(w^{(l)}(m))$ where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence $(w^{(l)}(m))$. At 520, each DMRS of the plurality of DMRSs is mapped to its corresponding OFDM symbol (l) of the subframe.

[0062] The operations of method 500 may be performed by an application specific processor, programmable application specific integrated circuit (ASIC), field programmable gate array (FPGA), or the like.

[0063] FIG. 6 is a flow diagram of a method 600 for enabling V2X communication. The method 600 is performed by a device, such as a user equipment (UE), V2X UE, or the like. In particular, the method 600 may be performed by a processor (e.g., a baseband processor) within the device. Although the operations of method 600 are illustrated as being performed in a particular order, it is understood that the operations of method 600 may be reordered without departing from the scope of the method.

[0064] At 605, a symbol index (m) is determined from a plurality of symbol indices where the plurality of symbol indices include 0, 1, and 2 or 0, 1, 2, and 3. At 610, a reference signal sequence is generated for the determined symbol index (m) . At

615, an element of an orthogonal sequence ($w^{(n)}(m)$) is applied to the reference signal sequence to generate a demodulation reference signal (DMRS) where the element is selected based on the determined symbol index (m). At 620, the generated DMRS are mapped to a symbol of a subframe of a Sidelink physical channel where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0065] The operations of method 600 may be performed by an application specific processor, programmable application specific integrated circuit (ASIC), field programmable gate array (FPGA), or the like.

[0066] FIG. 7 is a flow diagram of a method 700 for enabling V2X communication. The method 700 is performed by a device, such as a user equipment (UE), V2X UE, or the like. In particular, the method 700 may be performed by a processor (e.g., a baseband processor) within the device. Although the operations of method 700 are illustrated as being performed in a particular order, it is understood that the operations of method 700 may be reordered without departing from the scope of the method.

[0067] At 705, a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a Sidelink physical channel is generated. At 710, an orthogonal sequence that includes at least three elements is generated. At 715, at least three demodulation reference signals (DMRSs) are generated for the subframe where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence. At 720, each DMRS of the plurality of DMRSs is mapped to its corresponding symbol of the subframe.

[0068] The operations of method 700 may be performed by an application specific processor, programmable application specific integrated circuit (ASIC), field programmable gate array (FPGA), or the like.

[0069] FIG. 8 is a block diagram illustrating electronic device circuitry 800 that may be eNB circuitry, UE circuitry, network node circuitry, or some other type of circuitry in accordance with various embodiments. In embodiments, the electronic device circuitry 800 may be, or may be incorporated into or otherwise a part of, an eNB, a UE, a mobile station (MS), a BTS, a network node, or some other type of electronic device. In embodiments, the electronic device circuitry 800 may include radio transmit circuitry 805 and receive circuitry 810 coupled to control circuitry 815.

In embodiments, the transmit circuitry 805 and/or receive circuitry 810 may be elements or modules of transceiver circuitry, as shown. The electronic device circuitry 800 may be coupled with one or more antenna elements 820 of one or more antennas. The electronic device circuitry 800 and/or the components of the electronic device circuitry 800 may be configured to perform operations similar to those described elsewhere in this disclosure.

[0070] In embodiments where the electronic device circuitry 800 is or is incorporated into or otherwise part of a UE, the transmit circuitry 805 can transmit DMRS in various Sidelink physical channels, as shown in FIGS. 2, 3, and 4. The receive circuitry 810 can receive DMRS in various Sidelink physical channels as shown in FIGS. 2, 3, and 4.

[0071] In embodiments where the electronic device circuitry 800 is an eNB, UE, BTS, and/or a network node, or is incorporated into or is otherwise part of an eNB, UE, BTS, and/or a network node, the transmit circuitry 805 can transmit DMRS in various Sidelink physical channels, as shown in FIGS. 2, 3, and 4. The receive circuitry 810 can receive DMRS in various Sidelink physical channels as shown in FIGS. 2, 3, and 4.

[0072] In certain embodiments, the electronic device circuitry 800 shown in FIG. 8 is operable to perform one or more methods, such as the methods shown in FIGS. 5-7.

[0073] 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.

[0074] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 9 is a block diagram illustrating, for one embodiment, example components of a V2X user equipment (UE), UE, mobile station (MS) device, or evolved Node B (eNB) 900. In some embodiments, the UE device 900 may include application circuitry 905, baseband

circuitry 910, Radio Frequency (RF) circuitry 915, front-end module (FEM) circuitry 920, and one or more antennas 925, coupled together at least as shown in FIG. 9.

[0075] The application circuitry 905 may include one or more application processors. By way of non-limiting example, the application circuitry 905 may include 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 processor(s) may be operably coupled and/or include memory/storage, and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0076] By way of non-limiting example, the baseband circuitry 910 may include one or more single-core or multi-core processors. The baseband circuitry 910 may include one or more baseband processors and/or control logic. The baseband circuitry 910 may be configured to process baseband signals received from a receive signal path of the RF circuitry 915. The baseband circuitry 910 may also be configured to generate baseband signals for a transmit signal path of the RF circuitry 915. The baseband circuitry 910 may interface with the application circuitry 905 for generation and processing of the baseband signals, and for controlling operations of the RF circuitry 915.

[0077] By way of non-limiting example, the baseband circuitry 910 may include at least one of a second generation (2G) baseband processor 910A, a third generation (3G) baseband processor 910B, a fourth generation (4G) baseband processor 910C, other baseband processor(s) 910D for other existing generations, and generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 910 (e.g., at least one of baseband processors 910A-910D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 915. By way of non-limiting example, the radio control functions may include signal modulation/demodulation, encoding/decoding, radio frequency shifting, other functions, and combinations thereof. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 910 may be programmed to perform Fast-Fourier Transform (FFT), precoding, constellation mapping/demapping functions, other functions, and combinations thereof. In some embodiments, encoding/decoding circuitry of the baseband circuitry 910 may be programmed to perform convolutions, tail-biting

convolutions, turbo, Viterbi, Low Density Parity Check (LDPC) encoder/decoder functions, other functions, and combinations thereof. Embodiments of modulation/demodulation and encoder/decoder functions are not limited to these examples, and may include other suitable functions.

[0078] In some embodiments, the baseband circuitry 910 may include elements of a protocol stack. By way of non-limiting example, elements of an evolved universal terrestrial radio access network (E-UTRAN) 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) 910E of the baseband circuitry 910 may be programmed 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 910 may include one or more audio digital signal processor(s) (DSP) 910F. The audio DSP(s) 910F may include elements for compression/decompression and echo cancellation. The audio DSP(s) 910F may also include other suitable processing elements.

[0079] The baseband circuitry 910 may further include memory/storage 910G. The memory/storage 910G may include data and/or instructions for operations performed by the processors of the baseband circuitry 910 stored thereon. In some embodiments, the memory/storage 910G may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 910G may also include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. In some embodiments, the memory/storage 910G may be shared among the various processors or dedicated to particular processors.

[0080] Components of the baseband circuitry 910 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 910 and the application circuitry 905 may be implemented together, such as, for example, on a system on a chip (SOC).

[0081] In some embodiments, the baseband circuitry 910 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 910 may support communication with an

evolved universal terrestrial radio access network (E-UTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), or a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 910 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0082] The RF circuitry 915 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 915 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. The RF circuitry 915 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 920, and provide baseband signals to the baseband circuitry 910. The RF circuitry 915 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 910, and provide RF output signals to the FEM circuitry 920 for transmission.

[0083] In some embodiments, the RF circuitry 915 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 915 may include mixer circuitry 915A, amplifier circuitry 915B, and filter circuitry 915C. The transmit signal path of the RF circuitry 915 may include filter circuitry 915C and mixer circuitry 915A. The RF circuitry 915 may further include synthesizer circuitry 915D configured to synthesize a frequency for use by the mixer circuitry 915A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 915A of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 920 based on the synthesized frequency provided by synthesizer circuitry 915D. The amplifier circuitry 915B may be configured to amplify the down-converted signals.

[0084] The filter circuitry 915C may include a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 910 for further processing. In some embodiments, the output baseband signals may include zero-frequency baseband signals, although this is not a requirement. In some embodiments, the mixer circuitry 915A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0085] In some embodiments, the mixer circuitry 915A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 915D to generate RF output signals for the FEM circuitry 920. The baseband signals may be provided by the baseband circuitry 910 and may be filtered by filter circuitry 915C. The filter circuitry 915C may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 915A of the receive signal path and the mixer circuitry 915A of the transmit signal path may include two or more mixers, and may be arranged for quadrature downconversion and/or upconversion, respectively. In some embodiments, the mixer circuitry 915A of the receive signal path and the mixer circuitry 915A 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 915A of the receive signal path and the mixer circuitry 915A of the transmit signal path may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 915A of the receive signal path and the mixer circuitry 915A of the transmit signal path may be configured for super-heterodyne operation.

[0086] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In such embodiments, the RF circuitry 915 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry, and the baseband circuitry 910 may include a digital baseband interface to communicate with the RF circuitry 915.

[0087] In some dual-mode embodiments, separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[0088] In some embodiments, the synthesizer circuitry 915D may include one or more of a fractional-N synthesizer and 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 915D may include a delta-sigma synthesizer, a frequency multiplier, a synthesizer comprising a phase-locked loop with a frequency divider, other synthesizers, and combinations thereof.

[0089] The synthesizer circuitry 915D may be configured to synthesize an output frequency for use by the mixer circuitry 915A of the RF circuitry 915 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 915D may be a fractional $N/N+1$ synthesizer.

[0090] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 910 or the applications processor 905 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 905.

[0091] The synthesizer circuitry 915D of the RF circuitry 915 may include a divider, a delay-locked loop (DLL), a multiplexer, and a phase accumulator. In some embodiments, the divider may include a dual modulus divider (DMD), and the phase accumulator may include a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump, and a D-type flip-flop. In such embodiments, the delay elements may be configured to break a VCO period into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL may provide negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0092] In some embodiments, the synthesizer circuitry 915D may be configured to generate a carrier frequency as the output frequency. In some embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency, etc.) and used in conjunction with a quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 915 may include an IQ/polar converter.

[0093] The FEM circuitry 920 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 925, amplify the received signals, and provide the amplified versions of the received signals to the RF circuitry 915 for further processing. The FEM circuitry 920

may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 915 for transmission by at least one of the one or more antennas 925.

[0094] In some embodiments, the FEM circuitry 920 may include a TX/RX switch configured to switch between a transmit mode and a receive mode operation. The FEM circuitry 920 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 920 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 915). The transmit signal path of the FEM circuitry 920 may include a power amplifier (PA) configured to amplify input RF signals (e.g., provided by RF circuitry 915), and one or more filters configured to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 925).

[0095] In some embodiments, the MS device 900 may include additional elements such as, for example, memory/storage, a display, a camera, one or more sensors, an input/output (I/O) interface, other elements, and combinations thereof.

[0096] In some embodiments, the MS device 900 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof.

[0097] Examples

[0098] The following examples pertain to further embodiments.

[0099] Example 1 is an apparatus for a user equipment. The apparatus includes logic to determine a symbol index (m) from a plurality of symbol indices, where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and where the plurality of symbol indices includes at least three symbol indices (m); logic to determine a plurality of elements of an orthogonal sequence ($w^{(\lambda)}(m)$), where each element in the orthogonal sequence ($w^{(\lambda)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices; and one or more processing units to: generate a plurality of demodulation reference signals (DMRSs) based on the plurality of elements of the orthogonal sequence ($w^{(\lambda)}(m)$), where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(\lambda)}(m)$), and map

each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.

[0100] Example 2 is the apparatus of Example 1 and/or any of the other Examples described herein, where the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).

[0101] Example 3 is the apparatus of Example 2 and/or any of the other Examples described herein, wherein the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), wherein three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and wherein the three corresponding symbols (l) are symbols 4, 6, and 9.

[0102] Example 4 is the apparatus of Example 2 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and wherein the first sequence is $[+1, +1, +1]$, and where the second sequence is $[+1, -1, +1]$.

[0103] Example 5 is the apparatus of Example 4 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), where the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and where the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.

[0104] Example 6 is the apparatus of Example 1 and/or any of the other Examples described herein, where the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

[0105] Example 7 is the apparatus of Example 6 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), where four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and where the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

[0106] Example 8 is the apparatus of Example 7 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSCCH, and wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1, +1, +1]$.

[0107] Example 9 is the apparatus of Example 7, where the LTE sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and wherein the first sequence is [+1, +1, +1, +1], and where the second sequence is [+1, -1, +1, -1].

[0108] Example 10 is the apparatus of Example 9 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, where the first sequence is selected when $n_{ID} \bmod 2 = 0$, and where the second sequence is selected when $n_{ID} \bmod 2 = 1$.

[0109] Example 11 is an apparatus for a user equipment. The apparatus includes logic to determine a symbol index (m) from a plurality of symbol indices, where the plurality of symbol indices include 0, 1, and 2; and one or more processing units to: generate a reference signal sequence for the determined symbol index (m), apply an element of an orthogonal sequence ($w^{(\lambda)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS), where the element is selected based on the determined symbol index (m), and map the generated DMRS to a symbol of a subframe of a sidelink physical channel, where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0110] Example 12 is the apparatus of Example 11 and/or any of the other Examples described herein, where the one or more processing units are further to: provide the mapped DMRSs to a transmitter for transmission.

[0111] Example 13 is the apparatus of Examples 11 or 12 and/or any of the other Examples described herein, where the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

[0112] Example 14 is the apparatus of Example 13 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$] for symbol indices (m) = 0, 1, and 2, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1] when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1] when $N_{ID}^{SL} \bmod 2 = 1$.

[0113] Example 15 is the apparatus of Examples 11 or 12 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a

physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and where the plurality of symbol indices include 0, 1, 2, and 3.

[0114] Example 16 is the apparatus of Example 15 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$ $w^{(\lambda)}(3)$] for symbol indices (m) = 0, 1, 2, and 3.

[0115] Example 17 is the apparatus of Example 16 and/or any of the other Examples described herein, where the sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1] when $n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1 -1] when $n_{ID} \bmod 2 = 1$.

[0116] Example 18 is the apparatus of Example 17 and/or any of the other Examples described herein, where the sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1].

[0117] Example 19 is the apparatus of Example 11 and/or any of the other Examples described herein, where the one or more processing units are further to: apply a cyclic shift (α_λ) to a base sequence ($\tilde{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), where the cyclic shift (α_λ) depends on the symbol index (m) and is defined as $\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12$.

[0118] Example 20 is the apparatus of Example 11 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$) using a sequence-group number (u) and wherein the sequence-group number (u) is changed for each symbol index (m).

[0119] Example 21 is the apparatus of Example 20 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and wherein the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

[0120] Example 22 is the apparatus of Example 20 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the sequence-group number (u) using a group hopping pattern (f_{gh}) and wherein the group hopping pattern (f_{gh}) is changed for each symbol index (m).

[0121] Example 23 is an apparatus for a user equipment. The apparatus includes logic to generate a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel,

logic to generate an orthogonal sequence that includes at least three elements, logic to generate at least three demodulation reference signals (DMRSs) for the subframe, where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence, and one or more processing units to: map each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

[0122] Example 24 is the apparatus of Example 23 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

[0123] Example 25 is an apparatus for a user equipment. The apparatus includes one or more baseband processing units that executes instructions that cause the one or more baseband processing units to: determine a symbol index (m) from a plurality of symbol indices, where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and where the plurality of symbol indices includes at least three symbol indices (m), determine a plurality of elements of an orthogonal sequence ($w^{(A)}(m)$), where each element in the orthogonal sequence ($w^{(A)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices, generate a plurality of demodulation reference signals (DMRSs) based on the plurality of elements of the orthogonal sequence ($w^{(A)}(m)$), where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(A)}(m)$), and map each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.

[0124] Example 26 is the apparatus of Example 25 and/or any of the other Examples described herein, where the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).

[0125] Example 27 is the apparatus of Example 26 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), where three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and where the three corresponding symbols (l) are symbols 4, 6, and 9.

[0126] Example 28 is the apparatus of Example 26 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(A)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second

sequence, and where the first sequence is $[+1, +1, +1]$, and where the second sequence is $[+1, -1, +1]$.

[0127] Example 29 is the apparatus of Example 28 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), where the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and where the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.

[0128] Example 30 is the apparatus of Example 25 and/or any of the other Examples described herein, where the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

[0129] Example 31 is the apparatus of Example 30 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), where four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and where the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

[0130] Example 32 is the apparatus of Example 31 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1, +1, +1, +1]$.

[0131] Example 33 is the apparatus of Example 31 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and where the first sequence is $[+1, +1, +1, +1]$, and where the second sequence is $[+1, -1, +1, -1]$.

[0132] Example 34 is the apparatus of Example 33 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, where the first sequence is selected when $n_{ID} \bmod 2 = 0$, and where the second sequence is selected when $n_{ID} \bmod 2 = 1$.

[0133] Example 35 is an apparatus for a user equipment. The apparatus includes one or more baseband processing units, where instructions are executable by the one or more baseband processing that cause the one or more baseband processing units to: determine a symbol index (m) from a plurality of symbol indices, where the

plurality of symbol indices include 0, 1, and 2, generate a reference signal sequence for the determined symbol index (m), apply an element of an orthogonal sequence ($w^{(\lambda)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS), where the element is selected based on the determined symbol index (m), and map the generated DMRS to a symbol of a subframe of a sidelink physical channel, where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0134] Example 36 is the apparatus of Example 35 and/or any of the other Examples described herein, where the one or more processing units are further to: provide the mapped DMRSs to a transmitter for transmission.

[0135] Example 37 is the apparatus of Examples 35 or 36 and/or any of the other Examples described herein, where the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

[0136] Example 38 is the apparatus of Example 37 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$] for symbol indices (m) = 0, 1, and 2, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1] when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1] when $N_{ID}^{SL} \bmod 2 = 1$.

[0137] Example 39 is the apparatus of Examples 35 or 36 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and where the plurality of symbol indices include 0, 1, 2, and 3.

[0138] Example 40 is the apparatus of Example 39 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$ $w^{(\lambda)}(3)$] for symbol indices (m) = 0, 1, 2, and 3.

[0139] Example 41 is the apparatus of Example 40 and/or any of the other Examples described herein, where the sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1] when $n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1 -1] when $n_{ID} \bmod 2 = 1$.

[0140] Example 42 is the apparatus of Example 41 and/or any of the other Examples described herein, where the sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1].

[0141] Example 43 is the apparatus of Example 35 and/or any of the other Examples described herein, where the one or more processing units are further to: apply a cyclic shift (α_λ) to a base sequence ($\bar{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), where the cyclic shift (α_λ) depends on the symbol index (m) and is defined as $\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12$.

[0142] Example 44 is the apparatus of Example 35 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$) using a sequence-group number (u) and wherein the sequence-group number (u) is changed for each symbol index (m).

[0143] Example 45 is the apparatus of Example 44 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and wherein the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

[0144] Example 46 is the apparatus of Example 44 and/or any of the other Examples described herein, where the one or more processing units are further to: generate the sequence-group number (u) using a group hopping pattern (f_{gh}) and wherein the group hopping pattern (f_{gh}) is changed for each symbol index (m).

[0145] Example 47 is an apparatus for a user equipment. The apparatus includes one or more baseband processing units that execute instructions that cause the one or more baseband processing units to: generate a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel, generate an orthogonal sequence that includes at least three elements, generate at least three demodulation reference signals (DMRSs) for the subframe, where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence, and map each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

[0146] Example 48 is the apparatus of Example 47 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a

physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

[0147] Example 49 is an apparatus for a user equipment. The apparatus includes means for determining a symbol index (m) from a plurality of symbol indices, where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and where the plurality of symbol indices includes at least three symbol indices (m), means for determining a plurality of elements of an orthogonal sequence ($w^{(l)}(m)$), where each element in the orthogonal sequence ($w^{(l)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices, means for generating a plurality of demodulation reference signals (DMRSs) based on the plurality of elements of the orthogonal sequence ($w^{(l)}(m)$), where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(l)}(m)$), and means for mapping each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.

[0148] Example 50 is the apparatus of Example 49 and/or any of the other Examples described herein, where the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).

[0149] Example 51 is the apparatus of Example 50 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), where three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and where the three corresponding symbols (l) are symbols 4, 6, and 9.

[0150] Example 52 is the apparatus of Example 50 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(l)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and wherein the first sequence is [+1, +1, +1], and where the second sequence is [+1, -1, +1].

[0151] Example 53 is the apparatus of Example 52 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(l)}(m)$) is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), where the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and where the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.

[0152] Example 54 is the apparatus of Example 53 and/or any of the other Examples described herein, where the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

[0153] Example 55 is the apparatus of Example 54 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), where four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and where the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

[0154] Example 56 is the apparatus of Example 55 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(A)}(m)$) is [+1, +1, +1, +1].

[0155] Example 57 is the apparatus of Example 55 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(A)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and where the first sequence is [+1, +1, +1, +1], and where the second sequence is [+1, -1, +1, -1].

[0156] Example 58 is the apparatus of Example 57 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(A)}(m)$) is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, where the first sequence is selected when $n_{ID} \bmod 2 = 0$, and where the second sequence is selected when $n_{ID} \bmod 2 = 1$.

[0157] Example 59 is an apparatus for a user equipment. The apparatus includes means for determining a symbol index (m) from a plurality of symbol indices, where the plurality of symbol indices include 0, 1, and 2, means for generating a reference signal sequence for the determined symbol index (m), means for applying an element of an orthogonal sequence ($w^{(A)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS), where the element is selected based on the determined symbol index (m), and means for mapping the generated DMRS to a symbol of a subframe of a sidelink physical channel, where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0158] Example 60 is the apparatus of Example 59 and/or any of the other Examples described herein, further including means for providing the mapped DMRSs to a transmitter for transmission.

[0159] Example 61 is the apparatus of Examples 59 or 60 and/or any of the other Examples described herein, where the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

[0160] Example 62 is the apparatus of Example 61 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2)]$ for symbol indices (m) = 0, 1, and 2, where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 +1 +1]$ when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 -1 +1]$ when $N_{ID}^{SL} \bmod 2 = 1$.

[0161] Example 63 is the apparatus of Examples 59 or 60 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and where the plurality of symbol indices include 0, 1, 2, and 3.

[0162] Example 64 is the apparatus of Example 63 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2) w^{(\lambda)}(3)]$ for symbol indices (m) = 0, 1, 2, and 3.

[0163] Example 65 is the apparatus of Example 64 and/or any of the other Examples described herein, where the sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 +1 +1 +1]$ when $n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 -1 +1 -1]$ when $n_{ID} \bmod 2 = 1$.

[0164] Example 66 is the apparatus of Example 65 and/or any of the other Examples described herein, where the sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 +1 +1 +1]$.

[0165] Example 67 is the apparatus of Example 59 and/or any of the other Examples described herein, further including means for applying a cyclic shift (α_λ) to a base sequence ($\bar{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), where the cyclic shift (α_λ) depends on the symbol index (m) and is defined as $\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12$.

[0166] Example 68 is the apparatus of Example 59 and/or any of the other Examples described herein, further including means for generating the reference signal sequence ($r_{u,v}^{\alpha\lambda}(n)$) using a sequence-group number (u) and where the sequence-group number (u) is changed for each symbol index (m).

[0167] Example 69 is the apparatus of Example 68 and/or any of the other Examples described herein, further including means for generating the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and where the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

[0168] Example 70 is the apparatus of Example 69 and/or any of the other Examples described herein, further including means for generating the sequence-group number (u) using a group hopping pattern (f_{gh}) and where the group hopping pattern (f_{gh}) is changed for each symbol index (m).

[0169] Example 71 is an apparatus for a user equipment. The apparatus includes means for generating a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel, means for generating an orthogonal sequence that includes at least three elements, means for generating at least three demodulation reference signals (DMRSs) for the subframe, where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence, and means for mapping each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

[0170] Example 72 is the apparatus of Example 71 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

[0171] Example 73 is a method for wireless communication. The method includes determining a symbol index (m) from a plurality of symbol indices, where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and where the plurality of symbol indices includes at least three symbol indices (m), determining a plurality of elements of an orthogonal sequence ($w^{(\lambda)}(m)$), where each element in the orthogonal sequence ($w^{(\lambda)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices, generating a plurality of demodulation reference signals (DMRSs) based on

the plurality of elements of the orthogonal sequence ($w^{(\lambda)}(m)$), where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(\lambda)}(m)$), and mapping each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.

[0172] Example 74 is the method of Example 73 and/or any of the other Examples described herein, where the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).

[0173] Example 75 is the method of Example 74 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), where three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and where the three corresponding symbols (l) are symbols 4, 6, and 9.

[0174] Example 76 is the method of Example 74 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and where the first sequence is [+1, +1, +1], and where the second sequence is [+1, -1, +1].

[0175] Example 77 is the method of Example 76, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), where the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and where the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.

[0176] Example 78 is the method of Example 77 and/or any of the other Examples described herein, where the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

[0177] Example 79 is the method of Example 78 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), where four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and where the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

[0178] Example 80 is the method of Example 79 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1, +1, +1, +1].

[0179] Example 81 is the method of Example 79 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and where the first sequence is [+1, +1, +1, +1], and where the second sequence is [+1, -1, +1, -1].

[0180] Example 82 is the method of Example 81 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, where the first sequence is selected when $n_{ID} \bmod 2 = 0$, and where the second sequence is selected when $n_{ID} \bmod 2 = 1$.

[0181] Example 83 is a method for wireless communication. The method includes determining a symbol index (m) from a plurality of symbol indices, where the plurality of symbol indices include 0, 1, and 2, generating a reference signal sequence for the determined symbol index (m), applying an element of an orthogonal sequence ($w^{(\lambda)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS), where the element is selected based on the determined symbol index (m), and mapping the generated DMRS to a symbol of a subframe of a sidelink physical channel, where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0182] Example 84 is the method of Example 83 and/or any of the other Examples described herein, further including providing the mapped DMRSs to a transmitter for transmission.

[0183] Example 85 is the method of Examples 83 or 84 and/or any of the other Examples described herein, where the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

[0184] Example 86 is the method of Example 85 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$] for symbol indices (m) = 0, 1, and 2, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1] when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1] when $N_{ID}^{SL} \bmod 2 = 1$.

[0185] Example 87 is the method of Examples 83 or 84 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a

physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and where the plurality of symbol indices include 0, 1, 2, and 3.

[0186] Example 88 is the method of Example 87 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$ $w^{(\lambda)}(3)$] for symbol indices (m) = 0, 1, 2, and 3.

[0187] Example 89 is the method of Example 88 and/or any of the other Examples described herein, where the sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1] when $n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1 -1] when $n_{ID} \bmod 2 = 1$.

[0188] Example 90 is the method of Example 89 and/or any of the other Examples described herein, where the sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1].

[0189] Example 91 is the method of Example 83 and/or any of the other Examples described herein, further including applying a cyclic shift (α_λ) to a base sequence ($\tilde{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), where the cyclic shift (α_λ) depends on the symbol index (m) and is defined as

$$\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12.$$

[0190] Example 92 is the method of Example 83 and/or any of the other Examples described herein, further including generating the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$) using a sequence-group number (u) and where the sequence-group number (u) is changed for each symbol index (m).

[0191] Example 93 is the method of Example 92 and/or any of the other Examples described herein, further including generating the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and where the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

[0192] Example 94 is the method of Example 93 and/or any of the other Examples described herein, further including means for generating the sequence-group number (u) using a group hopping pattern (f_{gh}) and where the group hopping pattern (f_{gh}) is changed for each symbol index (m).

[0193] Example 95 is a method for wireless communication. The method includes generating a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel,

generating an orthogonal sequence that includes at least three elements, generating at least three demodulation reference signals (DMRSs) for the subframe, where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence, and mapping each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

[0194] Example 96 is the method of Example 95 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

[0195] Example 97 is a computer-readable medium having instructions stored thereon, the instructions, when executed by a computing device, cause the computing device to determine a symbol index (m) from a plurality of symbol indices, where each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and where the plurality of symbol indices includes at least three symbol indices (m), determine a plurality of elements of an orthogonal sequence ($w^{(l)}(m)$), where each element in the orthogonal sequence ($w^{(l)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices, generate a plurality of demodulation reference signals (DMRSs) based on the plurality of elements of the orthogonal sequence ($w^{(l)}(m)$), where each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(l)}(m)$), and map each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.

[0196] Example 98 is the computer-readable medium of Example 97 and/or any of the other Examples described herein, where the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).

[0197] Example 99 is the computer-readable medium of Example 98 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), where three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and where the three corresponding symbols (l) are symbols 4, 6, and 9.

[0198] Example 100 is the computer-readable medium of Example 98 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(l)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a

second sequence, and where the first sequence is $[+1, +1, +1]$, and where the second sequence is $[+1, -1, +1]$.

[0199] Example 101 is the computer-readable medium of Example 100 and/or any of the other Examples described herein, where the orthogonal sequence $(w^{(A)}(m))$ is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), where the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and where the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.

[0200] Example 102 is the computer-readable medium of Example 97 and/or any of the other Examples described herein, where the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

[0201] Example 103 is the computer-readable medium of Example 102 and/or any of the other Examples described herein, where the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), where four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and where the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

[0202] Example 104 is the computer-readable medium of Example 103 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSCCH, and where the orthogonal sequence $(w^{(A)}(m))$ is $[+1, +1, +1, +1]$.

[0203] Example 105 is the computer-readable medium of Example 104 and/or any of the other Examples described herein, where the LTE sidelink physical channel is the PSSCH, where the orthogonal sequence $(w^{(A)}(m))$ is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and where the first sequence is $[+1, +1, +1, +1]$, and where the second sequence is $[+1, -1, +1, -1]$.

[0204] Example 106 is the computer-readable medium of Example 105 and/or any of the other Examples described herein, where the orthogonal sequence $(w^{(A)}(m))$ is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, where the first sequence is selected when $n_{ID} \bmod 2 = 0$, and where the second sequence is selected when $n_{ID} \bmod 2 = 1$.

[0205] Example 107 is a computer-readable medium having instructions stored thereon, the instructions, when executed by a computing device, cause the

computing device to determine a symbol index (m) from a plurality of symbol indices, where the plurality of symbol indices include 0, 1, and 2, generate a reference signal sequence for the determined symbol index (m), apply an element of an orthogonal sequence ($w^{(\lambda)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS), where the element is selected based on the determined symbol index (m), and map the generated DMRS to a symbol of a subframe of a sidelink physical channel, where the subframe includes a DMRS for each of the plurality of symbol indices (m).

[0206] Example 108 is the computer-readable medium of Example 107 and/or any of the other Examples described herein, where the instructions further cause the computing device to provide the mapped DMRSs to a transmitter for transmission.

[0207] Example 109 is the computer-readable medium of Examples 107 or 108, where the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

[0208] Example 110 is the computer-readable medium of Example 109 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2)]$ for symbol indices (m) = 0, 1, and 2, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 +1 +1]$ when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 -1 +1]$ when $N_{ID}^{SL} \bmod 2 = 1$.

[0209] Example 111 is the computer-readable medium of Examples 107 or 108 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and where the plurality of symbol indices include 0, 1, 2, and 3.

[0210] Example 112 is the computer-readable medium of Example 111 and/or any of the other Examples described herein, where the orthogonal sequence ($w^{(\lambda)}(m)$) has the form $[w^{(\lambda)}(0) w^{(\lambda)}(1) w^{(\lambda)}(2) w^{(\lambda)}(3)]$ for symbol indices (m) = 0, 1, 2, and 3.

[0211] Example 113 is the computer-readable medium of Example 112 and/or any of the other Examples described herein, where the sidelink physical channel is the PSSCH, where the orthogonal sequence ($w^{(\lambda)}(m)$) is $[+1 +1 +1 +1]$ when

$n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1 -1] when $n_{ID} \bmod 2 = 1$.

[0212] Example 114 is the computer-readable medium of Example 113 and/or any of the other Examples described herein, where the sidelink physical channel is the PSCCH, and where the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1].

[0213] Example 115 is the computer-readable medium of Example 107 and/or any of the other Examples described herein, where the instructions further cause the computing device to apply a cyclic shift (α_λ) to a base sequence ($\bar{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), where the cyclic shift (α_λ) depends on the symbol index (m) and is defined as $\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12$.

[0214] Example 116 is the computer-readable medium of Example 107 and/or any of the other Examples described herein, where the instructions further cause the computing device to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$) using a sequence-group number (u) and where the sequence-group number (u) is changed for each symbol index (m).

[0215] Example 117 is the computer-readable medium of Example 116 and/or any of the other Examples described herein, where the instructions further cause the computing device to generate the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and wherein the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

[0216] Example 118 is the computer-readable medium of Example 116 and/or any of the other Examples described herein, where the instructions further cause the computing device to generate the sequence-group number (u) using a group hopping pattern (f_{gh}) and where the group hopping pattern (f_{gh}) is changed for each symbol index (m).

[0217] Example 119 is a computer-readable medium having instructions stored thereon, the instructions, when executed by a computing device, cause the computing device to generate a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel, generate an orthogonal sequence that includes at least three elements, generate at least three demodulation reference signals (DMRSs) for the subframe, where each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal

sequence, and map each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

[0218] Example 120 is the computer-readable medium of Example 119 and/or any of the other Examples described herein, where the sidelink physical channel is at least one of a physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

[0219] It will be obvious to those having skill in the art that many changes may be made to the details of the above-described embodiments without departing from the underlying principles of the invention. The scope of the present invention should, therefore, be determined only by the following claims.

Claims

1. An apparatus for a user equipment, the apparatus comprising:
one or more baseband processing units to:
determine a symbol index (m) from a plurality of symbol indices,
wherein each symbol index (m) corresponds to a symbol (l) of a subframe of a Long-Term Evolution (LTE) sidelink physical channel, and wherein the plurality of symbol indices includes at least three symbol indices (m);
determine a plurality of elements of an orthogonal sequence ($w^{(l)}(m)$),
wherein each element in the orthogonal sequence ($w^{(l)}(m)$) corresponds to one of the symbol indices (m) in the plurality of symbol indices;
generate a plurality of demodulation reference signals (DMRSs) based on the plurality of elements of the orthogonal sequence ($w^{(l)}(m)$), wherein each DMRS in the plurality of DMRSs corresponds to one of the elements in the orthogonal sequence ($w^{(l)}(m)$); and
map each DMRS of the plurality of DMRSs to its corresponding symbol (l) of the subframe.
2. The apparatus of claim 1, wherein the LTE sidelink physical channel is a Physical Sidelink Broadcast Channel (PSBCH).
3. The apparatus of claim 2, wherein the plurality of symbol indices include 0, 1, and 2 as symbol indices (m), wherein three DMRS are mapped to three corresponding symbols (l) of the subframe used for DMRS transmission, and wherein the three corresponding symbols (l) are symbols 4, 6, and 9.
4. The apparatus of claim 2, wherein the orthogonal sequence ($w^{(l)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and wherein the first sequence is [+1, +1, +1], and wherein the second sequence is [+1, -1, +1].
5. The apparatus of claim 4, wherein the orthogonal sequence ($w^{(l)}(m)$) is selected based on a physical layer sidelink synchronization identity (N_{ID}^{SL}), wherein the first sequence is selected when $N_{ID}^{SL} \bmod 2 = 0$, and wherein the second sequence is selected when $N_{ID}^{SL} \bmod 2 = 1$.
6. The apparatus of claim 1, wherein the LTE sidelink physical channel is one of a Physical Sidelink Shared Channel (PSSCH) and a Physical Sidelink Control Channel (PSCCH).

7. The apparatus of claim 6, wherein the plurality of symbol indices include 0, 1, 2, and 3 as symbol indices (m), wherein four DMRS are mapped to four corresponding symbols (l) of the subframe used for DMRS transmission, and wherein the four corresponding symbols (l) are symbols 2, 5, 8, and 11.

8. The apparatus of claim 7, wherein the LTE sidelink physical channel is the PSCCH, and wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1, +1, +1, +1].

9. The apparatus of claim 7, wherein the LTE sidelink physical channel is the PSSCH, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is selected from a set of orthogonal sequences that includes a first sequence and a second sequence, and wherein the first sequence is [+1, +1, +1, +1], and wherein the second sequence is [+1, -1, +1, -1].

10. The apparatus of claim 9, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is selected based on a sidelink destination identifier (n_{ID}) provided in the PSCCH, wherein the first sequence is selected when $n_{ID} \bmod 2 = 0$, and wherein the second sequence is selected when $n_{ID} \bmod 2 = 1$.

11. An apparatus for a user equipment, the apparatus comprising:
one or more baseband processing units to:

determine a symbol index (m) from a plurality of symbol indices,
wherein the plurality of symbol indices include 0, 1, and 2;

generate a reference signal sequence for the determined symbol index (m);

apply an element of an orthogonal sequence ($w^{(\lambda)}(m)$) to the reference signal sequence to generate a demodulation reference signal (DMRS),
wherein the element is selected based on the determined symbol index (m);
and

map the generated DMRS to a symbol of a subframe of a sidelink physical channel, wherein the subframe includes a DMRS for each of the plurality of symbol indices (m).

12. The apparatus of claim 11, wherein the one or more processing units are further to:

provide the mapped DMRSs to a transmitter for transmission.

13. The apparatus of claims 11 or 12, wherein the sidelink physical channel is a physical sidelink broadcast channel (PSBCH).

14. The apparatus of claim 13, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$] for symbol indices (m) = 0, 1, and 2, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1] when $N_{ID}^{SL} \bmod 2 = 0$, where N_{ID}^{SL} is a physical layer sidelink synchronization identity, and wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1] when $N_{ID}^{SL} \bmod 2 = 1$.

15. The apparatus of claims 11 or 12, wherein the sidelink physical channel is at least one of a physical sidelink shared channel (PSSCH) and a physical sidelink control channel (PSCCH), and wherein the plurality of symbol indices include 0, 1, 2, and 3.

16. The apparatus of claim 15, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) has the form [$w^{(\lambda)}(0)$ $w^{(\lambda)}(1)$ $w^{(\lambda)}(2)$ $w^{(\lambda)}(3)$] for symbol indices (m) = 0, 1, 2, and 3.

17. The apparatus of claim 16, wherein the sidelink physical channel is the PSSCH, wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1] when $n_{ID} \bmod 2 = 0$, where n_{ID} is a sidelink identifier provided in the PSCCH, and wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 -1 +1 -1] when $n_{ID} \bmod 2 = 1$.

18. The apparatus of claim 17, wherein the sidelink physical channel is the PSCCH, and wherein the orthogonal sequence ($w^{(\lambda)}(m)$) is [+1 +1 +1 +1].

19. The apparatus of claim 11, wherein the one or more processing units are further to:

apply a cyclic shift (α_λ) to a base sequence ($\bar{r}_{u,v}(n)$) to generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$), wherein the cyclic shift (α_λ) depends on the symbol index (m) and is defined as $\alpha_\lambda = 2\pi n_{cs,\lambda}(m)/12$.

20. The apparatus of claim 11, wherein the one or more processing units are further to:

generate the reference signal sequence ($r_{u,v}^{\alpha_\lambda}(n)$) using a sequence-group number (u) and wherein the sequence-group number (u) is changed for each symbol index (m).

21. The apparatus of claim 20, wherein the one or more processing units are further to:

generate the sequence-group number (u) using a sequence-shift pattern (f_{ss}) and wherein the sequence-shift pattern (f_{ss}) is changed for each symbol index (m).

22. The apparatus of claim 20, wherein the one or more processing units are further to:

generate the sequence-group number (u) using a group hopping pattern (f_{gh}) and wherein the group hopping pattern (f_{gh}) is changed for each symbol index (m).

23. An apparatus for a user equipment, the apparatus comprising: one or more baseband processing units to:

generate a reference signal sequence that includes at least three subsets corresponding to at least three symbols of a subframe of a sidelink physical channel;

generate an orthogonal sequence that includes at least three elements;

generate at least three demodulation reference signals (DMRSs) for the subframe, wherein each DMRS of the at least three DMRSs is generated using a subset of the reference signal sequence and one of the elements of the orthogonal sequence; and

map each DMRS of the plurality of the DMRSs to its corresponding symbol of the subframe.

24. The apparatus of claim 23, wherein the sidelink physical channel is at least one of a physical sidelink broadcast channel (PSBCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH).

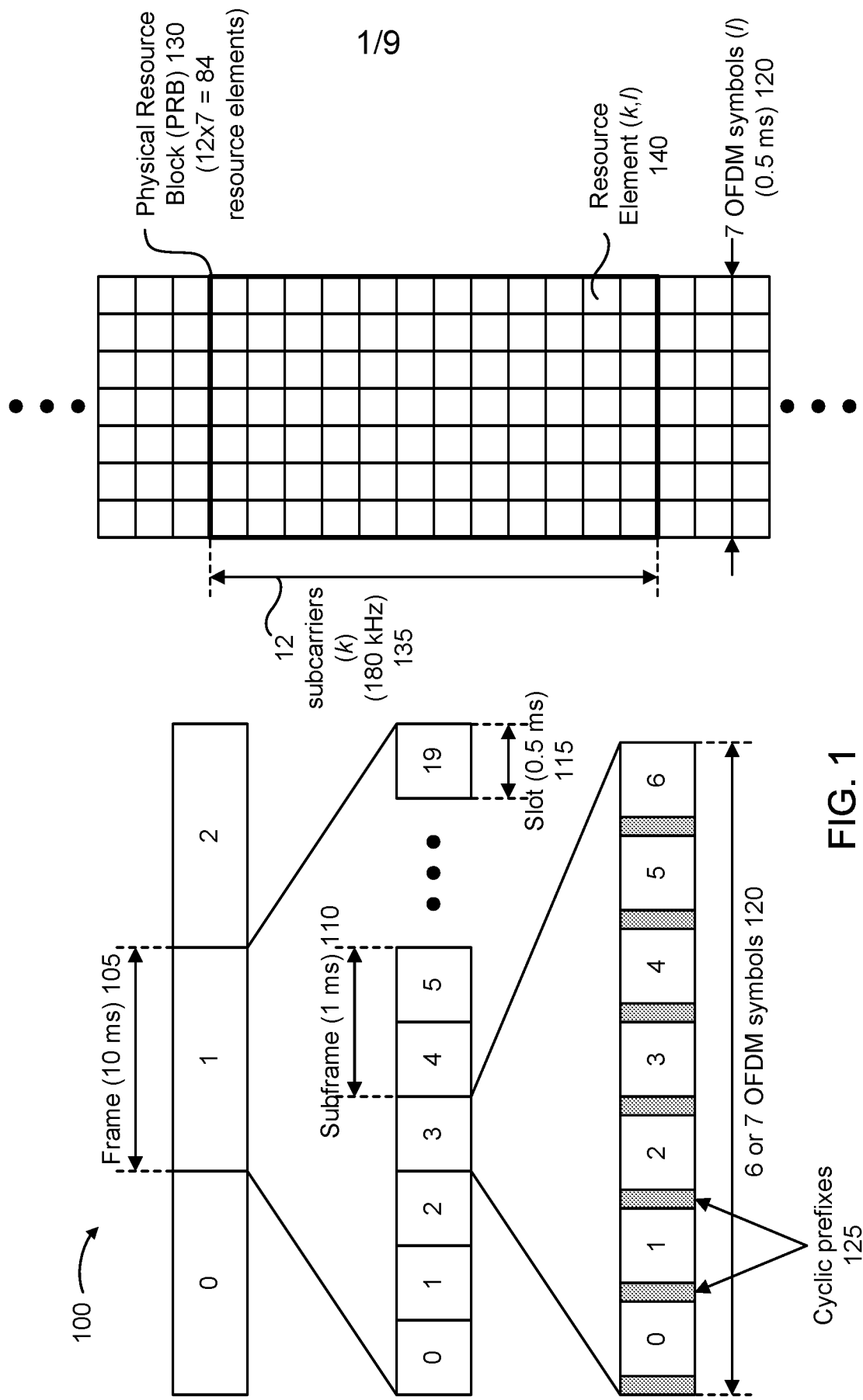


FIG. 1

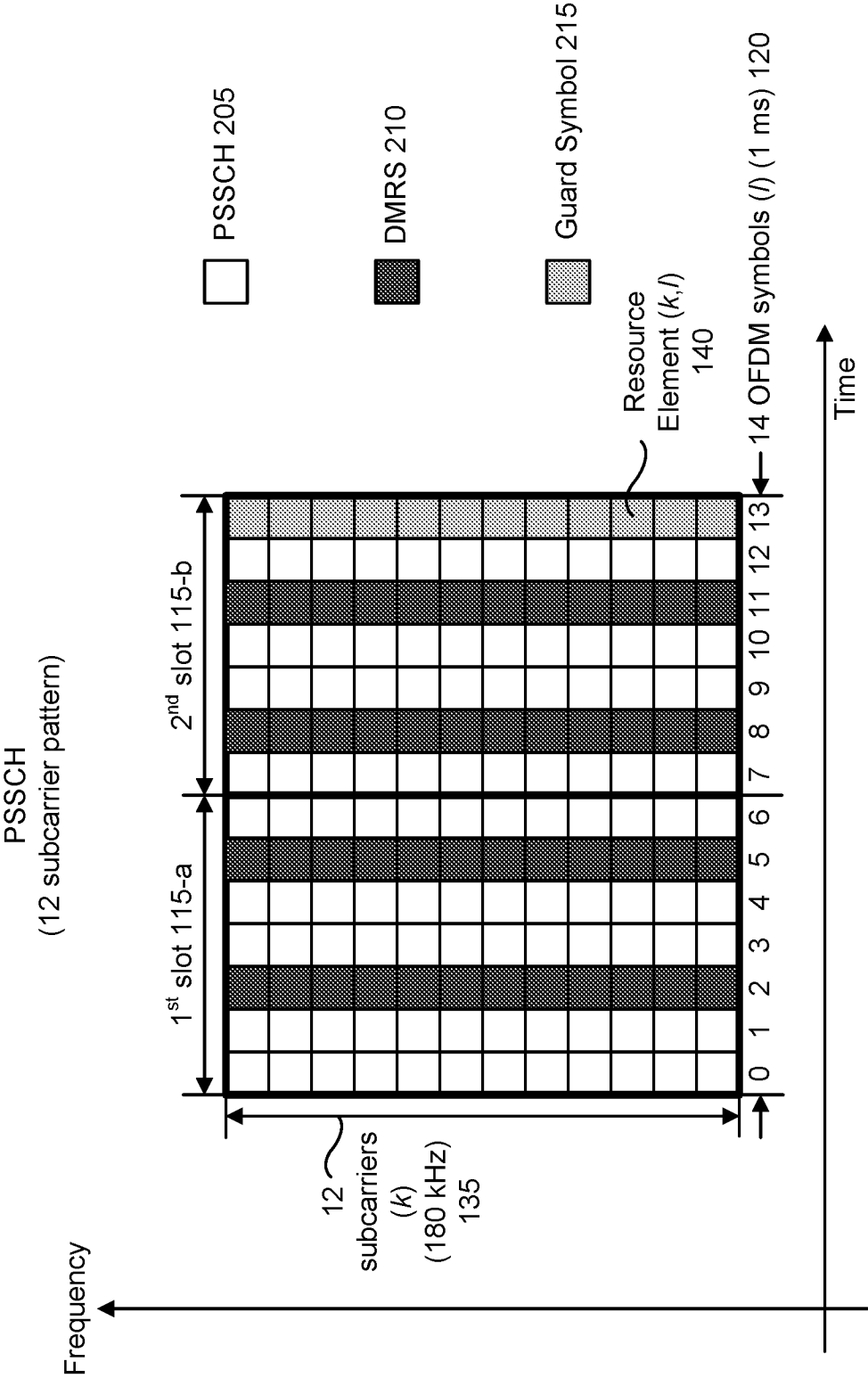


FIG. 2

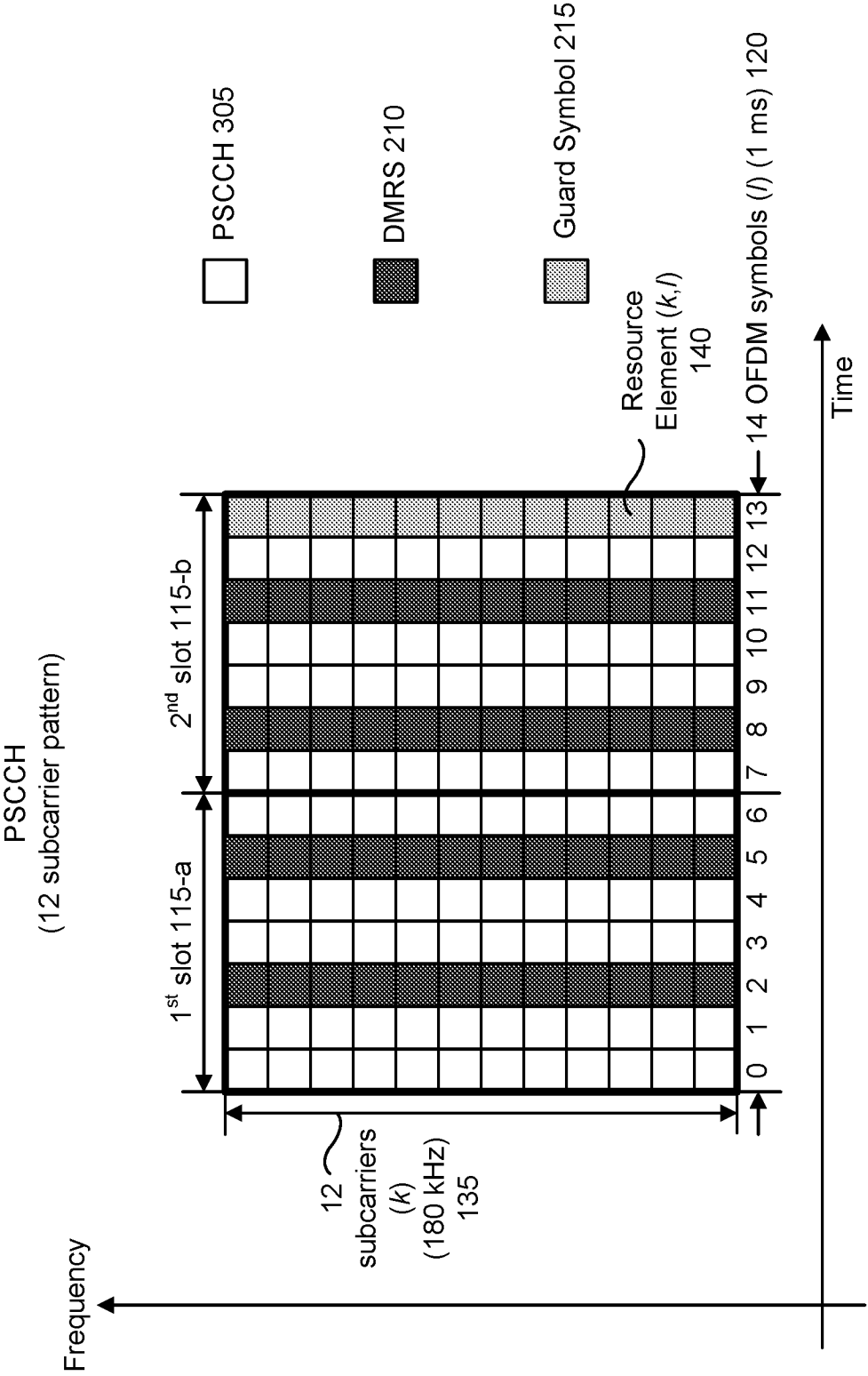


FIG. 3

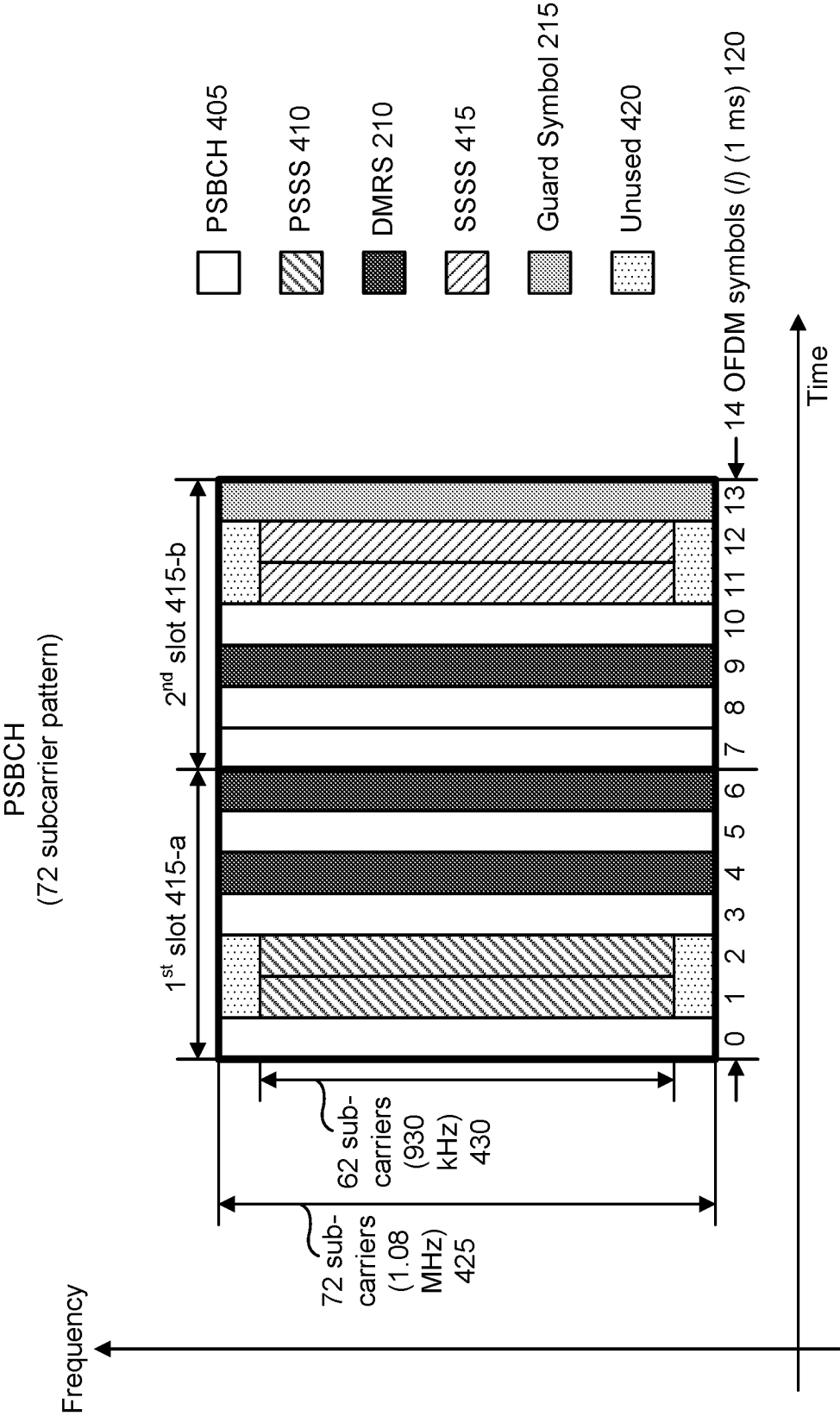


FIG. 4

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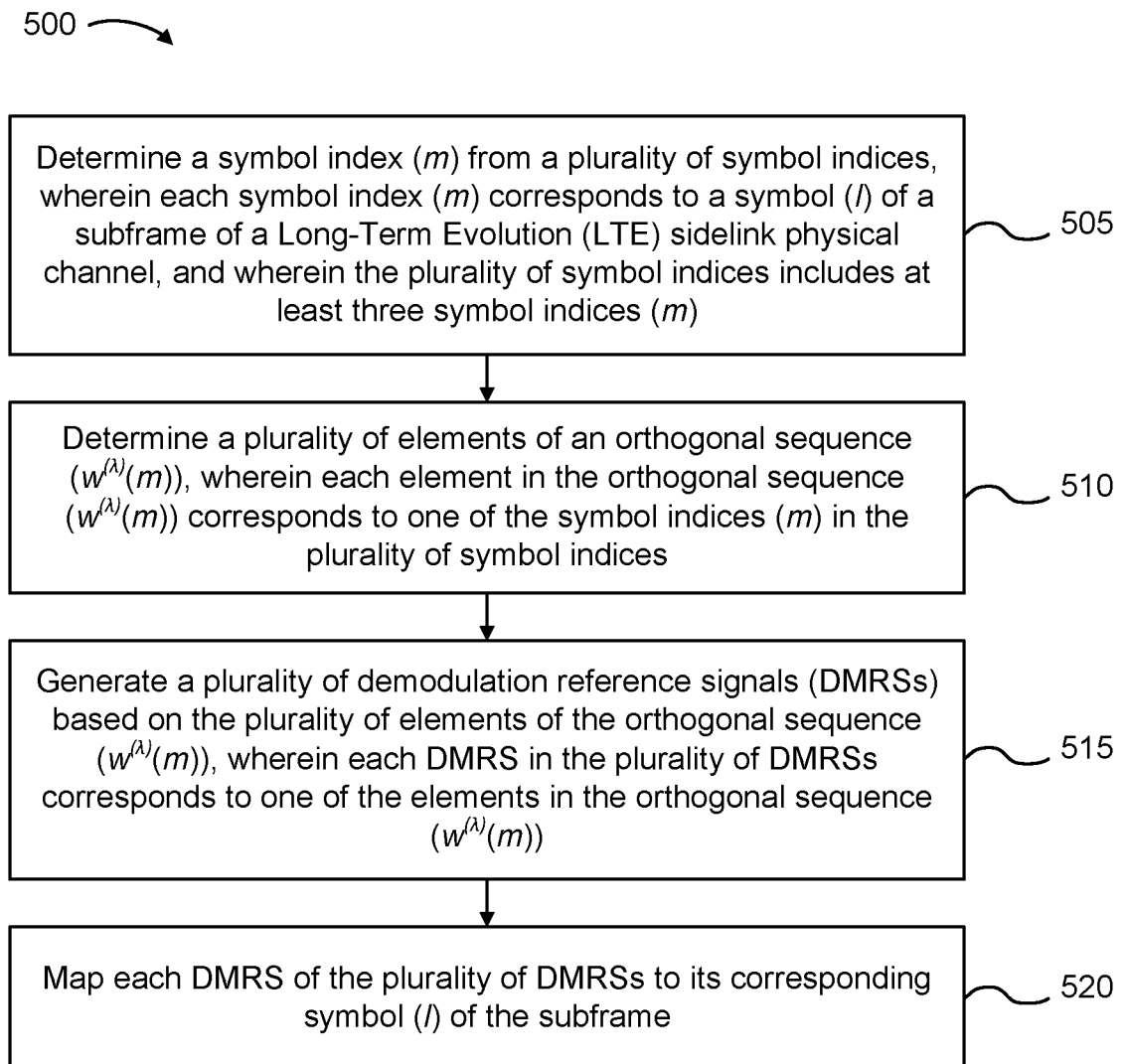


FIG. 5

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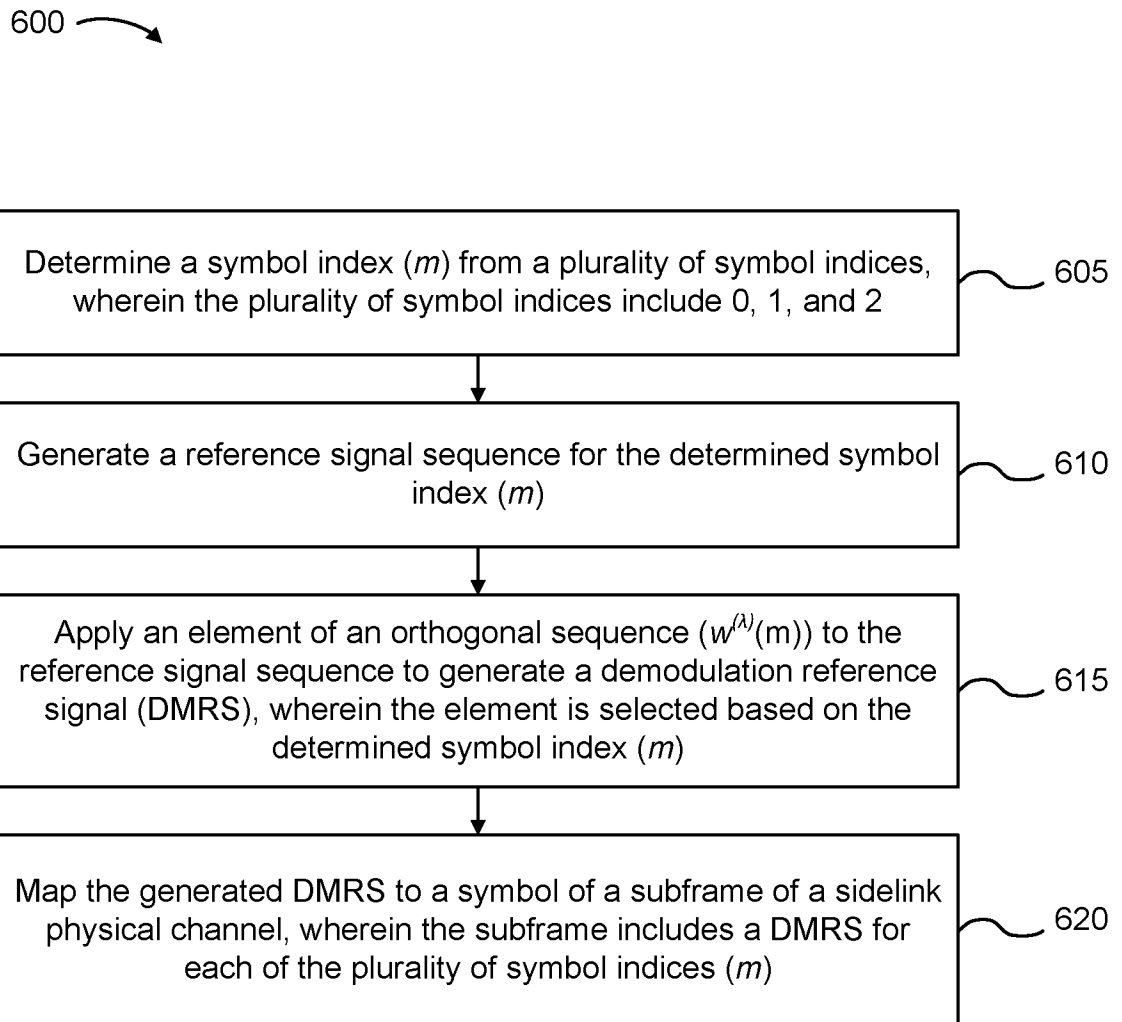


FIG. 6

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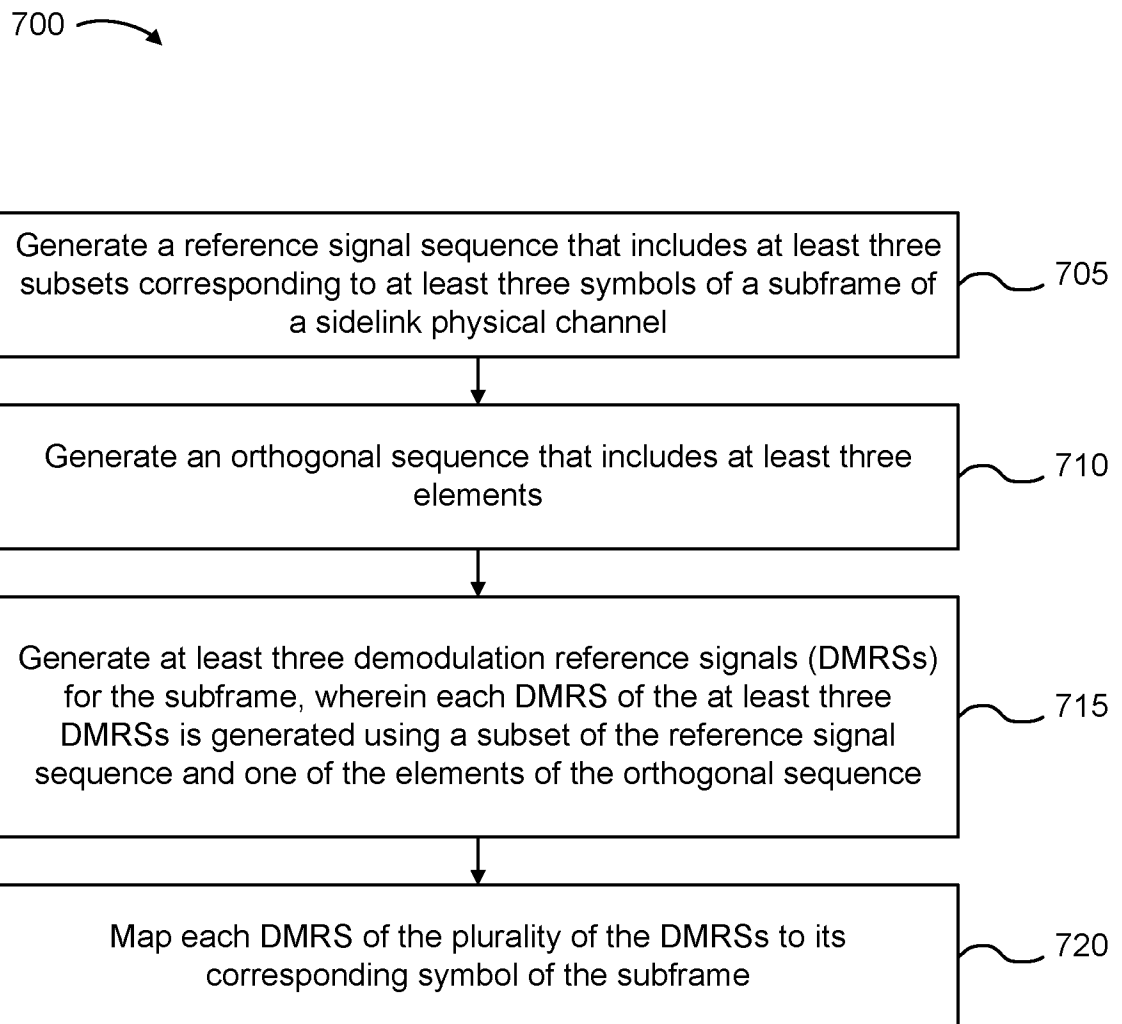


FIG. 7

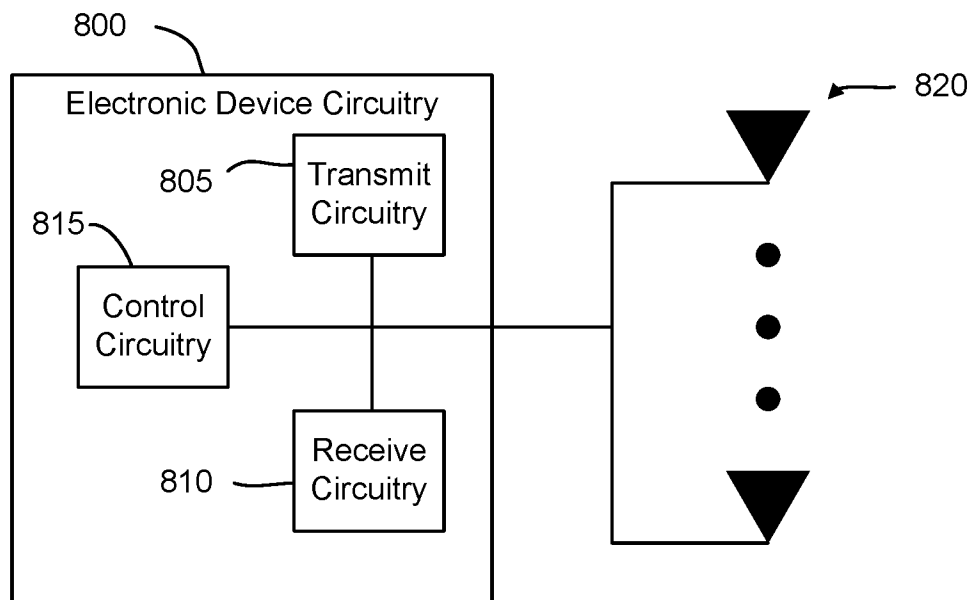


FIG. 8

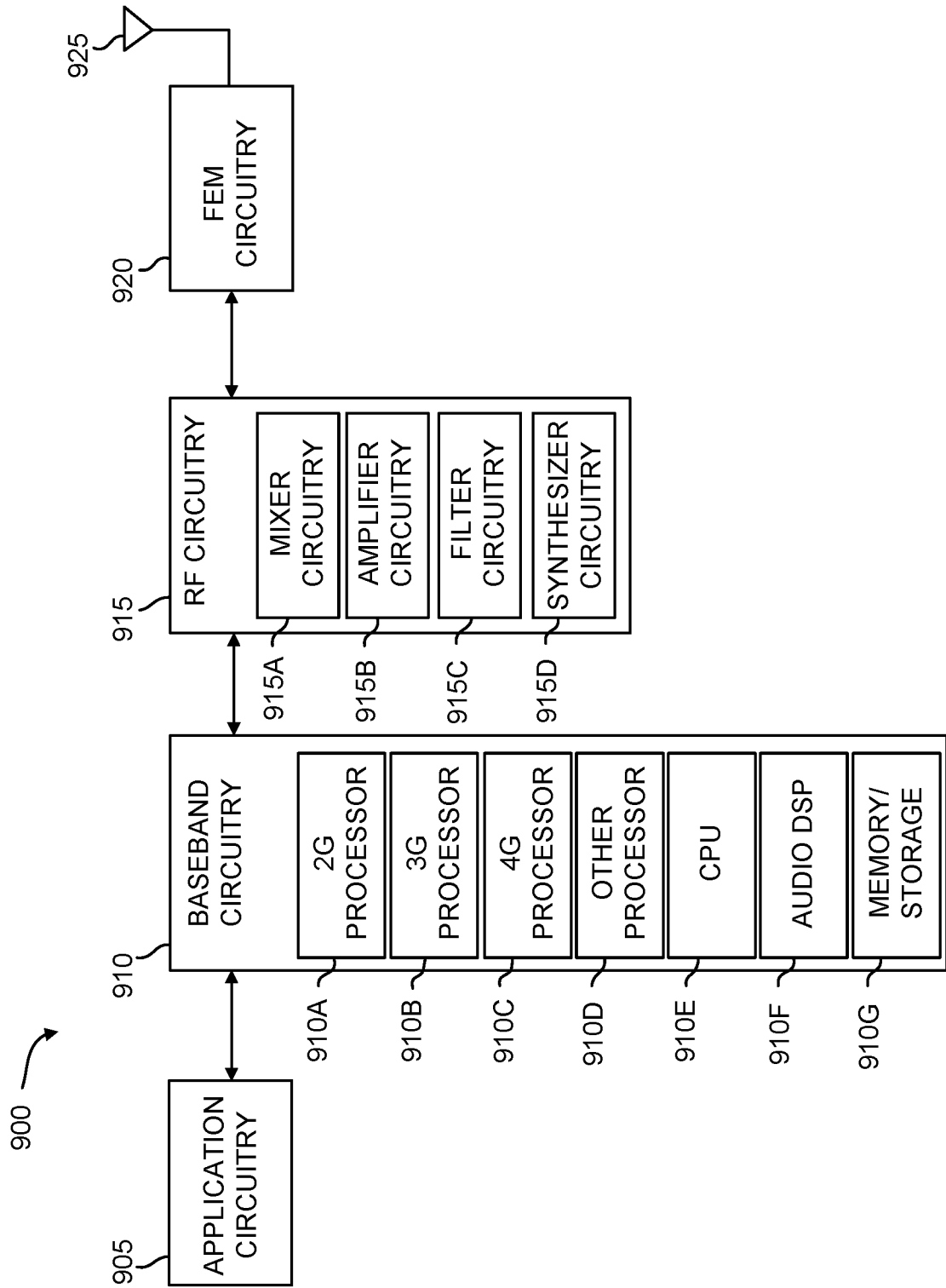


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/014033

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, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016/143038 A1 (GOTO JUNGO [JP] ET AL) 19 May 2016 (2016-05-19) page 5, paragraph 0063; figure 7 ----- -/--	1-24



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 April 2017

Date of mailing of the international search report

10/05/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Fonseca dos Santos

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/014033

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	----- CATT: "Considerations on synchronization signal/channel Enhancement", 3GPP DRAFT; R1-156606, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Anaheim, USA; 20151115 - 20151122 15 November 2015 (2015-11-15), XP051039890, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_ SYNC/RAN1/Docs/ [retrieved on 2015-11-15] page 1 - page 2	2,13
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/014033

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WO 2017052307 A1	30-03-2017	US 2017094657 A1	30-03-2017
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