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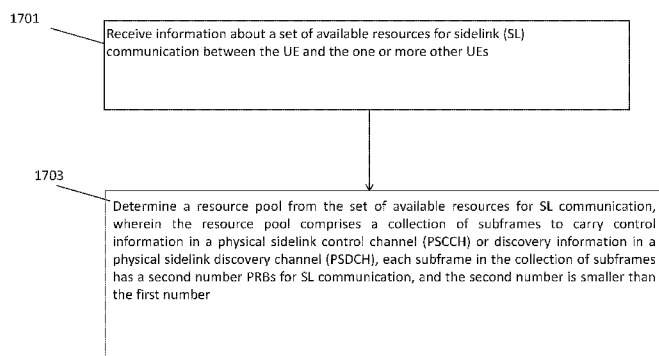


Figure 17

(57) Abstract: An apparatus for use in a user equipment (UE), the apparatus includes circuitry to configure subframes in a resource pool of the PSCCH or the PSDCH with smaller number of PRBs for sidelink communication compared with a number of PRBs in a subframe used for public safety information. The apparatus also includes circuitry to determine a correspondence between transmission and reception spaces for the PSDCH to avoid blind decoding of the entire PSDCH. One or more computer-readable media comprise instructions to cause a UE to configure the PSCCH based on a resource configuration message for the PSCCH received through the RRC signaling from the eNB or through the discovery message in the PSDCH, or instructions to identify, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission and restrict blind decoding attempts to the one or more subframes.

BLIND DECODING REDUCTION FOR DEVICE-TO-DEVICE COMMUNICATION

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority from U.S. Provisional Patent Application
5 No. 62/316,020, filed March 31, 2016, and entitled “BLIND DECODING REDUCTION
TECHNIQUES FOR DEVICE-TO-DEVICE COMMUNICATION”, the entire disclosure
of which is hereby incorporated by reference.

TECHNICAL FIELD

Embodiments generally may relate to the field of wireless communications.

10

BACKGROUND

LTE (long-term evolution) networks, for example may provide for device-to-
device (D2D) communication.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a schematic high-level example of a network that includes user
15 equipments (UEs) and an evolved NodeB (eNB), in accordance with various
embodiments.

Figure 2 illustrates signaling in a network in accordance with some embodiments.

Figure 3 illustrates a resource pool configuration example for Mode-2 in
accordance with some embodiments.

20 Figure 4 illustrates a frequency resource pool configuration in accordance with
some embodiments.

Figure 5 illustrates an example of Time Resource Patterns (TRP) in accordance
with some embodiments.

25 Figure 6 illustrates a call flow for Proximity Services (ProSe) user equipment
(UE)-Network Relay in accordance with some embodiments.

Figure 7 illustrates a one-to-one association of transmission and reception spaces in
accordance with some embodiments.

Figure 8 illustrates a one-to-many association of transmission and reception spaces
in accordance with some embodiments.

30 Figure 9 illustrates an activation pattern for transmission within T-RPT in
accordance with some embodiments.

Figure 10 illustrates an end of data signaling option in accordance with some
embodiments.

Figure 11 illustrates example components of an electronic device according to some embodiments.

Figure 12 illustrates a UE in accordance with some embodiments.

Figure 13 illustrates hardware resources in accordance with, or suitable for use
5 with, some embodiments.

Figure 14 illustrates a procedure for D2D communication, in accordance with various embodiments.

Figure 15 illustrates another procedure for D2D communication, in accordance with various embodiments.

10 Figure 16 illustrates another procedure for D2D communication, in accordance with various embodiments.

Figure 17 illustrates another procedure for D2D communication, in accordance with various embodiments.

15 Figure 18 illustrates another procedure for D2D communication, in accordance with various embodiments.

Figure 19 illustrates another procedure for D2D communication, in accordance with various embodiments.

Figure 20 illustrates another procedure for D2D communication, in accordance with various embodiments.

20 DETAILED DESCRIPTION

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,
25 techniques, etc. in order to provide a thorough understanding of the various aspects of the claimed 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 embodiments and claims 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
30 to obscure the description of the present embodiments with unnecessary detail.

For the purposes of the present disclosure, the phrases “A or B” and “A and/or B” mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase “A, B, and/or C” means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

The description may use the phrases “in an embodiment,” or “in embodiments,” which may each refer to one or more of the same or different embodiments. Furthermore, the terms “comprising,” “including,” “having,” and the like, as used with respect to embodiments of the present disclosure, are synonymous.

5 As discussed herein, the term “module” may be used to refer to one or more physical or logical components or elements of a system. In some embodiments a module may be a distinct circuit, while in other embodiments a module may include a plurality of circuits.

10 The 3rd Generation Partnership Project (3GPP) is a collaboration between groups of telecommunications associations, known as the Organizational Partners. 3GPP standards are structured as Releases. Discussion of 3GPP thus frequently refers to the functionality in one release or another. Long-Term Evolution (LTE), commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. A LTE network includes user equipments (UEs)
15 communicating with evolved base stations, called eNodeBs or eNBs.

 Device-to-Device (D2D) communication refers to a radio technology that enables devices, e.g., UEs, to communicate directly with each other, that is without routing the data paths through a network infrastructure. Proximity-based services can be provided when UEs are close to each other. Terms D2D, sidelink (SL), and Proximity Services
20 (ProSe) are used interchangeably herein.

 In 3GPP Release (Rel.) 12, an initial framework of D2D communication for LTE (LTE D2D) is introduced targeting public safety use cases and consumer use cases. The framework includes D2D discovery and D2D communication. D2D discovery is supported for consumer use cases, while D2D communication, supported for both
25 consumer and public safety use cases, is mainly optimized for out-of-coverage, partial coverage, and long-range voice communication in public safety use cases. In Rel. 13, a functionality of UE-to-network (NW) relaying using layer 3 (L3) forwarding is introduced. Additionally, out-of-coverage discovery is introduced to aid UE-to-NW relay discovery and group discovery.

30 For LTE D2D as discussed in Rel. 12/13, the D2D transmission is allowed only in dedicated or uplink (UL) resources, which may be dedicated D2D carrier, UL carrier in frequency-division duplex (FDD), or UL subframes in time-division duplex (TDD). The transmission resources are allocated by configuring resource pools shared among multiple

UEs. Transmission resource pool configurations are signaled in dedicated system information blocks (SIBs).

Accordingly, LTE D2D reuses LTE UL physical layer as much as possible. For example, single carrier frequency division multiple access (SC-FDMA) waveform, physical uplink shared channel (PUSCH) interleaving, common turbo or convolutional coding, transport block size (TBS), modulation and coding (MCS) tables, and demodulation reference signals (DMRSs) of LTE can be reused for LTE D2D.

As a result, the emerging use cases for consumer D2D communication, such as wearable device communication and Internet of Things (IoT) communication, are not considered by LTE D2D in Rel. 12/13. On the other hand, the Internet of Things (IoT) is one of the important transformation paradigms of the upcoming 5G communication era. Connection of a massive number of devices to network is one of the main problems to be addressed by the 5G wireless technologies. The number of devices that may be connected by wireless connection to the network is rapidly growing nowadays, and is expected to exponentially grow in the upcoming IoT decades. Devices of a variety of different wireless devices classes, from low cost/low power/low rate to high-end devices, and associated services may benefit from the connections to the network.

Such emerging user cases involving wearable UEs and/or IoT devices may be sensitive to energy consumption and operation complexity. However, due to the broadcast nature of the physical layer used in LTE D2D in Rel. 12/13, where the public safety use cases are mainly considered, only limited consideration has been placed on the cost and power consumption of D2D communication in Rel. 12/13. Embodiments herein illustrate how to reduce power consumptions by reducing the number of blind decodings performed by UEs in LTE D2D communications.

In LTE D2D communication, UEs perform blind decodings on a potentially excessive number of receive (RX) processes for some applications. UEs share the uplink resources with the devices attached to the network. Two physical channels have been introduced: the physical sidelink control channel (PSCCH) carrying the control information, and the physical sidelink shared channel (PSSCH) carrying the data. The control and data may be placed in the PSCCH and the PSSCH, while the discovery information is carried in the physical sidelink discovery channel (PSDCH). The PSSCH is processed based on a received PSCCH containing layer 1 (L1) identity. Devices interested in receiving D2D services blindly scan the whole PSCCH resource pool to search for information.

Table 1 below summarizes blind decoding and parallel RX process numbers for Rel.12/13 sidelink, where TRP is the time resource pattern, #BD is the number of blind decodings, #RX proc. is the number of RX processes, and TTI is a transmission time interval (TTI):

Table 1

	# BD in a TTI	# RX proc.
PSDCH	50	[50, 400]
PSCCH	50	N/A
PSSCH	Whole TRP	16

As shown in Table 1, a large number of blind decodings may be performed for D2D communication based on Rel. 12/13. For example, in LTE Rel. 12, a UE may perform 50 blind decodings of Sidelink Control Information (SCI) per subframe depending on PSCCH resource pool configuration. The 50 blind decodings correspond to the 50 physical resource blocks (PRBs) in a subframe used to transmit public safety information to the UE. The high number of blind decodings may substantially complicate receiver implementation, which may not be suitable for wearable UEs or IoT devices that may desire low power and low cost operations.

Example embodiments herein provide enhancements to D2D communications, and in particular, enhancements to D2D communications for wearable computing devices, machine-type communication (MTC) devices, and/or IoT devices. More specifically, example embodiments provide enhancements to D2D communications with a reduced number of blind decodings, which may be less than the number of blind decodings used to decode the public safety information.

Figure 1 depicts a high-level example of network 1000. Network 1000 may include two or more UEs, such as UE 120 and UE 130. Either of UE 120 and UE 130 may be a D2D transmitter, or a D2D receiver. Network 1000 may further include an eNB, e.g., eNB 115. In embodiments, eNB 115 may be configured to transmit or receive one or more signals to or from UEs 120 and 130, for example, via a radio interface Uu as indicated by the solid lines in Figure 1. In some embodiments, network 1000 may be included in a wide area network (WAN), and transmissions between eNB 115 and UEs 120 or 130 may use resources of the WAN. Additionally, UEs 120 and 130 may be configured to transmit or receive one or more signals to or from one another via D2D communication interface PC5, as indicated by the dashed line. For example, UEs 120 and

130 may exchange control information via one or more Scheduling Assignment (SA) transmissions, and/or data transmissions as explained herein. In embodiments, UE 120 or UE 130 may perform mode switching between PC5 interface and Uu interface to communicate in either D2D mode or cellular mode. In some instances, the PC5 interface may also be referred to as a sidelink interface.

In embodiments, UE 130 may be a wearable/IoT UE accessing a network using a relayed D2D connection with UE 120, where UE 120 may be a non-IoT, e.g., a smartphone, a tablet computing device, etc., acting as a D2D or ProSe relay node. The connection between wearable/IoT UE 130 and relay UE 120 may be a “sidelink.” Wearable/IoT UE 130 may have the capability for direct communication with the eNB; however, this capability may be used in exceptional cases and/or for acquisition of control information, e.g., attachment to an access network such as the Evolved Universal Terrestrial Access Network (E-UTRAN). In D2D communication, e.g., communication over the PC5 interface, UEs may share the uplink resources with the devices attached to the network.

In embodiments, regardless of possible cellular capabilities of the device, UE 130 may be one of the following D2D capability categories:

Table 1

<u>Wearable Category 1</u>	<u>Wearable Category 2</u>
Low power, low rate, low cost (Reduced D2D capabilities)	Reduced power & cost, various rate (High D2D capabilities)
Sensor type devices, wearable device (e.g. health/wellness all Bluetooth use cases)	Low power/complexity & high rate (e.g. phone accessories: glasses, watches, camera, etc.)

Example embodiments herein provide mechanisms to reduce the sidelink channels blind decodings in order to reduce the device complexity and power consumption.

The following example embodiments may provide reductions for sidelink decoding complexity:

- 1) configuring narrow resources pools to reduce reception bandwidth, and thus, reduce the number of parallel blind decodings;
- 2) introducing one-to-one or one-to-many association for transmission and reception space so that a remote UE, e.g., wearable/IoT/MTC UE, is aware where to expect messages of relay UEs; and
- 3) introducing additional signaling for alignment of transmission and reception space.

As shown in Table 1, D2D communication in Rel. 12/13 assumes wide reception bandwidth and large blind decoding capability at any D2D capable device, such as

blind decodings to satisfy the public safety use cases. The example embodiments herein may reduce the reception bandwidth and the number of parallel blind decodings, thus reducing complexity and power consumption of a device, compared to the public safety use cases.

5 The following terms are used herein:

- **Remote UE** – a wearable computing device (e.g., smartwatch or health sensor) or IoT/MTC device (e.g., stationary smart meter) that communicates with a network via another UE using D2D air-interface. Remote UEs may communicate over a Uu air-interface, which is the radio interface between the UE and the eNB. In
10 embodiments, a remote UE may have lower capabilities and may benefit from low-power and low-cost operations.
- **Relay UE** – a UE capable of relaying traffic to/from another UE from/to network using D2D air-interface. Examples of relay UEs may include smartphones, tablet computing devices, laptops, desktop personal computers, and/or any other like
15 computing device. Relay UEs may communicate with remote UEs over the Uu air-interface. A relay UE may be a D2D capable UE and/or ProSe enabled UE such that the relay UE is capable of supporting of D2D/ProSe direct discovery, communication, and/or act as a D2D/ProSe UE-to-NW relay.
- **Relay discovery** – a procedure of discovering and selecting a relay UE by a remote
20 UE. Relay discovery may also be referred to as “ProSe Direct Discovery.” The procedure may be performed before transmitting control and data on sidelink.

Example embodiments herein may illustrate enhancements and signaling to reduce the number of blind decoding for a D2D UE, without reducing reception bandwidth. In some embodiments, the number of blind decodings may be reduced by reducing operation
25 bandwidth of a UE, such as a remote UE.

There are three points of concern with blind decodings in UE operation as stated in Rel. 12/13:

- 1) PSDCH decoding – a UE may process 50 transport blocks in a TTI to decode PSDCH information. The whole pool may be processed, hence a UE may be
30 assumed to be capable to process 50 or 400 parallel transmissions and retransmissions.
- 2) PSCCH decoding – a UE may process 50 Sidelink Control Information (SCI) resources in a given subframe to decode PSCCH information. Additionally, the

whole pool may be processed and two TTIs may be used for each SCI transmission that may lead to a very large number of parallel RX processes for SCI. For example, if 50 PRBs and 40 subframes are configured for a single pool, it is possible to perform up to 1000 parallel processes to successfully
5 decode one PSCCH pool.

- 3) Whole time resource pattern of transmission (T-RPT) decoding – a UE may decode every TTI in a SCI period signaled by T-RPT, while the number of eventually used TTIs by the UE may be much smaller, e.g. four.

An apparatus for use in a UE is disclosed herein. The apparatus may include
10 circuitry to configure subframes in a resource pool of the PSCCH or the PSDCH with smaller number of PRBs for sidelink communication compared with a number of PRBs in a subframe used for public safety information. The apparatus may also include circuitry to determine a correspondence between transmission and reception spaces for the PSDCH to avoid blind decoding of the entire PSDCH. One or more computer-readable media
15 comprise instructions to cause a UE to configure the PSCCH based on a resource configuration message for the PSCCH received through the RRC signaling from the eNB or through the discovery message in the PSDCH, or instructions to identify, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission and restrict blind decoding attempts to the one or more subframes.

20 In the subsequent descriptions, embodiments for both the D2D discovery and the D2D communication with reduced number of blind decodings for these general cases are discussed.

Discovery

The D2D discovery procedure is performed to enable proximity triggered services
25 deployed at application layers. To do so, a special periodic discovery announcement is transmitted and received. The D2D discovery transmission may be allowed only inside discovery resource pool, which may be allocated periodically with minimum occasion periodicity of 320 milliseconds (ms) and 10240 ms maximum periodicity. A D2D discovery transmission may span 2 PRBs in frequency domain and X subframes in time
30 domain (where X is configurable between 1 and 4). There may also be two different resource allocation modes: autonomous resource selection (random resource selection); or eNB-controlled resource selection, where resources for transmission are configured by Radio Resource Control (RRC) signaling. In Rel.13, the discovery periodicity is reduced

to the level of communication pool periodicity, e.g., 40/80/160/320 ms in FDD and corresponding values for TDD.

Communication

The Rel.12/13 D2D communication is designed for long-range voice
5 communication with broadcast physical layer nature, without considering the power consumption and operational complexity. The D2D data communication is specified only for public safety operations in different scenarios within network coverage, partial network coverage, or out-of-network coverage. The public safety application is voice service, e.g., voice over IP (VoIP). Accordingly, Rel. 12/13 D2D communication is
10 designed for robust long-range voice communication with semi-persistent randomized resource allocation. In more details, a two-step data transmission procedure is adopted: (1) control information transmission, e.g., SCI or SA, inside a PSCCH resource pool pointing to the subsequent data transmission with the specified physical layer parameters, (2) data transmission inside a PSSCH resource pool following the transmission of control
15 information.

Figure 2 illustrates signaling in a network including eNB 115, D2D transmitter 120 and D2D receiver 130 in accordance with some embodiments. D2D transmitter 120 transmits a request for resources 132 to eNB 115 and receives a resource grant 135 from the eNB in response. The resource grant 135 includes an allocation of resources for
20 scheduling control information in PSCCH and data in PSSCH. D2D transmitter 120 obtains SCI and D2D data resources from the resource grant 135. D2D transmitter 120 then transmits SCI 140 in PSCCH to D2D receiver 130, in accordance with the allocated resources. D2D receiver 130 receives the SCI 140 by blind decodings over the PSCCH and from this acquires information about the subsequent data transmission from the D2D
25 transmitter 120. D2D transmitter 120 then transmits the D2D data 145 in PSSCH according to the SCI previously sent to D2D receiver 130, and as allocated by the eNB. D2D receiver 130 receives the D2D data in accordance with the previously received SCI 140.

Depending on how the resources for transmission are acquired, there are two
30 different resource allocation modes: Mode-1 is eNB controlled resource allocation and Mode-2 is autonomous resource allocation. In Mode-1, which is illustrated in Figure 2, the resource for transmission is signaled by eNB in a downlink control information (DCI) Format 5 message, and eNB schedules both SCI and PSSCH transmission. The only transmission parameter that may not be controlled by eNB is the MCS, which may be

optionally set by UE-specific RRC signaling or be left up to UE choice. In Mode-2, the step of requesting resources and receiving DCI Format 5 from an eNB may be replaced by an autonomous generation of a resource grant using a random resource selection rule.

Figure 3 shows an example of a pool configuration for Mode-2 using FDD. The SA cycle 210 of Figure 3 has a cycle length of 1024 ms, having an offset 212 from system frame number (SFN) ranging from 0 to 215. Each SA/data period 220 extends over 4 frames 222 and is used to transmit the SA Bitmap 225, with a duration of 40 ms. The SA bitmap 225 defines an SA pool 227 in a first portion 228 of the SA bitmap 225. A data bitmap 230 is offset relative to the SA bitmap 225 by an amount corresponding to the first portion 228. The data bitmap 230 is also truncated by a corresponding amount 235. The data bitmap 230 defines data subframes forming a data pool 237. The SA pool 227 and data pool 237 form resource pool 240.

Figure 4 shows an example of frequency resource pool configuration for Mode-2, in accordance with the example of Figure 3. In Figure 4, frequency is shown vertically and time is shown horizontally. The parameters saStartPRB 310, saNumPRB 315 and saEndPRB 320 define the PRBs that form the SA resource pool 227. The highest and lowest frequency PRBs of the SA resource pool 227 are given by saStartPRB 310 and saEndPRB 320, respectively. The SA resource pool 227 extends saNumPRB 315 above the lowest frequency PRB and saNumPRB 315 below the highest frequency PRB. Depending on the values of these parameters, the SA resource pool 227 may correspond to a continuous group of PRBs, or may correspond to two groups of PRBs separated by a gap.

The data resource pool 237 may be defined in a similar manner to the SA resource pool 227 by parameters dataStartPRB 330, dataNumPRB 335 and dataEndPRB 340. The highest and lowest frequency PRBs of the data resource pool 237 are given by dataStartPRB 330 and dataEndPRB 340, respectively. The data resource pool 237 extends dataNumPRB 335 above the lowest frequency PRB and dataNumPRB 335 below the highest frequency PRB. Depending on the values of these parameters, the data resource pool 237 may correspond to a continuous group of PRBs, or may correspond to two groups of PRBs separated by a gap 345.

In embodiments, *startPRB* may refer to either saStartPRB, dataStartPRB or discStartPRB, *endPRB* may refer to either saEndPRB, dataEndPRB or discEndPRB, and *numPRB* may refer to either saNumPRB, dataNumPRB, or discNumPRB, which is half of

the pool size. In embodiments, startPRB may refer to prb-Start, endPRB may refer to prb-End, and numPRB may refer to prb-Num.

The parameters defining the PRBs of the data resource pool 237 may be independent of the PRBs of the SA resource pool 227, such that the SA and Mode-2 data frequency resources 227, 237 may be configured independently.

In element 300 of Figure 4, each block in the horizontal direction represents a subframe in a logical resource pool. In elements 302 and 304 of Figure 4, each block in the horizontal direction represents a symbol in a subframe.

SCI format may be common for both Mode-1 and Mode-2 operation modes and may carry the following fields:

- Frequency hopping flag;
- Resource block assignment – frequency resource indication;
- TRP (time resource pattern) – time resource indication;
- MCS index – modulation and coding scheme index;
- TA (timing advance) – timing advance relative to the serving eNodeB;
- Group destination ID – layer 1 identity.

Resource block assignment and TRP point to particular spectrum resources inside the configured resource pool. Figure 5 shows how the TRP bitmap is applied inside the resource pool. Figure 5 shows three exemplary TRP bitmaps 410, where an assigned subframe is identified by a logical 1 in the TRP bitmap. Assigned subframes are indicated with shading. The TRP bitmap may be applied cyclically within the logical data pool. In the example of Figure 5, the TRP bitmap has a length of eight subframes and is repeated each eight subframes of the logical data pool.

Figure 6 illustrates a call flow for ProSe UE-Network Relay with layer-3 relaying support in accordance with some embodiments. The operations may be performed following a sequence of actions described below.

Relay UE 520 may perform initial attachment procedure 550 to attach UE 520 to the access network Evolved UMTS Terrestrial Radio Access Network (E-UTRAN), which involves signaling to/from mobility management entity (MME) 530 and home subscriber server (HSS) 540 as per usual E-UTRAN attachment procedure. Afterwards, the relay discovery and selection procedure 560 may be performed according to Model-A or Model-B discovery as described below. In embodiments, one-to-one or one-to-many correspondences between the transmission resources and reception resources of relay

discovery can be established to reduce the number of blind decodings. After the relay discovery and successful selection are performed, remote UE 510 and relay UE 520 may perform establishment of the one-to-one communication connection 570. After the one-to-one connection is established, the IP address assignment according to IPv4 (590) or IPv6 (580) procedure may be performed.

The Layer-3 operation means that relay UE acts as a proxy for IP traffic of the remote UE. In terms of L1/L2 (Layer 1/Layer 2), the operation may reuse Rel. 12 broadcast functionality with some enhancements in order to efficiently discover and select relays.

Example Embodiments

Configuration based approach

In embodiments, public safety information is carried through a first number of PRBs, e.g., 50, of a subframe. On the other hand, the resource pool for sidelink communication comprises a collection of subframes to carry control information in PSCCH or discovery information in PSDCH, each subframe in the collection of subframes has a second number PRBs for SL communication, e.g., 6, and the second number is smaller than the first number.

In embodiments, the pool size in frequency and time can be reduced, leading to the reduced number of blind decodings because the total size is reduced. For example, in order to reduce the number of PSCCH blind decodings, the pool size can be reduced from 50 as used in the public safety use case, to 6. This can be accomplished by setting the *numPRB* parameter value of a band 705 or 707 as $numPRB = 3$. Additionally, in order to support narrowband devices (e.g. with maximum 6 PRB bandwidth), the gap 703 between two bands 705 and 707 can be reduced as well, such as both parts of frequency configuration are adjacent to each other. In this case, the *startPRB* and *endPRB* should follow the equation: $endPRB - startPRB \leq BW_RB$ and $2 \cdot numPrb \leq (number\ of\ BD) \cdot (number\ of\ PRB\ per\ transport\ block)$, wherein *startPRB* is a starting resource block index, *endPRB* is an ending resource block index, *numPRB* is a number of PRBs, *BW_RB* is a cell bandwidth expressed in number of resource blocks, and *number of BD* is a number of blind decodings of PRBs performed by the UE.

In embodiments, a same approach may be used for PSDCH, to limit the size of the resource pools for the discovery, and to limit the gap between the two groups of PRBs within a subframe for the resource pool in PSDCH.

In embodiments, when multiple resource pools are configured, the sum of frequency resource blocks from all resource pools may not exceed the desired number of blind decoding (BD) within a supported reception bandwidth.

Search and transmission space approach

5 In embodiments when a remote UE communicates with a single relay UE during a relatively long period, resulting in a one-to-one unicast communication for the duration, the transmission space can have a one-to-one correspondence with the reception space for the remote UE and the relay UE.

- 10 • The transmission space may be a set of time-frequency resources where transmission of/by a current UE is allowed. In Rel. 12/13 the transmission space is equal to the selected transmission resource pool space.
- The reception space may be a set of time-frequency resource, which is to be monitored/received/processed by a UE. In Rel. 12/13, the reception space for PSDCH and PSCCH is determined by configured RX resource pools. For PSSCH, 15 the reception space is determined by pool configuration and sidelink control information.

Example embodiments associate transmission and reception spaces of communicating UEs for PSDCH and PSCCH. Based on the association of the transmission and reception spaces, instead of decoding the complete pool in PSDCH and 20 PSCCH, only those reception spaces associated with the transmission spaces are decoded, hence reducing the number of blind decodings performed.

Search/Transmission Space Approach for PSDCH

For the UE-to-NW relaying procedure, the relay discovery procedure may be made first, as shown in Figure 6. The relay discovery uses PSDCH for transmitting relay 25 discovery messages. There are two different discovery models supported in LTE:

- Model A – each UE transmits an “announcement” message of the same format, which contains the relay discovery information. An announcing UE may announce certain information that could be used by other UEs in proximity that have permission to discover the announcing UE. The other UEs may be referred to as 30 “monitoring UEs,” where the monitoring UEs monitor certain information of interest in proximity of announcing UEs.
- Model B – a remote UE transmits “solicitation” message or request message first and relay UEs, which are suitable for relaying transmit “response” messages after

receiving the request. In model B, a remote UE transmits a request containing certain information about what it is interested to discover, and a relay UE receives the request message and may respond with some information related to the discoverer UE request.

5 When Model A discovery is used, both a remote UE and its relay candidates may transmit discovery announcements independently. In Model B discovery, a remote UE transmits its solicitation with a request to relay its traffic, and a UE with activated relaying function responses on the solicitation.

10 In embodiments, a discovery message may be transmitted in a transmission resource with a first index in a PSDCH in a first discovery period. In a second discovery period next to the first discovery period, a reception space on the PSDCH with a second index can be decided for the UE, where the second index may be determined based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence on a third channel. In this way, the UE just needs to decode the reception space with the second
15 index, instead of decoding the whole PSDCH message blindly.

In general, in order to align the transmission and search spaces of communicating UEs, e.g., a remote UE and a relay UE, a rule may be defined for deriving a relationship between the transmission and reception resources. Such a rule may be pre-defined, signaled, or configured semi-statically. Taking into account this specific usage of PSDCH
20 in the target use case, there may be a number of options to reduce the number of blind decodings of PSDCH as described below.

Option 1 - As illustrated in Figure 7, a one-to-one mapping function can be introduced between transmission resource 701 of a remote UE and transmission resource 703 of a relay UE. In embodiments, a relay UE responds to the remote UE's solicitation
25 in the same time-frequency resource in the next discovery period (period $x+1$) after the request period (period x). This rule may be generalized as a one-to-one mapping function between solicitation message resources and response message resources:

$$i_response(x+1) = F(i_solicitation(x)),$$

where:

30 $i_solicitation(x)$ – time-frequency resource index of a UE's solicitation message in discovery period x ,

$i_response(x+1)$ – time-frequency resource index of a UE's response message in discovery period $x+1$,

$F(a)$ – a one-to-one mapping function.

This approach may be considered relatively simple, but may give rise to congestion if multiple relay UEs simultaneously respond to the solicitation request in the same resource and create mutual co-channel interference.

Option 2 - As illustrated in Figure 8, a one-to-many mapping function can be introduced between transmission resource 801 of a remote UE and transmission resource 803 of a relay UE. In embodiments, a relay UE responds to the remote UE's solicitation in a plurality of transmission resource 803 in the next discovery period (period x+1) after the request period (period x). In order to avoid congestion as demonstrated in option 1, a one-to-many mapping function may be applied. That is, a set of resources for response should be linked with one solicitation resource. The set may be constructed in a way to fulfil the constraint on reception bandwidth and number of blind decodings constraint. The following generalized rule may be applied.

$$i_response(x+1) = F(i_solicitation(x), relay_UE_Id)$$

Where:

$i_solicitation(x)$, $i_response(x+1)$ as described in the previous option,

$relay_UE_Id$ – a relay UE identity.

$F(a, b)$ – a one-to-many mapping function which generates different resource indexes for different relay UEs.

In embodiments, a mapping rule may map a solicitation resource to a subset of time-frequency resources and then each relay UE randomly selects one for transmission of the response. In another embodiment, a mapping function may utilize the UE identity (e.g., Radio Network Temporary Identity (RNTI), L1/L2 ProSe Group ID, etc.).

Option 3 - The information about transmission space of a UE may be transmitted in a newly designed channel, different from the PSDCH and the sidelink synchronization signal, which has a structure that does not perform a large number of blind decodings of PSDCH. This channel may carry a sequence, which can be detected and linked with transmission resources of current UE.

Option 4 - In case the SL synchronization procedure is used to synchronize one UE to another, the SL-SS identity may be used to indicate resources used for transmission and reception of associated UEs. This may happen when a relay UE transmits sidelink synchronization signal (SL-SS) and a remote UE synchronizes to it.

Search/transmission space approach for PSCCH

The transmission of PSCCH and its resource configuration is very similar to the discovery information carried in PSDCH, and thus, similar principles may be applied to PSCCH as demonstrated above for PSDCH. In general, PSCCH is transmitted after a UE performs the relay discovery procedure.

5 The following information about transmission and reception space of PSCCH may help a UE to reduce the blind decoding operations performed: exact PSCCH resource index (n_{PSCCH}), range of PSCCH resource indexes for the UE, random seed to generate the PSCCH resource index in case of Mode 2, frequency sub-band to be monitored (n_{F}).

- 10 - exact PSCCH resource index (n_{PSCCH}) - This knowledge may narrow down reception bandwidth to 1 PRB and the number of blind decodings to 1.
- range of PSCCH resource indexes for the UE - This knowledge may narrow down reception bandwidth to the range PSCCH resource indexes.
- random seed to generate the PSCCH resource index in case of Mode 2 - Since in Mode 2 the PSCCH resource for transmission is selected randomly, knowledge of
- 15 the random generation procedure and its initialization parameters or seeds at a receiving UE may facilitate calculation of PSCCH for each resource pool occasion and lead to 1 blind decoding.
- frequency sub-band to be monitored (n_{F}) - Partial information, e.g., frequency sub-band where PSCCH transmission may be an alternative solution if knowledge
- 20 of exact PSCCH resources is unavailable. Based on the frequency sub-band, the number of blind decodings may be reduced to the number of PRBs in the sub-band.

In embodiments, the above information of PSCCH may be made known to a UE in different ways, such as through a discovery message transmitted in a PSDCH, or a RRC signaling received from eNB.

25 **Option 1** - PSCCH configuration information may be made known to a UE through a discovery message transmitted in a PSDCH.

- Explicit information may be placed in the PSDCH channel. Currently, the PSDCH Medium Access Control (MAC) Protocol Data Unit (PDU) is created using transparent MAC mode. In embodiments, this may be changed in order to
- 30 multiplex the PSCCH configuration or alignment information. Example embodiments may introduce a MAC Control Element (CE) with the alignment information and multiplex it with the discovery channel payload (SL-DCH).
- PSCCH transmission resource index (or other info indicating transmission/search space highlighted above) may be associated with discovery resource index where

solicitation or response is received, thus a receiving UE may link the PSCCH search space with already processed discovery resources.

- UE identity acquired from SL-DCH or PSDCH may be associated with PSCCH resource set or index in order to reduce the search space / blind decoding number.

5 **Option 2.** PSCCH configuration information may be made known to a UE through a RRC signaling received from eNB.

Example embodiments may indicate the relevant information (e.g., exact resources, reduced set of resources, initialization seeds, etc.) by eNB using dedicated RRC signaling. In this case, the eNB may know ahead which devices want to communicate in order to provide the relevant information. In case of model-A, both relay UE and remote UE may send SL-BSR (Sidelink Buffer Status Report) accompanied with target ProSe Group ID that may be used by eNB to configure aligned search space and transmission space for both UEs.

15 *T-RPT Enhancements for PSSCH*

In some instances, excessive blind decodings may be caused by the fact that the T-RPT is repeated through whole SCI period, hence a UE may try to receive PSSCH in all T-RPT subframes. In embodiments, information about a T-RPT bitmap may be received by the UE. The UE may identify, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a sidelink control (SC) period; and further restrict blind decoding attempts to the one or more subframes. Various options described below can be considered in embodiments.

25 **Option 1** – Embodiments may explicitly indicate the number of PDUs, the number of TTIs per PDU, and TX start time within T-RPT, without decoding unnecessary information. Embodiments may indicate the number of MAC PDUs that may be transmitted consecutively during the SCI period starting from the beginning or from the signaled offset (TX start time). Embodiments may also indicate the number of TTIs utilized for transmission of one MAC PDU. Currently, the number of TTIs is fixed to 30 four, but in example embodiments it may be made configurable. In that case, the receiving UE will have information, which subframes of T-RPT should be processed and which subframes may be skipped. In embodiments, the number of PDUs may be signaled by a 4-bit field. Each value of this field may correspond to the exact number of PDUs to be transmitted. One value (e.g., 0000 or 1111) may be reserved to indicate that all

subframes or none of the subframes should be processed. The time offset to indicate the 1st subframe within T-RPT may also be indicated to randomize transmission.

Option 2 - Embodiments may introduce an activation pattern for T-RPT repetition for a UE so that the UE looks for the active pattern and decode those active patterns while ignoring other information. The idea is to use a short bitmap to indicate T-RPT repetitions actually used for transmission. The activation pattern may need to be placed into SCI or multiplexed into the first MAC PDU. This option may allow scheduling of a MAC PDU transmission not only in the beginning of the SCI period, but in any part of the period (with restriction on number of bits to signal the activation bitmap). Additional signaling can be used to indicate amount of TTIs per MAC PDU.

Figure 9 illustrates use of an active pattern bitmap by the UE to decode a transmission in accordance with some embodiments. In one SCI period, the T-RPT bitmap may occur up to 4 times as shown in Figure 9(a). However, if the UE receives an active-pattern bitmap of '1000,' the UE may know that transmissions are limited to only the first possible occurrence of the T-RPT bitmap and may only decode the information in the first occurrence of the T-RPT, ignoring the three possible subsequent occurrences of the T-RPT as shown in Figure 9(b).

Option 3 - Embodiments may signal the end of data transmission in current SCI period. This may be done by multiplexing into DMRS or by multiplexing into MAC PDU by a control element when transmitting the last transport block. The "end of data" flag may be multiplexed into DMRS by defining a Cyclic Shift or an Orthogonal Cover Code that is applied to the last MAC PDU transmission to all its TTIs. One of the drawbacks of that approach is the non-zero processing time, which means that after receiving the last MAC PDU with the corresponding flag, the UE will also process at most 4 ms after because of processing delay. Additionally, this option may be used complimentary to another described above.

Figure 10 shows an embodiment signaling the end of data. In a T-RPT bitmap, an end of data pattern is signaled by the block 1111, so that the UE would not blindly decode the entire repeated T-RPT within the SCI period.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 11 illustrates, for one embodiment, example components of an electronic device 100. In embodiments, the electronic device 100 may be, implement, be incorporated into, or otherwise be a part of a MTC UE described herein. In some embodiments, the electronic device 100 may include application

circuitry 102, baseband circuitry 104, Radio Frequency (RF) circuitry 106, front-end module (FEM) circuitry 108 and one or more antennas 110, coupled together at least as shown. In embodiments, baseband circuitry 104 may be a D2D circuitry to determine a resource pool from the set of available resources for SL communication, while RF
5 circuitry 106 may be an interface control circuitry to receive information about a set of available resources for SL communication.

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
10 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.

15 The application circuitry 102 may include one or more application processors. For example, the application circuitry 102 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may
20 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.

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

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

In some embodiments, the baseband circuitry 104 may include elements of a protocol stack such as, for example, elements of an D2D or EUTRAN protocol including, for example, physical (PHY), MAC, radio link control (RLC), packet data convergence protocol (PDCP), and/or RRC elements. A central processing unit (CPU) 104e of the baseband circuitry 104 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 104f. The audio DSP(s) 104f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

The baseband circuitry 104 may further include memory/storage 104g. The memory/storage 104g may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 104. Memory/storage for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 104g may 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. The memory/storage 104g may be shared among the various processors or dedicated to particular processors.

Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 104 and the application circuitry 102 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 104 may support communication with an EUTRAN and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

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

In some embodiments, the RF circuitry 106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 106 may include mixer circuitry 106a, amplifier circuitry 106b and filter circuitry 106c. The transmit signal path of the RF circuitry 106 may include filter circuitry 106c and mixer circuitry 106a. RF circuitry 106 may also include synthesizer circuitry 106d for synthesizing a frequency for use by the mixer circuitry 106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 108 based on the synthesized frequency provided by synthesizer circuitry 106d. The amplifier circuitry 106b may be configured to amplify the down-converted signals and the filter circuitry 106c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 104 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

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

In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some
10 embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the
15 mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may be configured for super-heterodyne operation.

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
20 baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 104 may include a digital baseband interface to communicate with the RF circuitry 106.

In some embodiments, the synthesizer circuitry 106d may be a fractional-N
25 synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

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

In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be

provided by either the baseband circuitry 104 or the applications processor 102 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 102.

5 Synthesizer circuitry 106d of the RF circuitry 106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional
10 division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the
15 delay line is one VCO cycle.

 In some embodiments, synthesizer circuitry 106d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and
20 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 106 may include an IQ/polar converter.

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

30 In some embodiments, the FEM circuitry 108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 106).

The transmit signal path of the FEM circuitry 108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 110).

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

 In embodiments where the electronic device 100 is, implements, is incorporated into, or is otherwise part of a UE, the RF circuitry 106 may be to receive one or more
10 signals. The baseband circuitry 104 may be to determine a configuration for communication between a remote UE and a relay UE. The configuration may indicate: one or more resource pools indicative of time and frequency resources to be used for transmission of a discovery announcement message, a mapping between transmission resources of remote UE and Relay UE, and transmission and reception resources of the
15 remote UE and the relay UE. The remote UE is to provide, to the relay UE over a sidelink control channel, SCI indicating one or more subframes to be used for transmissions over a sidelink data channel and indicating a TRP to be used for the transmission over the sidelink data channel.

 In embodiments where the electronic device 100 is, implements, is incorporated
20 into, or is otherwise part of a UE, the RF circuitry 106 may be to receive one or more signals. The baseband circuitry 104 may be to determine, based on the one or more signals, a resource pool indicative of time and frequency resources to be used for transmission of a discovery announcement message, a mapping between transmission resources of a remote UE and transmission resources of a relay UE, and resources to be
25 used for communication between the remote UE and the relay UE.

 In embodiments where the electronic device 100 is, implements, is incorporated into, or is otherwise part of a UE, baseband circuitry 104 may be to determine a resource pool indicative of time and frequency resources to be used for transmission of a discovery announcement message, determine a mapping between transmission resources of a remote
30 UE and transmission resources of a relay UE, determine resources to be used for communication between the remote UE and the relay UE, and generate information indicative of the resource pool, the mapping, and the resources. The RF circuitry 106 may be to transmit, to the relay UE and/or the remote UE, one or more signals to indicate the information.

Figure 12 illustrates a UE in accordance with some embodiments. The UE may be a D2D UE that is configured to operate as a low-power wearable or IoT device. The control circuitry may control various communication operations as described herein and may further control the transmission and reception of signals by the transmit/receive chain.

5 The transmit/receive chain may be a single transceiver chain.

In embodiments in which the electronic device illustrated in Figure 11 is used to implement the UE illustrated in Figure 12, the control circuitry may be implemented in parts of the baseband circuitry 104 and the transmit/receive chain may be implemented in parts of the RF circuitry 106 and/or FEM circuitry 108. In embodiments, the control
10 circuitry may be a D2D circuitry to determine a resource pool from the set of available resources for SL communication. In addition, the transmit/receive chain may be an interface control circuitry to receive information about a set of available resources for SL communication.

Figure 13 is a block diagram illustrating components, according to some example
15 embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 13 shows a diagrammatic representation of hardware resources 600 including one or more processors (or processor
cores) 1110, one or more memory/storage devices 1120, and one or more communication
20 resources 1130, each of which are communicatively coupled via a bus 1140.

The processors 1110 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated
25 circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 1112 and a processor 1114. The memory/storage devices 1120 may include main memory, disk storage, or any suitable combination thereof. In embodiments, processors 1110 may be a D2D circuitry to determine a resource pool from the set of available resources for SL communication.

30 The communication resources 1130 may include interconnection and/or network interface components or other suitable devices to communicate with one or more peripheral devices 1104 and/or one or more databases 1106 via a network 1108. For example, the communication resources 1130 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication

components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components. In embodiments, communication resources 1130 may be an interface control circuitry to receive information about a set of available resources for SL communication.

5 Instructions 1150 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1110 to perform any one or more of the methodologies discussed herein. The instructions 1150 may reside, completely or partially, within at least one of the processors 1110 (e.g., within the processor's cache memory), the memory/storage devices 1120, or any suitable
10 combination thereof. Furthermore, any portion of the instructions 1150 may be transferred to the hardware resources 1100 from any combination of the peripheral devices 1104 and/or the databases 1106. Accordingly, the memory of processors 1110, the memory/storage devices 1120, the peripheral devices 1104, and the databases 1106 are examples of computer-readable and machine-readable media.

15 In some embodiments, the electronic devices of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 14. For example, the process may include configuring or causing to configure, by an eNB, of narrow resource pools; configuring or causing to configure, by an eNB, of mapping between transmission
20 resources of remote UE and Relay UE; configuring or causing to configure, by an eNB, of transmission and reception resources to Remote UE and Relay UE; signaling or causing to signal, by a UE, of exact used subframes of TRP in SCI.

 In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or
25 portions thereof. One such process is depicted in Figure 15. For example, the process may include receiving or causing to receive one or more signals; and determining or causing to determine, based on the one or more signals, a resource pool indicative of time and frequency resources to be used for transmission of a discovery announcement message, a mapping between transmission resources of a remote UE and transmission resources of a
30 relay UE, and resources to be used for communication between the remote UE and the relay UE.

 In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 16. For example, the process may

include determining or causing to determine a resource pool indicative of time and frequency resources to be used for transmission of a discovery announcement message, a mapping between transmission resources of a remote UE and transmission resources of a relay UE, and resources to be used for communication between the remote UE and the relay UE. The process may include generating or causing to generate information indicative of the resource pool, the mapping, and the resources; and transmitting or causing to transmit, to the relay UE and/or the remote UE, one or more signals to indicate the information.

In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 17. For example, the process may include receiving information about a set of available resources for SL communication between the UE and the one or more other UEs (1701); and determining a resource pool from the set of available resources for SL communication, wherein the resource pool comprises a collection of subframes to carry control information in a PSCCH or discovery information in a PSDCH, each subframe in the collection of subframes has a second number PRBs for SL communication, and the second number is smaller than the first number (1703).

In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 18. For example, the process may include transmitting a discovery message in a transmission resource with a first index in a PSDCH in a first discovery period (1801); determining a reception space on the PSDCH with a second index in a second discovery period next to the first discovery period, wherein the second index is determined based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence on a third channel; and processing the determined reception space to obtain a discovery response (1803).

In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 19. For example, the process may include processing a discovery message transmitted in a PSDCH (1901); processing RRC signaling received from an evolved node B (eNB) (1903); and processing a control message transmitted in a PSCCH, wherein the PSCCH is configured based on a resource

configuration message for PSCCH channel received through the RRC signaling from the eNB, or the discovery message in the PSDCH (1905).

In some embodiments, the electronic device of Figures 11-13 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. One such process is depicted in Figure 20. For example, the process may include receiving by the UE, information about a T-RPT bitmap (2001); identifying, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a SC period (2003); and restricting blind decoding attempts to the one or more subframes (2005).

EXAMPLES

Example 1 may include an apparatus in a user equipment (UE) for device-to-device (D2D) communication between the UE and one or more other UEs in a mobile communication network, comprising:

interface control circuitry, the interface control circuitry to:

receive information about a set of available resources for sidelink (SL) communication between the UE and the one or more other UEs; and

device to device (D2D) circuitry coupled with the interface control circuitry to:

determine a resource pool from the set of available resources for SL communication, wherein the resource pool comprises a collection of subframes to carry control information in a physical sidelink control channel (PSCCH) or discovery information in a physical sidelink discovery channel (PSDCH), each subframe in the collection of subframes has a first number physical resource blocks (PRBs) for SL communication, and the first number PRBs is smaller than a second number PRBs used to transmit public safety information.

Example 2 may include the apparatus of example 1 and/or some other examples herein, wherein the resource pool is determined by an evolved node B (eNB) from the set of available resources.

Example 3 may include the apparatus of example 1 and/or some other examples herein, wherein the first number of PRBs has a first gap separating a first set of PRBs from a second set of PRBs within the subframe, the second number of PRBs for SL communication within each subframe has a second gap between a first sequence of consecutive PRBs for SL communication and a second sequence of consecutive PRBs for SL communication, and the second gap is smaller than the first gap.

Example 4 may include the apparatus of example 1 and/or some other examples herein, wherein the second number of PRBs within each subframe is less than or equal to 6.

Example 5 may include the apparatus of example 1 and/or some other examples
 5 herein, wherein the resource pool for PSDCH or PSCCH is configured to satisfy conditions $\text{endPRB} - \text{startPRB} \leq \text{BW_RB}$ and $2 \cdot \text{numPRB} \leq (\text{number of BD}) \cdot (\text{number of PRBs per transport block})$, wherein startPRB is a starting resource block index, endPRB is an ending resource block index, numPRB is a number of PRBs, BW_RB is a cell
 10 bandwidth expressed in number of resource blocks, and number of BD is a number of blind decoding of PRBs performed by the UE.

Example 6 may include the apparatus of example 1 and/or some other examples herein, wherein the resource pool indicates a maximum number of PRBs to be used for transmission of a discovery announcement message.

Example 7 may include the apparatus of example 6 and/or some other examples
 15 herein, wherein the maximum number of PRBs is used for performing blind decoding.

Example 8 may include the apparatus of example 2 and/or some other examples herein, wherein the sidelink (SL) communication between the UE and the one or more other UEs is through a D2D communication interface PC5, the eNB communicates with the UE through a radio interface Uu, and the UE is attached to an Evolved Universal
 20 Terrestrial Access Network (E-UTRAN).

Example 9 may include an apparatus in a user equipment (UE) for device-to-device (D2D) communication between the UE and one or more other UEs in a mobile communication network, comprising:

interface control circuitry, the interface control circuitry to:
 25 transmit a discovery message in a transmission resource with a first index in a physical sidelink discovery channel (PSDCH) in a first discovery period; and
 device to device (D2D) circuitry coupled with the interface control circuitry to:
 determine a reception space on the PSDCH with a second index in a second discovery period next to the first discovery period, wherein the second index is determined
 30 based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence on a third channel; and
 process the determined reception space to obtain a discovery response.

Example 10 may include the apparatus of example 9 and/or some other examples herein, wherein the discovery message is an announcement message sent by a remote UE

or a relay UE, or a solicitation message sent by a remote UE.

Example 11 may include the apparatus of example 9 and/or some other examples herein, wherein the second index is related to the first index by a one-to-one rule in which the first and second indices correspond to same time-frequency resources in the respective
5 first and second discovery periods.

Example 12 may include the apparatus of example 11 and/or some other examples herein, wherein the one-to-one rule is based on a UE identity including one of a Radio Network Temporary Identity (RNTI) or an L1/L2 ProSe Group ID.

Example 13 may include the apparatus of example 9 and/or some other examples
10 herein, wherein the interface control circuitry further transmits a Sidelink Buffer Status Report (SL-BSR) and a target ProSe Group identifier (ID) to an eNB, and the eNB is to determine the reception space on the PSDCH.

Example 14 may include the apparatus of example 9 and/or some other examples herein, wherein the second index is related to the first index by a one-to-many rule in
15 which the first index corresponds to a plurality of indices in the second discovery period, the plurality of indices to include the second index.

Example 15 may include the apparatus of example 14 and/or some other examples herein, wherein the second index is randomly selected from the plurality of indices determined by the one-to-many rule.

20 Example 16 may include the apparatus of example 9 and/or some other examples herein, wherein the second index is determined based on the sequence and the device to device (D2D) circuitry is further to

detect the sequence on the third channel, wherein the third channel is different from the PSDCH and the sidelink synchronization signal; and

25 link the sequence with the transmission resource on the PSDCH and the reception spaces on the PSDCH.

Example 17 may include the apparatus of example 9 and/or some other examples herein, wherein the second index is based on the SLSS identity and the SLSS identity is to indicate the transmission resource on the PSDCH and the reception space on the PSDCH.

30 Example 18 may include the apparatus of example 10 and/or some other examples herein, wherein the relay UE communicates with the remote UE through a D2D communication interface PC5, the relay UE communicates with an eNB through a radio interface Uu, and the relay UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN).

Example 19 may include one or more computer-readable media comprising instructions to cause a user equipment (UE), upon execution of the instructions by one or more processors of the UE, to:

- 5 process a discovery message transmitted in a physical sidelink discovery channel (PSDCH);
- process radio resource control (RRC) signaling received from an evolved node B (eNB); and
- process a control message transmitted in a physical sidelink control channel (PSCCH), wherein the PSCCH is configured based on a resource configuration message for PSCCH channel received through the RRC signaling from the eNB, or the discovery message in the PSDCH.

Example 20 may include one or more computer-readable media of example 19 and/or some other examples herein, wherein the PSSCH is configured based on the resource configuration message and the resource configuration message comprises
15 information related to an exact PSCCH resource index, a range of PSCCH resource indexes, a random seed to generate the PSCCH resource index, or a frequency sub-band to be monitored.

Example 21 may include one or more computer-readable media of example 19 and/or some other examples herein, wherein the PSSCH is configured based on the
20 resource configuration message and the resource configuration message is multiplexed with a discovery channel payload (SL-DCH) using a MAC control element (CE) in the PSDCH.

Example 22 may include one or more computer-readable media of example 19 and/or some other examples herein, wherein the PSSCH is configured based on the
25 resource configuration message and the resource configuration message is associated with an UE identity acquired from the SL-DCH.

Example 23 may include one or more computer-readable media of example 19 and/or some other examples herein, wherein the resource configuration message is configured by the eNB based on a group identification of the UE and one or more other
30 UEs.

Example 24 may include one or more computer-readable media of example 19 and/or some other examples herein, wherein the eNB communicates with the UE through a radio interface Uu, the UE is attached to an Evolved Universal Terrestrial Access

Network (E-UTRAN), and the UE communicates with one or more other UEs through a D2D communication interface PC5.

Example 25 may include one or more computer-readable media comprising instructions to cause a user equipment (UE), upon execution of the instructions by one or more processors of the UE, to:

receive by the UE, information about a time resource pattern for transmission (T-RPT) bitmap;

identify, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a sidelink control (SC) period; and

restrict blind decoding attempts to the one or more subframes.

Example 26 may include one or more computer-readable media of example 25 and/or some other examples herein, wherein the one or more subframes are indicated by an explicit indication of a number of protocol data units (PDUs), a number of transmission time intervals (TTIs) per PDU, or a transmission start time within the T-RPT bitmap.

Example 27 may include one or more computer-readable media of example 25 and/or some other examples herein, wherein the one or more subframes are indicated by a short bitmap to indicate subframes actually used for transmission to the UE, wherein the T-RPT bitmap is a number of repetitions of the short bitmap.

Example 28 may include one or more computer-readable media of example 27 and/or some other examples herein, wherein any '1' in the short bitmap indicates activated TRP repetition, and any '0' in the short bitmap indicates deactivated TRP repetition.

Example 29 may include one or more computer-readable media of example 25 and/or some other examples herein, wherein the one or more subframes are indicated by an end of data transmission in the SC period.

Example 30 may include one or more computer-readable media of example 25 and/or some other examples herein, wherein the one or more subframes are indicated by a combinatorial index.

Example 31 may include one or more computer-readable media of example 25 and/or some other examples herein, wherein the UE communicates with an eNB through a radio interface Uu, the UE communicates with one or more other UEs through a D2D communication interface PC5, and the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN).

Example 32 may include an apparatus for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

- means for receiving information about a set of available resources for sidelink (SL) communication between the UE and the one or more other UEs; and
- means for determining a resource pool from the set of available resources for SL communication, wherein the resource pool comprises a collection of subframes to carry control information in a physical sidelink control channel (PSCCH) or discovery information in a physical sidelink discovery channel (PSDCH), each subframe in the collection of subframes has a first number physical resource blocks (PRBs) for SL communication, and the first number PRBs is smaller than a second number PRBs used to transmit public safety information.

Example 33 may include the apparatus of example 32 and/or some other examples herein, wherein the first number of PRBs has a first gap separating a first set of PRBs from a second set of PRBs within the subframe, the second number of PRBs for SL communication within each subframe has a second gap between a first sequence of consecutive PRBs for SL communication and a second sequence of consecutive PRBs for SL communication, and the second gap is smaller than the first gap.

Example 34 may include the apparatus of example 32 and/or some other examples herein, wherein the second number of PRBs within each subframe is less than or equal to 6.

Example 35 may include the apparatus of example 32 and/or some other examples herein, wherein the resource pool for PSDCH or PSCCH is configured to satisfy conditions $\text{endPRB} - \text{startPRB} \leq \text{BW_RB}$ and $2 \cdot \text{numPRB} \leq (\text{number of BD}) \cdot (\text{number of PRBs per transport block})$, wherein startPRB is a starting resource block index, endPRB is an ending resource block index, numPRB is a number of PRBs, BW_RB is a cell bandwidth expressed in number of resource blocks, and number of BD is a number of blind decoding of PRBs performed by the UE.

Example 36 may include the apparatus of example 32 and/or some other examples herein, wherein the resource pool indicates a maximum number of PRBs to be used for transmission of a discovery announcement message.

Example 37 may include the apparatus of example 36 and/or some other examples herein, wherein the maximum number of PRBs is used for performing blind decoding.

Example 38 may include the apparatus of example 32 and/or some other examples herein, wherein the sidelink (SL) communication between the UE and the one or more other UEs is through a D2D communication interface PC5, the UE communicates with an eNB through a radio interface Uu, and the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN).

Example 39 may include an apparatus for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

means for transmitting a discovery message in a transmission resource with a first index in a physical sidelink discovery channel (PSDCH) in a first discovery period;

means for determining a reception space on the PSDCH with a second index in a second discovery period next to the first discovery period, wherein the second index is determined based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence on a third channel; and

means for processing the determined reception space to obtain a discovery response.

Example 40 may include the apparatus of example 39 and/or some other examples herein, wherein the means for transmitting the discovery message comprises a remote UE or a relay UE for sending an announcement message, or a remote UE for sending a solicitation message.

Example 41 may include the apparatus of example 39 and/or some other examples herein, wherein the second index is related to the first index by a one-to-one rule in which the first and second indices correspond to same time-frequency resources in the respective first and second discovery periods.

Example 42 may include the apparatus of example 41 and/or some other examples herein, wherein the one-to-one rule is based on a UE identity including one of a Radio Network Temporary Identity (RNTI) or an L1/L2 ProSe Group ID.

Example 43 may include the apparatus of example 39 and/or some other examples herein, further comprising:

means for transmitting a Sidelink Buffer Status Report (SL-BSR) and a target ProSe Group identifier (ID) to an eNB, wherein the eNB is to determine the reception space on the PSDCH.

Example 44 may include the apparatus of example 39 and/or some other examples herein, wherein the second index is related to the first index by a one-to-many rule in

which the first index corresponds to a plurality of indices in the second discovery period, the plurality of indices to include the second index.

Example 45 may include the apparatus of example 44 and/or some other examples herein, wherein the second index is randomly selected from the plurality of indices

5 determined by the one-to-many rule.

Example 46 may include the apparatus of example 39 and/or some other examples herein, wherein the second index is determined based on the sequence, and the apparatus further comprising:

means for detecting the sequence on the third channel, wherein the third channel is
10 different from the PSDCH and the sidelink synchronization signal; and

means for associating the sequence with the transmission resource on the PSDCH and the reception spaces on the PSDCH.

Example 47 may include the apparatus of example 39 and/or some other examples herein, wherein the second index is based on the SLSS identity and the SLSS identity is to
15 indicate the transmission resource on the PSDCH and the reception space on the PSDCH.

Example 48 may include the apparatus of example 40 and/or some other examples herein, wherein the relay UE communicates with the remote UE through a D2D communication interface PC5, the relay UE communicates with an eNB through a radio interface Uu, and the relay UE is attached to an Evolved Universal Terrestrial Access
20 Network (E-UTRAN).

Example 49 may include an apparatus for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

means for processing a discovery message transmitted in a physical sidelink
25 discovery channel (PSDCH);

means for processing radio resource control (RRC) signaling received from an evolved node B (eNB); and

means for processing a control message transmitted in a physical sidelink control channel (PSCCH), wherein the PSCCH is configured based on a resource configuration
30 message for PSCCH channel received through the RRC signaling from the eNB, or the discovery message in the PSDCH.

Example 50 may include the apparatus of example 49 and/or some other examples herein, further comprising means for configuring the PSSCH based on the resource configuration message, wherein the resource configuration message comprises information

related to an exact PSCCH resource index, a range of PSCCH resource indexes, a random seed to generate the PSCCH resource index, or a frequency sub-band to be monitored.

Example 51 may include the apparatus of example 49 and/or some other examples herein, further comprising means for configuring the PSSCH based on the resource
5 configuration message, wherein the resource configuration message is multiplexed with a discovery channel payload (SL-DCH) using a MAC control element (CE) in the PSDCH.

Example 52 may include the apparatus of example 49 and/or some other examples herein, further comprising means for configuring the PSSCH based on the resource
10 configuration message, wherein the resource configuration message is associated with an UE identity acquired from the SL-DCH.

Example 53 may include the apparatus of example 49 and/or some other examples herein, wherein the resource configuration message is configured by the eNB based on a group identification of the UE and one or more other UEs.

15 Example 54 may include the apparatus of example 49 and/or some other examples herein, wherein the eNB communicates with the UE through a radio interface Uu, the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN), and the UE communicates with one or more other UEs through a D2D communication interface PC5.

Example 55 may include an apparatus for device-to-device (D2D) communication
20 between a UE and one or more other UEs in a mobile communication network, comprising:

means for receiving by the UE, information about a time resource pattern for transmission (T-RPT) bitmap;

means for identifying, based on the T-RPT bitmap, a pattern of one or more
25 subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a sidelink control (SC) period; and

means for restricting blind decoding attempts to the one or more subframes.

Example 56 may include the apparatus of example 55 and/or some other examples herein, wherein the one or more subframes are indicated by an explicit indication of a
30 number of protocol data units (PDUs), a number of transmission time intervals (TTIs) per PDU, or a transmission start time within the T-RPT bitmap.

Example 57 may include the apparatus of example 55 and/or some other examples herein, wherein the one or more subframes are indicated by a short bitmap to indicate

subframes actually used for transmission to the UE, wherein the T-RPT bitmap is a number of repetitions of the short bitmap.

Example 58 may include the apparatus of example 57 and/or some other examples herein, wherein any '1' in the short bitmap indicates activated TRP repetition, and any '0' in the short bitmap indicates deactivated TRP repetition.

Example 59 may include the apparatus of example 55 and/or some other examples herein, wherein the one or more subframes are indicated by an end of data transmission in the SC period.

Example 60 may include the apparatus of example 55 and/or some other examples herein, wherein the one or more subframes are indicated by a combinatorial index.

Example 61 may include the apparatus of example 55 and/or some other examples herein, wherein the UE communicates with an eNB through a radio interface Uu, the UE communicates with one or more other UEs through a D2D communication interface PC5, and the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN).

Example 62 may include a method for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

receiving information about a set of available resources for sidelink (SL) communication between the UE and the one or more other UEs; and

determining a resource pool from the set of available resources for SL communication, wherein the resource pool comprises a collection of subframes to carry control information in a physical sidelink control channel (PSCCH) or discovery information in a physical sidelink discovery channel (PSDCH), each subframe in the collection of subframes has a first number physical resource blocks (PRBs) for SL communication, and the first number PRBs is smaller than a second number PRBs used to transmit public safety information.

Example 63 may include the method of example 62 and/or some other examples herein, wherein the first number of PRBs has a first gap separating a first set of PRBs from a second set of PRBs within the subframe, the second number of PRBs for SL communication within each subframe has a second gap between a first sequence of consecutive PRBs for SL communication and a second sequence of consecutive PRBs for SL communication, and the second gap is smaller than the first gap.

Example 64 may include the method of example 62 and/or some other examples herein, wherein the resource pool for PSDCH or PSCCH is configured to satisfy

conditions $\text{endPRB} - \text{startPRB} \leq \text{BW_RB}$ and $2 \cdot \text{numPRB} \leq (\text{number of BD}) \cdot (\text{number of PRBs per transport block})$, wherein startPRB is a starting resource block index, endPRB is an ending resource block index, numPRB is a number of PRBs, BW_RB is a cell bandwidth expressed in number of resource blocks, and number of BD is a number of

5 blind decoding of PRBs performed by the UE.

Example 65 may include a method for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

10 transmitting a discovery message in a transmission resource with a first index in a physical sidelink discovery channel (PSDCH) in a first discovery period;

determining a reception space on the PSDCH with a second index in a second discovery period next to the first discovery period, wherein the second index is determined based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence on a third channel; and

15 processing the determined reception space to obtain a discovery response.

Example 66 may include the method of example 65 and/or some other examples herein, further comprising:

20 transmitting a Sidelink Buffer Status Report (SL-BSR) and a target ProSe Group identifier (ID) to an eNB, wherein the eNB is to determine the reception space on the PSDCH.

Example 67 may include the method of example 65 and/or some other examples herein, wherein the second index is determined based on the sequence, and the apparatus further comprising:

25 detecting the sequence on the third channel, wherein the third channel is different from the PSDCH and the sidelink synchronization signal; and

associating the sequence with the transmission resource on the PSDCH and the reception spaces on the PSDCH.

30 Example 68 may include a method for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

processing a discovery message transmitted in a physical sidelink discovery channel (PSDCH);

processing radio resource control (RRC) signaling received from an evolved node B (eNB); and

processing a control message transmitted in a physical sidelink control channel (PSCCH), wherein the PSCCH is configured based on a resource configuration message for PSCCH channel received through the RRC signaling from the eNB, or the discovery message in the PSDCH.

5 Example 69 may include the method of example 68 and/or some other examples herein, further comprising:

 configuring the PSSCH based on the resource configuration message, wherein the resource configuration message comprises information related to an exact PSCCH resource index, a range of PSCCH resource indexes, a random seed to generate the
10 PSCCH resource index, or a frequency sub-band to be monitored.

 Example 70 may include the method of example 68 and/or some other examples herein, further comprising:

 configuring the PSSCH based on the resource configuration message, wherein and the resource configuration message is multiplexed with a discovery channel payload (SL-
15 DCH) using a MAC control element (CE) in the PSDCH.

 Example 71 may include a method for device-to-device (D2D) communication between a UE and one or more other UEs in a mobile communication network, comprising:

 receiving by the UE, information about a time resource pattern for transmission (T-
20 RPT) bitmap;

 identifying, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a sidelink control (SC) period; and

 restricting blind decoding attempts to the one or more subframes.

25 Example 72 may include the method of example 71 and/or some other examples herein, wherein the one or more subframes are indicated by an explicit indication of a number of protocol data units (PDUs), a number of transmission time intervals (TTIs) per PDU, or a transmission start time within the T-RPT bitmap.

 Example 73 may include the method of example 71 and/or some other examples
30 herein, wherein the one or more subframes are indicated by a short bitmap to indicate subframes actually used for transmission to the UE, wherein the T-RPT bitmap is a number of repetitions of the short bitmap.

 The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments

to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

CLAIMS

What is claimed is:

1. An apparatus in a user equipment (UE) for device-to-device (D2D)
 5 communication between the UE and one or more other UEs in a mobile communication network, comprising:

interface control circuitry, the interface control circuitry to:

receive information about a set of available resources for sidelink (SL)
 communication between the UE and the one or more other UEs; and

10 device to device (D2D) circuitry coupled with the interface control circuitry to:

determine a resource pool from the set of available resources for SL
 communication, wherein the resource pool comprises a collection of subframes to carry
 control information in a physical sidelink control channel (PSCCH) or discovery
 information in a physical sidelink discovery channel (PSDCH), each subframe in the
 15 collection of subframes has a first number physical resource blocks (PRBs) for SL
 communication, and the first number PRBs is smaller than a second number PRBs used to
 transmit public safety information.

2. The apparatus of claim 1, wherein the resource pool is determined by an evolved
 20 node B (eNB) from the set of available resources.

3. The apparatus of claim 1, wherein the first number of PRBs has a first gap
 separating a first set of PRBs from a second set of PRBs within the subframe, the second
 number of PRBs for SL communication within each subframe has a second gap between a
 25 first sequence of consecutive PRBs for SL communication and a second sequence of
 consecutive PRBs for SL communication, and the second gap is smaller than the first gap.

4. The apparatus of claim 1, wherein the second number of PRBs within each
 subframe is less than or equal to 6.

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5. The apparatus of claim 1, wherein the resource pool for PSDCH or PSCCH is
 configured to satisfy conditions $\text{endPRB} - \text{startPRB} \leq \text{BW_RB}$ and $2 \cdot \text{numPRB} \leq (\text{number of BD}) \cdot (\text{number of PRBs per transport block})$, wherein startPRB is a starting resource
 block index, endPRB is an ending resource block index, numPRB is a number of PRBs,

BW_RB is a cell bandwidth expressed in number of resource blocks, and number of BD is a number of blind decoding of PRBs performed by the UE.

6. The apparatus of claim 2, wherein the sidelink (SL) communication between the
5 UE and the one or more other UEs is through a D2D communication interface PC5, the eNB communicates with the UE through a radio interface Uu, and the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN).

7. An apparatus in a user equipment (UE) for device-to-device (D2D)
10 communication between the UE and one or more other UEs in a mobile communication network, comprising:

interface control circuitry, the interface control circuitry to:

transmit a discovery message in a transmission resource with a first index
in a physical sidelink discovery channel (PSDCH) in a first discovery period; and

15 device to device (D2D) circuitry coupled with the interface control circuitry to:

determine a reception space on the PSDCH with a second index in a second
discovery period next to the first discovery period, wherein the second index is determined
based on the first index, a sidelink synchronization signal (SLSS) identity, or a sequence
on a third channel; and

20 process the determined reception space to obtain a discovery response.

8. The apparatus of claim 7, wherein the discovery message is an announcement
message sent by a remote UE or a relay UE, or a solicitation message sent by a remote
UE.

25

9. The apparatus of claim 7, wherein the second index is related to the first index
by a one-to-one rule in which the first and second indices correspond to same time-
frequency resources in the respective first and second discovery periods.

30 10. The apparatus of claim 7, wherein the second index is related to the first index
by a one-to-many rule in which the first index corresponds to a plurality of indices in the
second discovery period, the plurality of indices to include the second index.

11. The apparatus of claim 7, wherein the second index is determined based on the sequence and the device to device (D2D) circuitry is further to

detect the sequence on the third channel, wherein the third channel is different from the PSDCH and the sidelink synchronization signal; and

5 link the sequence with the transmission resource on the PSDCH and the reception spaces on the PSDCH.

12. The apparatus of claim 7, wherein the second index is based on the SLSS identity and the SLSS identity is to indicate the transmission resource on the PSDCH and
10 the reception space on the PSDCH.

13. The apparatus of claim 8, wherein the relay UE communicates with the remote UE through a D2D communication interface PC5, the relay UE communicates with an eNB through a radio interface Uu, and the relay UE is attached to an Evolved Universal
15 Terrestrial Access Network (E-UTRAN).

14. One or more computer-readable media comprising instructions to cause a user equipment (UE), upon execution of the instructions by one or more processors of the UE, to:

20 process a discovery message transmitted in a physical sidelink discovery channel (PSDCH);

process radio resource control (RRC) signaling received from an evolved node B (eNB); and

process a control message transmitted in a physical sidelink control channel (PSCCH), wherein the PSCCH is configured based on a resource configuration message
25 for PSCCH channel received through the RRC signaling from the eNB, or the discovery message in the PSDCH.

15. The one or more computer-readable media of claim 14, wherein the PSSCH is
30 configured based on the resource configuration message and the resource configuration message comprises information related to an exact PSCCH resource index, a range of PSCCH resource indexes, a random seed to generate the PSCCH resource index, or a frequency sub-band to be monitored.

16. The one or more computer-readable media of claim 14, wherein the PSSCH is configured based on the resource configuration message and the resource configuration message is multiplexed with a discovery channel payload (SL-DCH) using a MAC control element (CE) in the PSDCH.

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17. The one or more computer-readable media of claim 14, wherein the PSSCH is configured based on the resource configuration message and the resource configuration message is associated with an UE identity acquired from the SL-DCH.

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18. The one or more computer-readable media of claim 14, wherein the resource configuration message is configured by the eNB based on a group identification of the UE and one or more other UEs.

15

19. The one or more computer-readable media of claim 14, wherein the eNB communicates with the UE through a radio interface Uu, the UE is attached to an Evolved Universal Terrestrial Access Network (E-UTRAN), and the UE communicates with one or more other UEs through a D2D communication interface PC5.

20

20. One or more computer-readable media comprising instructions to cause a user equipment (UE), upon execution of the instructions by one or more processors of the UE, to:

receive by the UE, information about a time resource pattern for transmission (T-RPT) bitmap;

25

identify, based on the T-RPT bitmap, a pattern of one or more subframes used for data transmission between the UE and one or more other UEs that is extended until an end of a sidelink control (SC) period; and

restrict blind decoding attempts to the one or more subframes.

30

21. The one or more computer-readable media of claim 20, wherein the one or more subframes are indicated by an explicit indication of a number of protocol data units (PDUs), a number of transmission time intervals (TTIs) per PDU, or a transmission start time within the T-RPT bitmap.

22. The one or more computer-readable media of claim 20, wherein the one or more subframes are indicated by a short bitmap to indicate subframes actually used for transmission to the UE, wherein the T-RPT bitmap is a number of repetitions of the short bitmap.

5

23. The one or more computer-readable media of claim 20, wherein the one or more subframes are indicated by an end of data transmission in the SC period.

24. The one or more computer-readable media of claim 20, wherein the one or
10 more subframes are indicated by a combinatorial index.

25. The one or more computer-readable media of claim 20, wherein the UE
communicates with an eNB through a radio interface Uu, the UE communicates with one
or more other UEs through a D2D communication interface PC5, and the UE is attached to
15 an Evolved Universal Terrestrial Access Network (E-UTRAN).

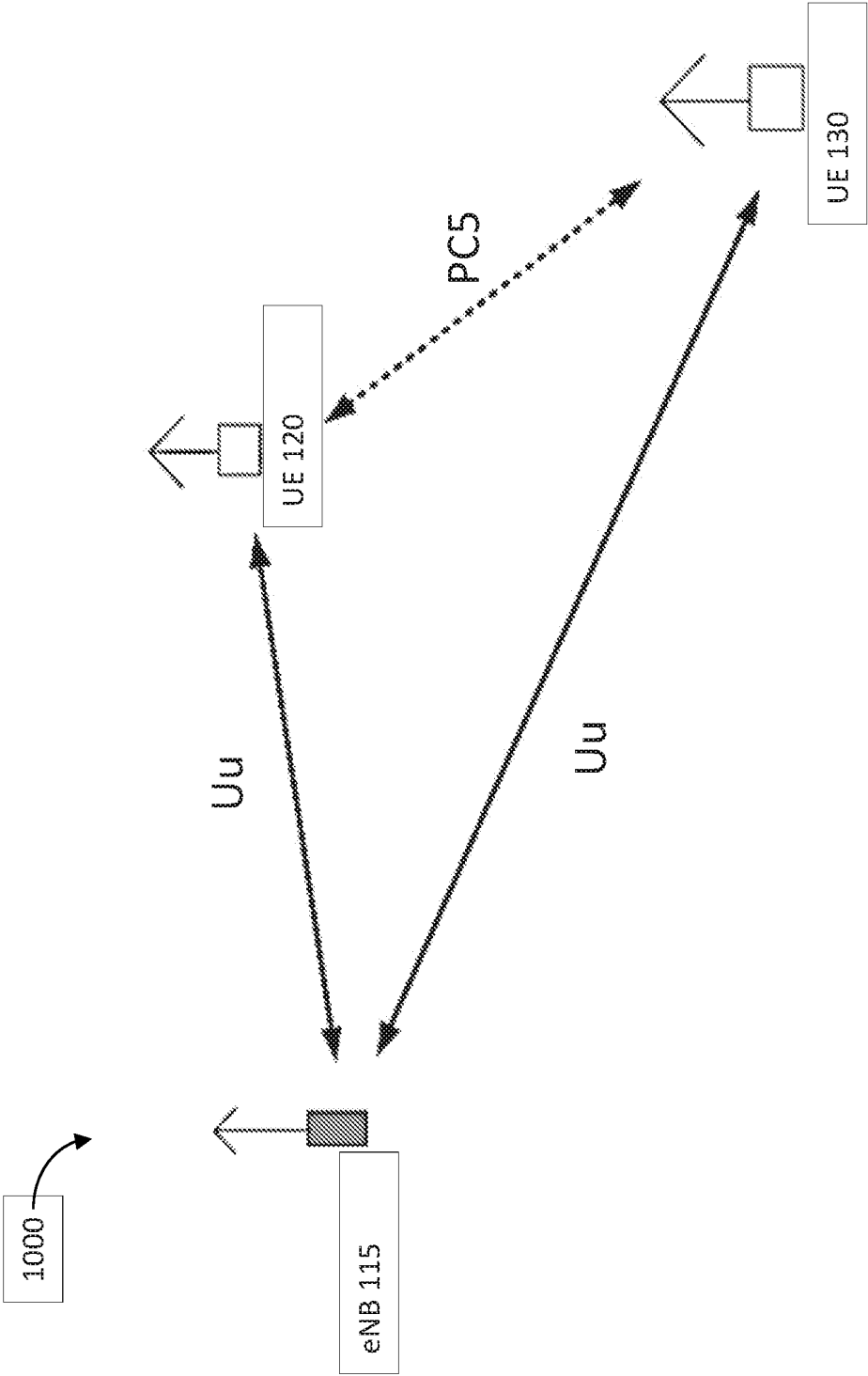


Figure 1

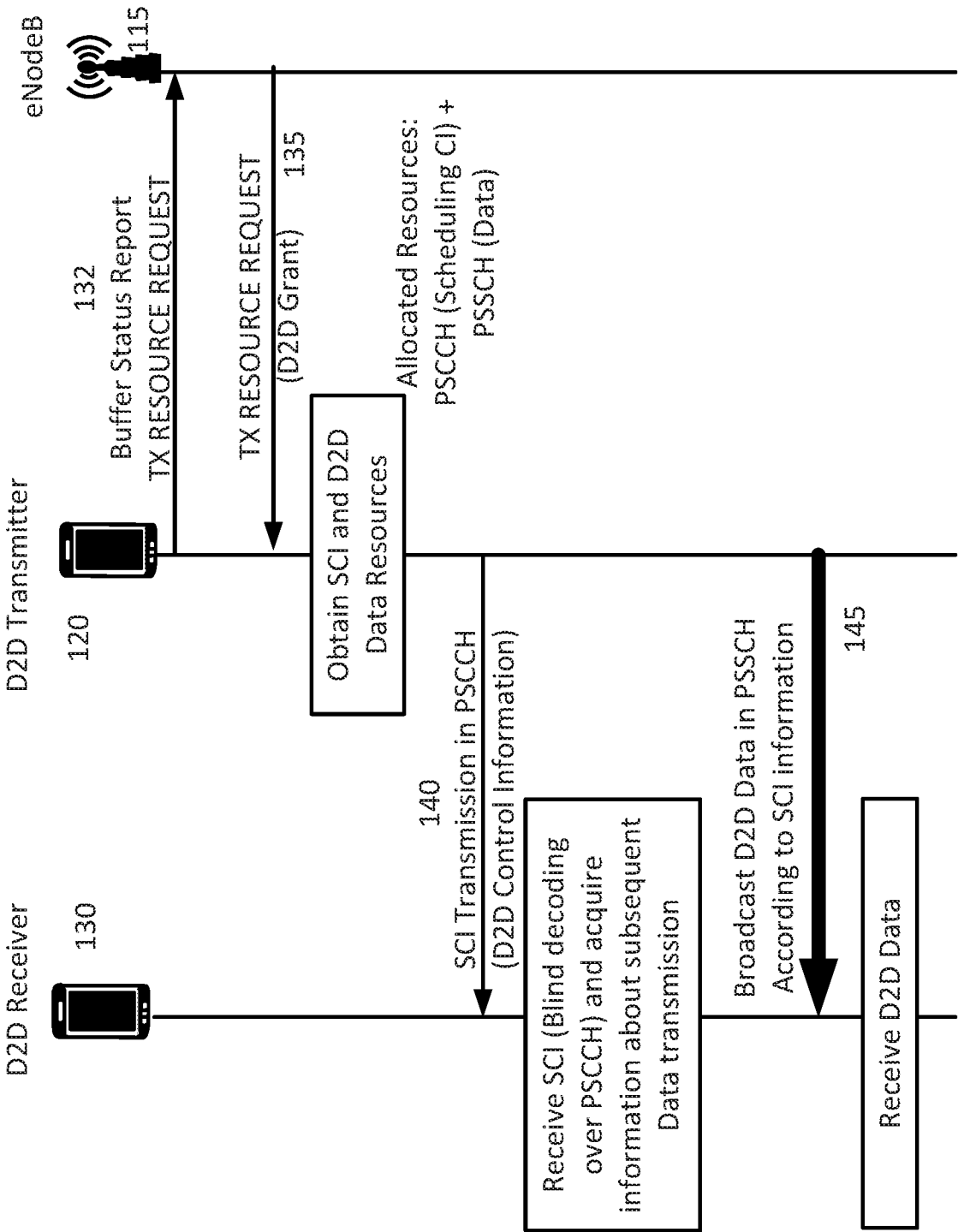


Figure 2

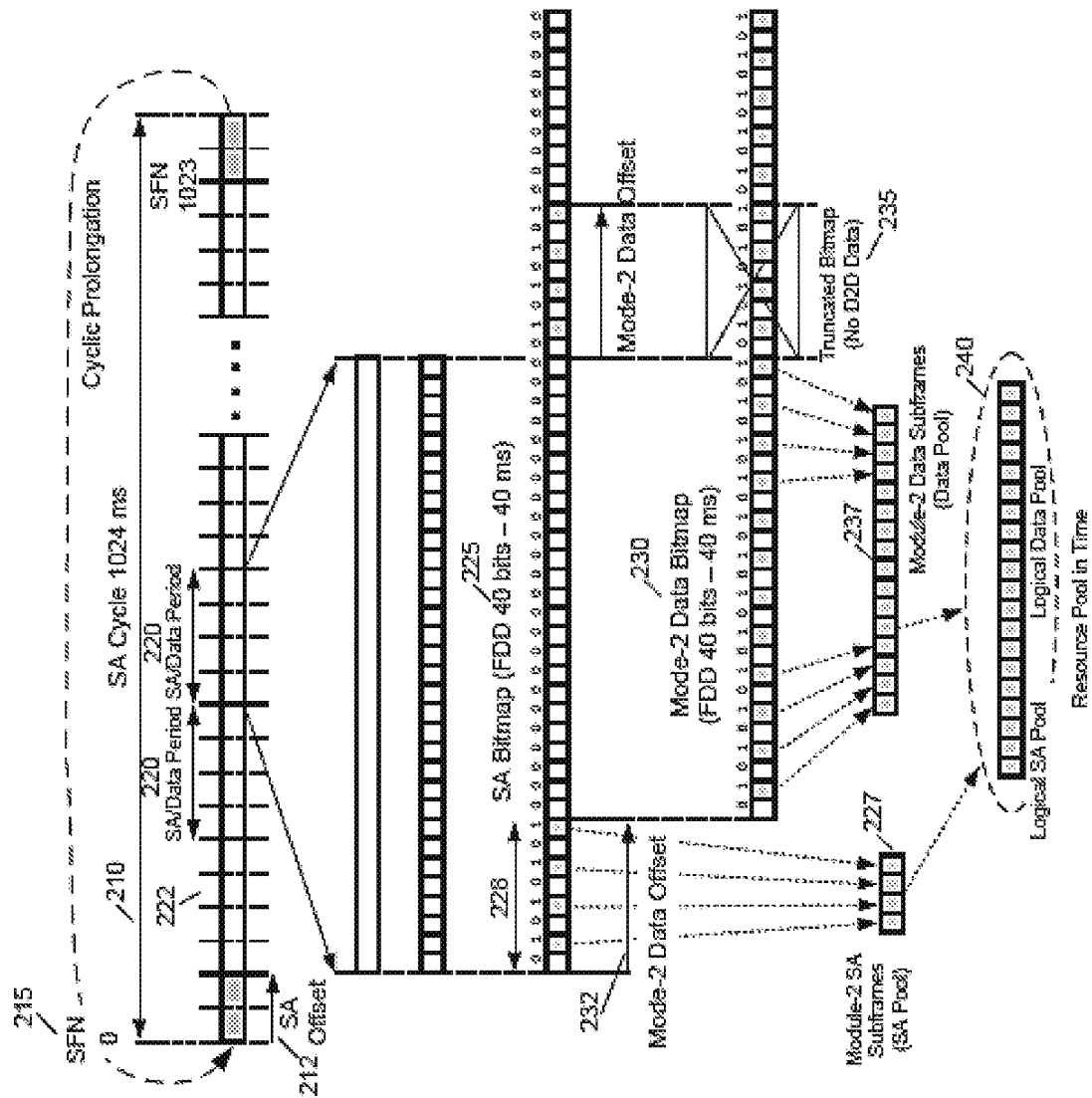


Figure 3

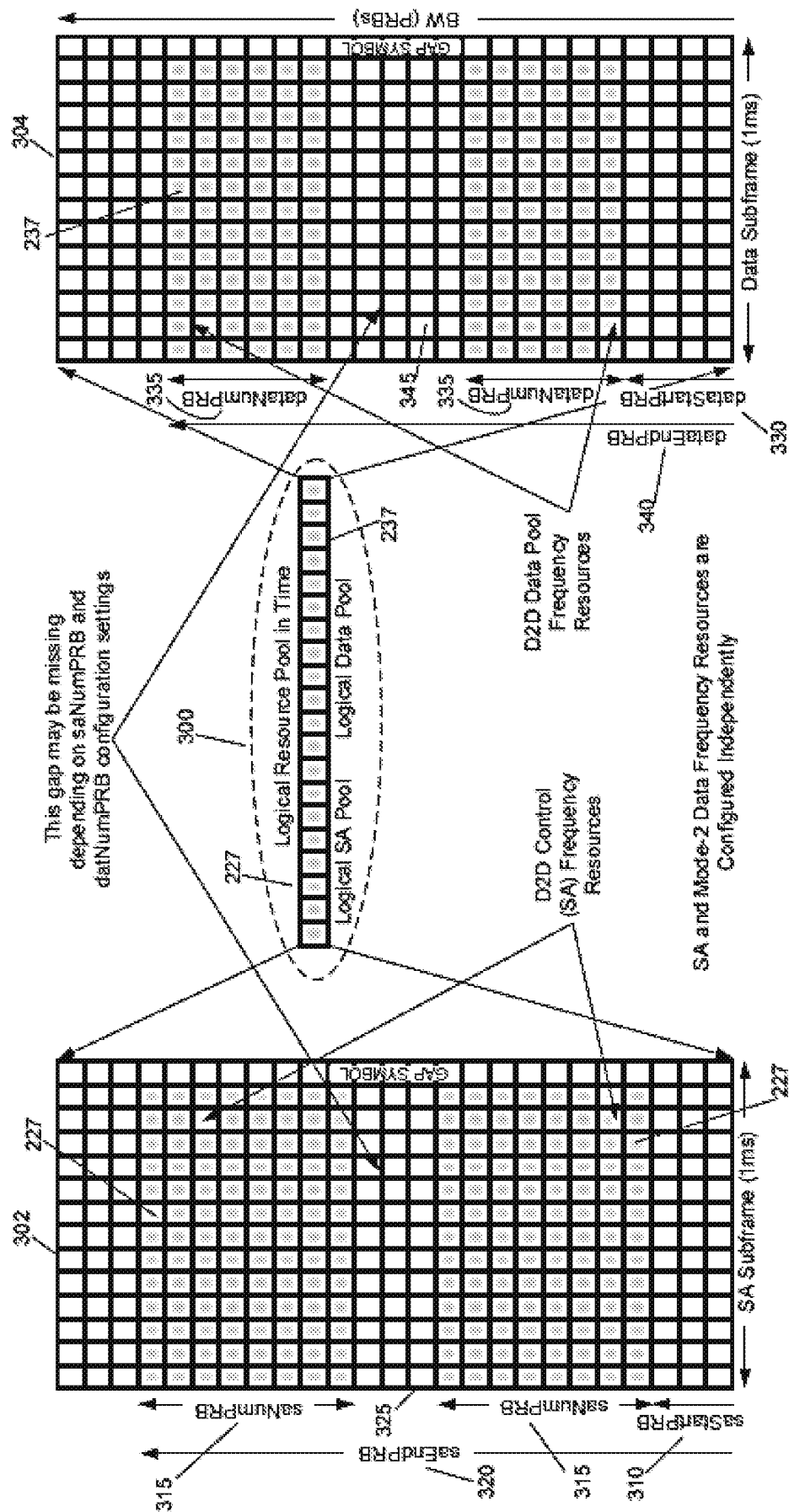


Figure 4

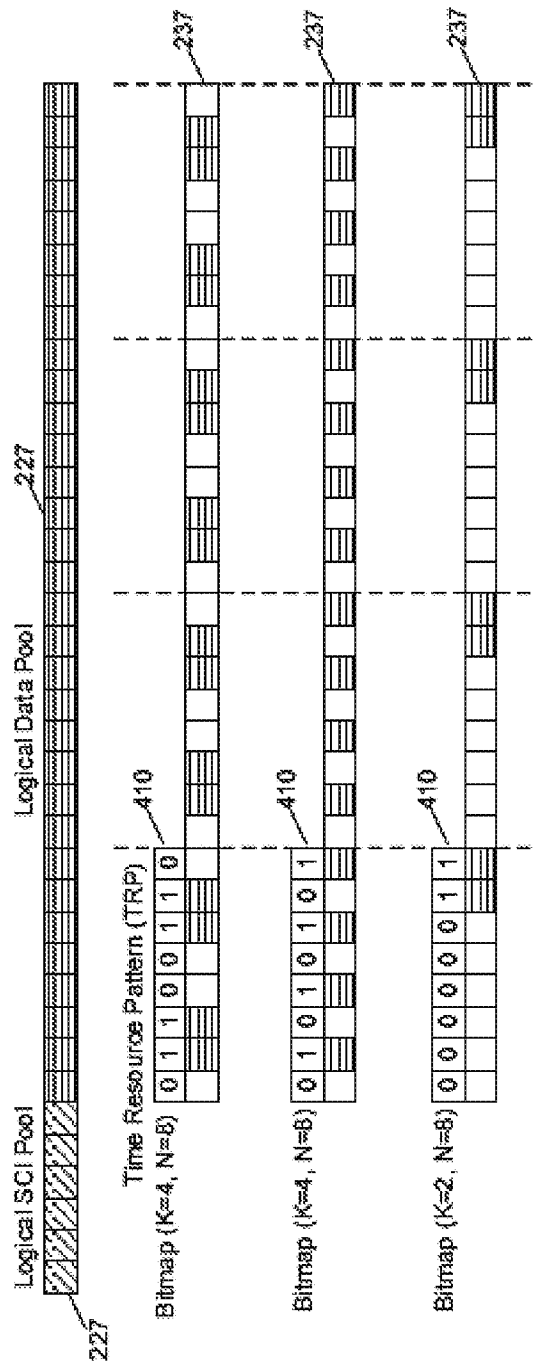


Figure 5

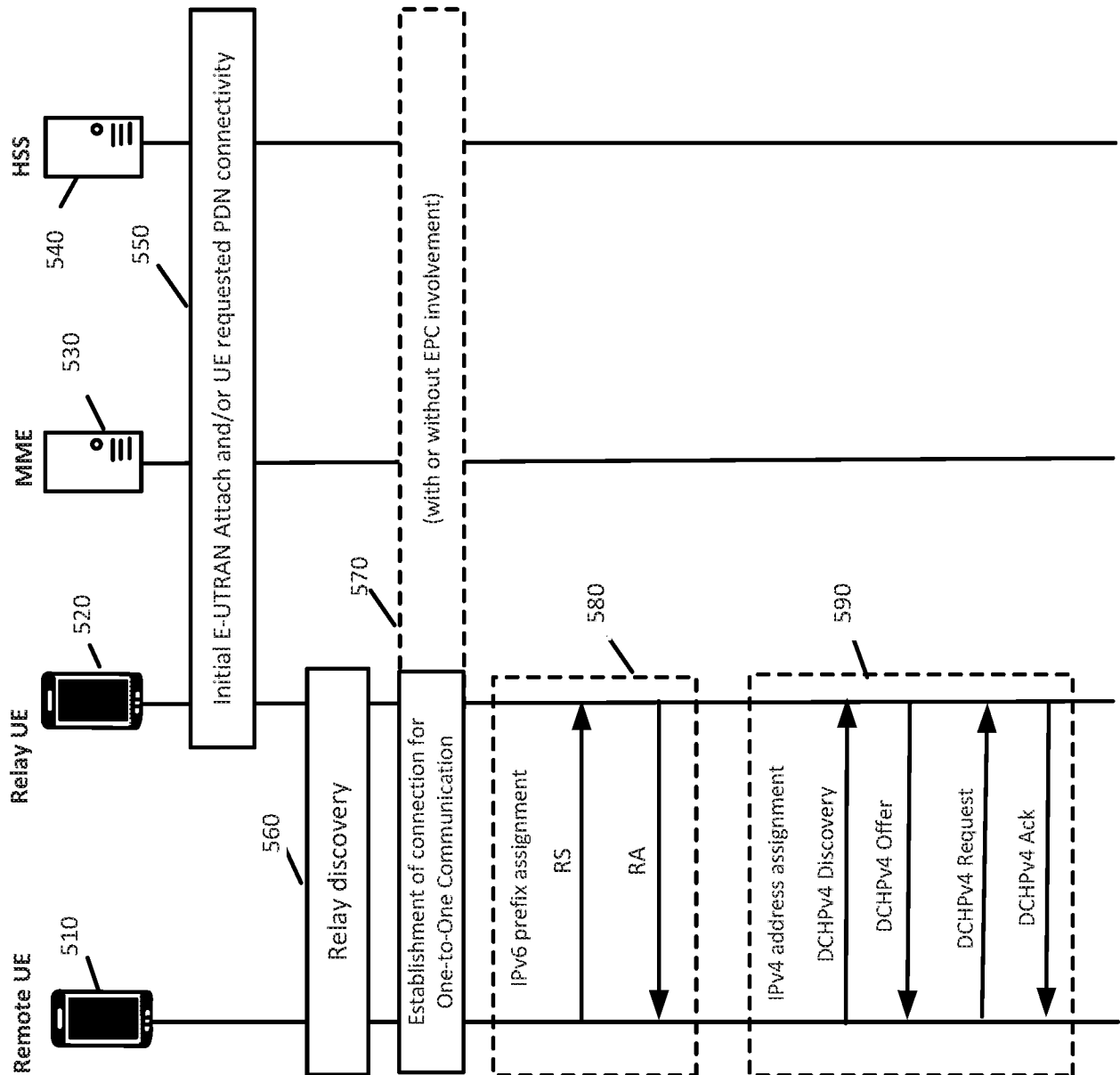


Figure 6

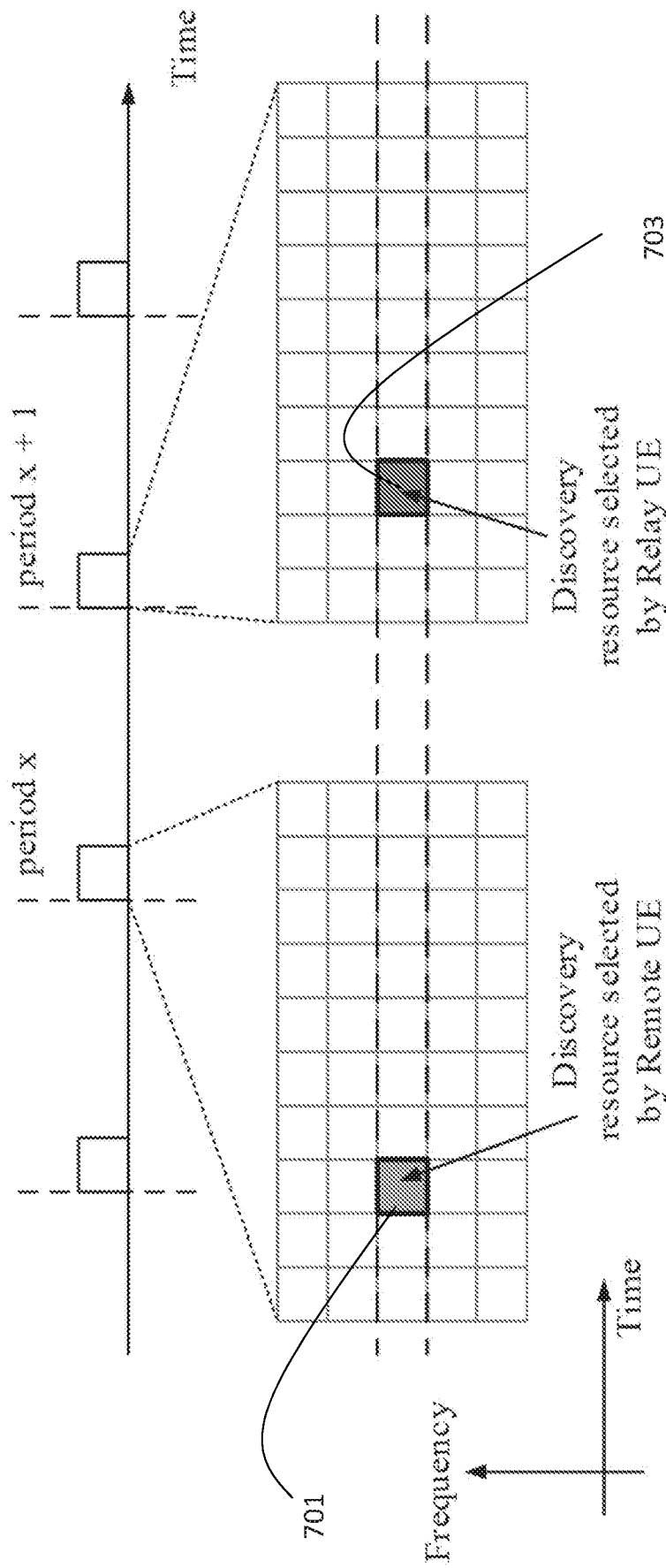


Figure 7

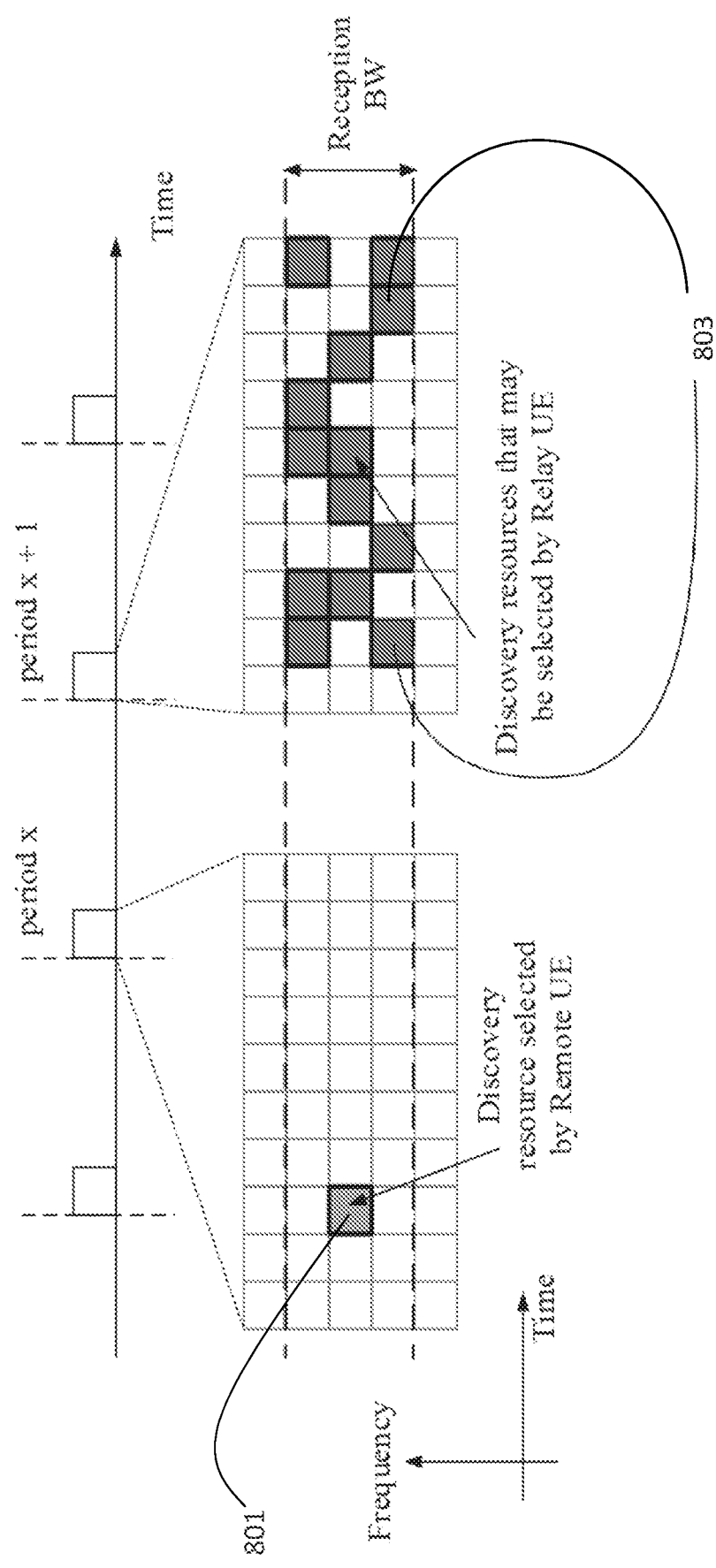


Figure 8

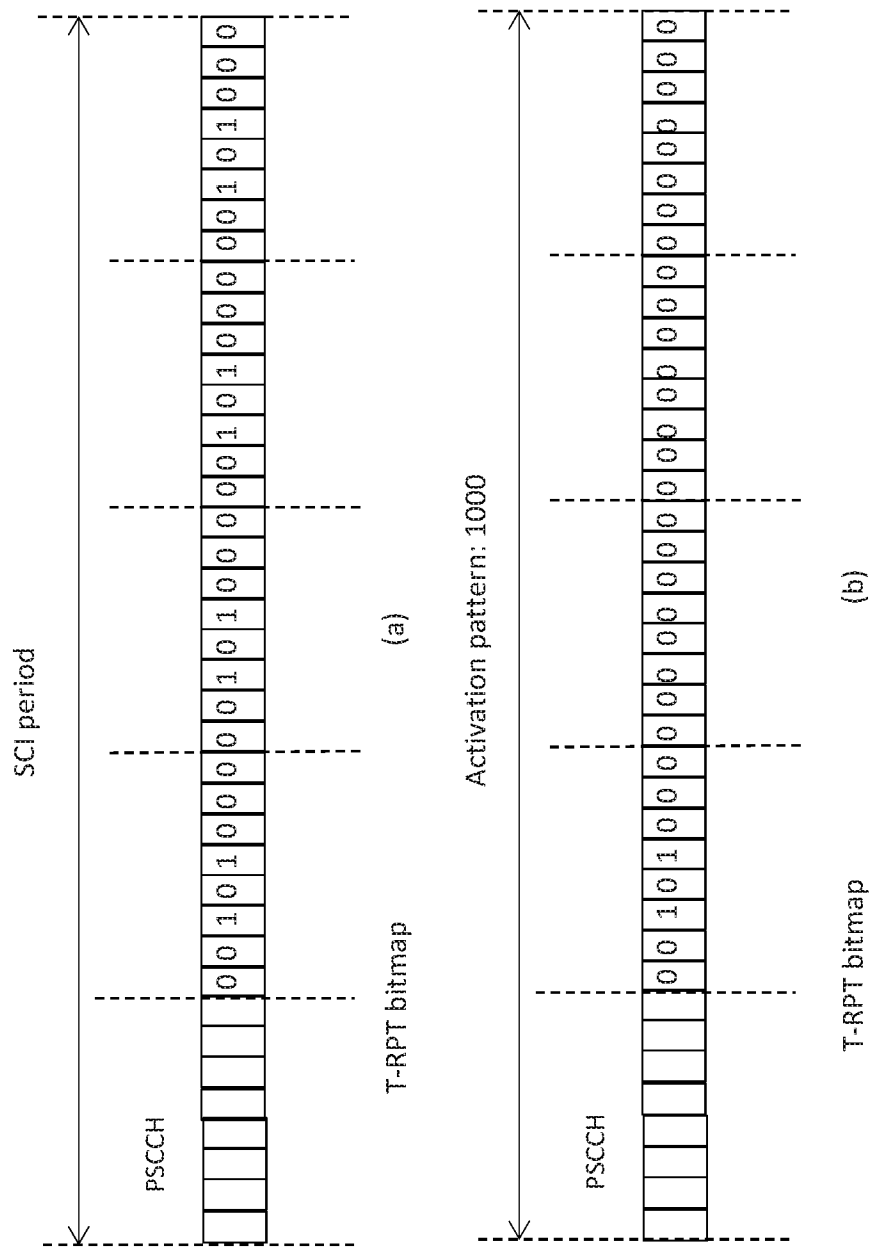


Figure 9

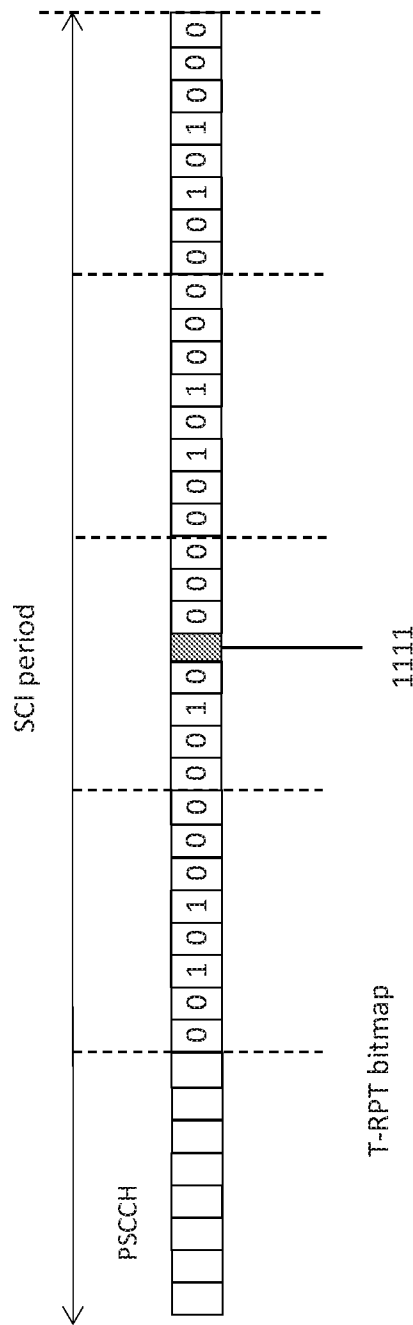


Figure 10

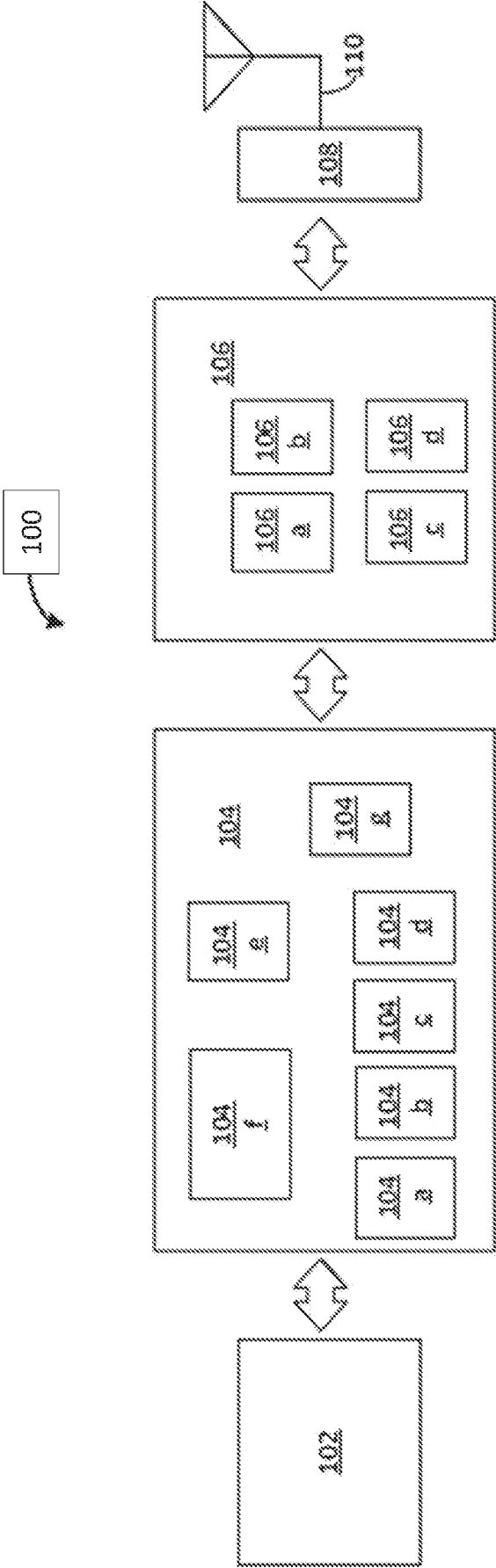


Figure 11

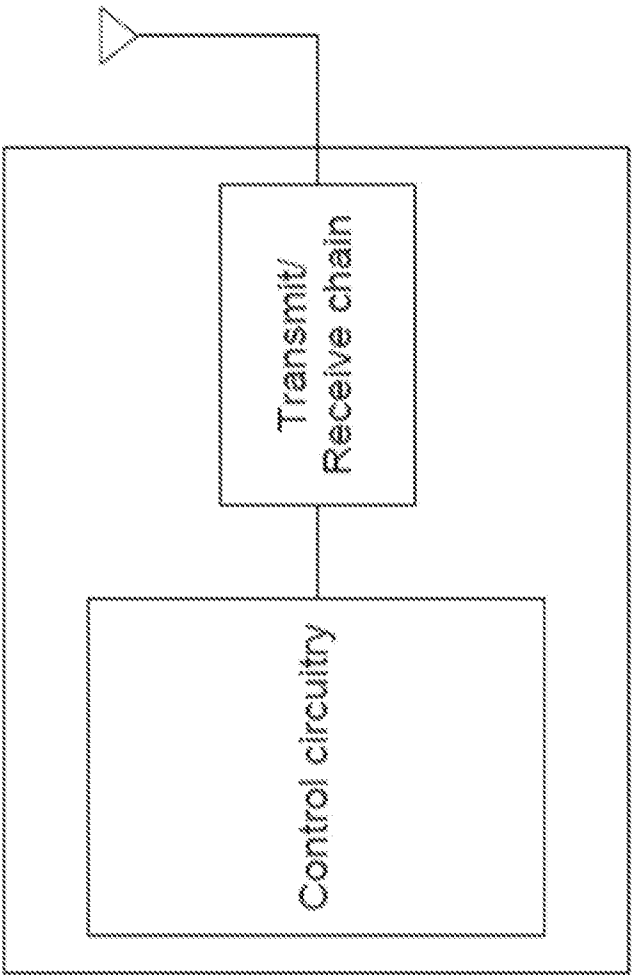


Figure 12

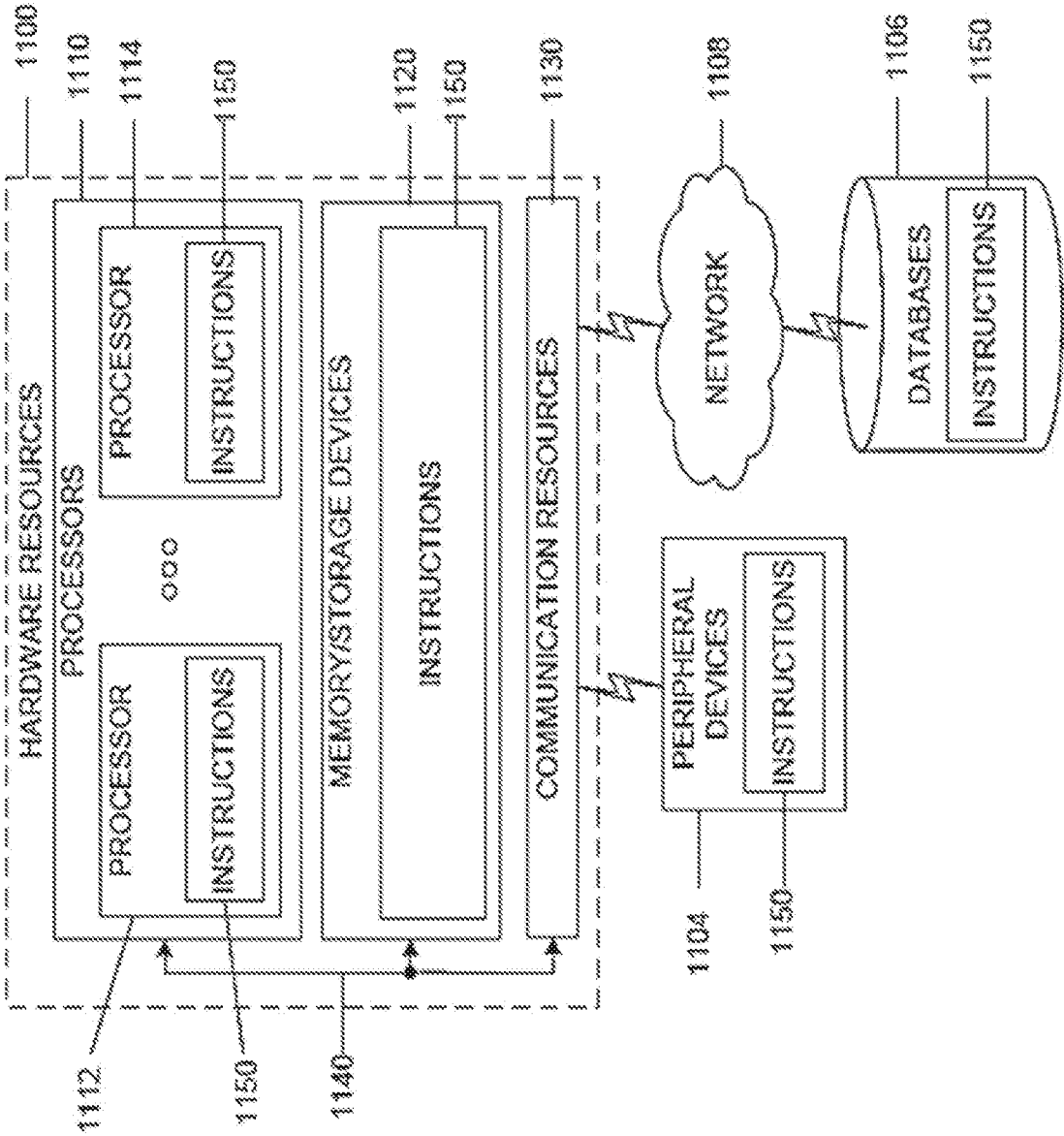


Figure 13

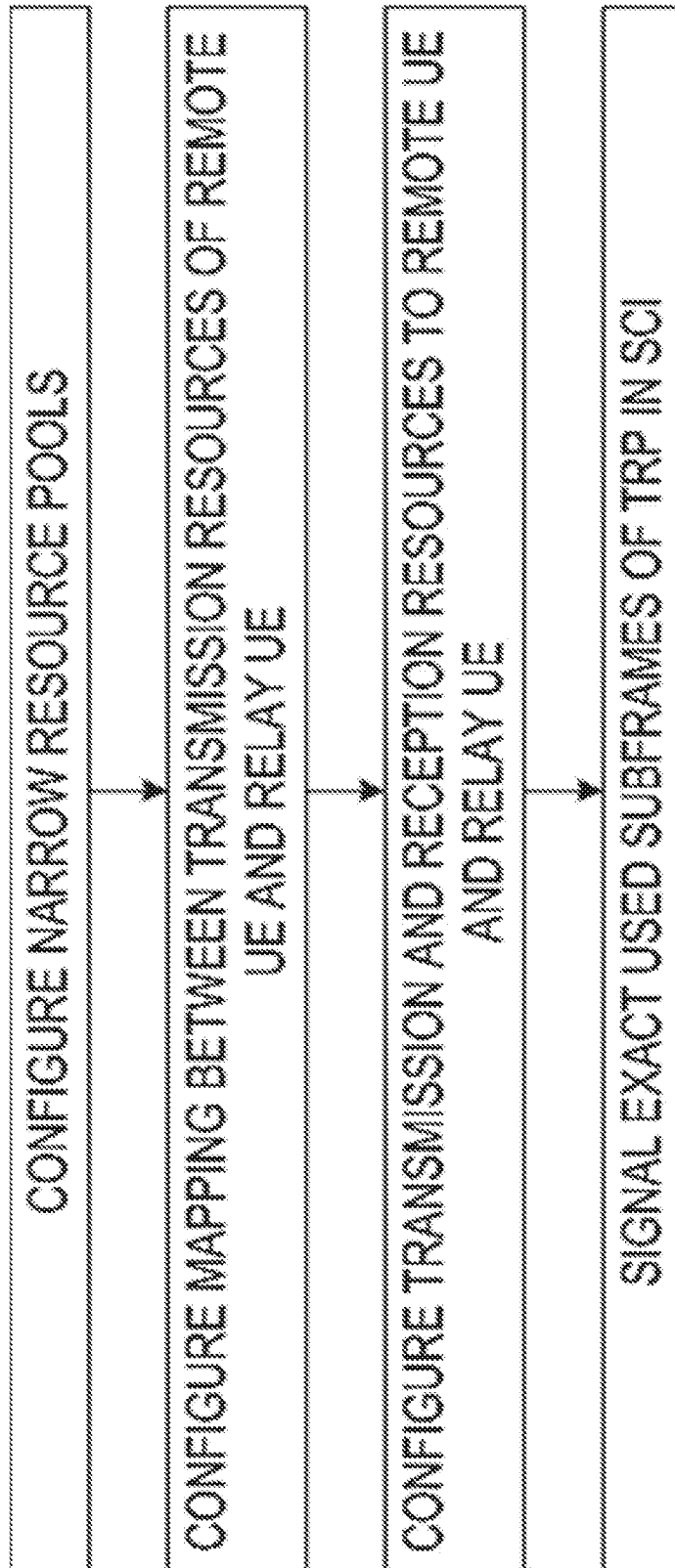


Figure 14

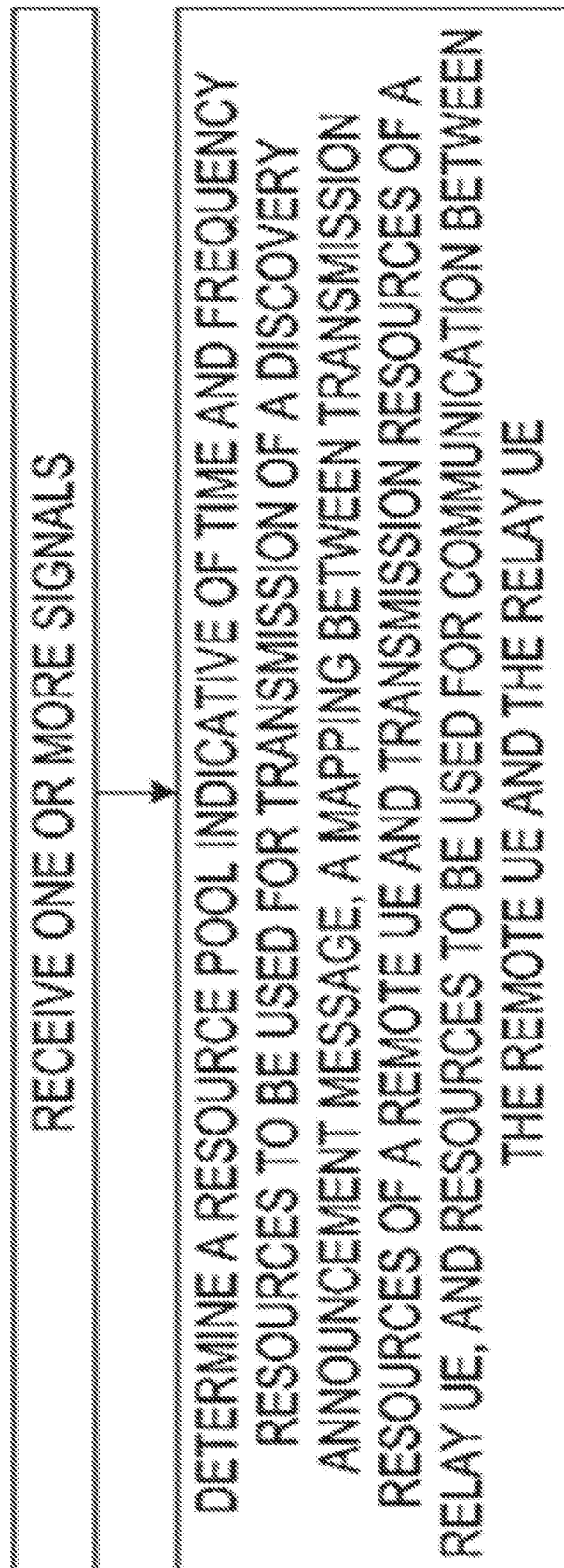


Figure 15

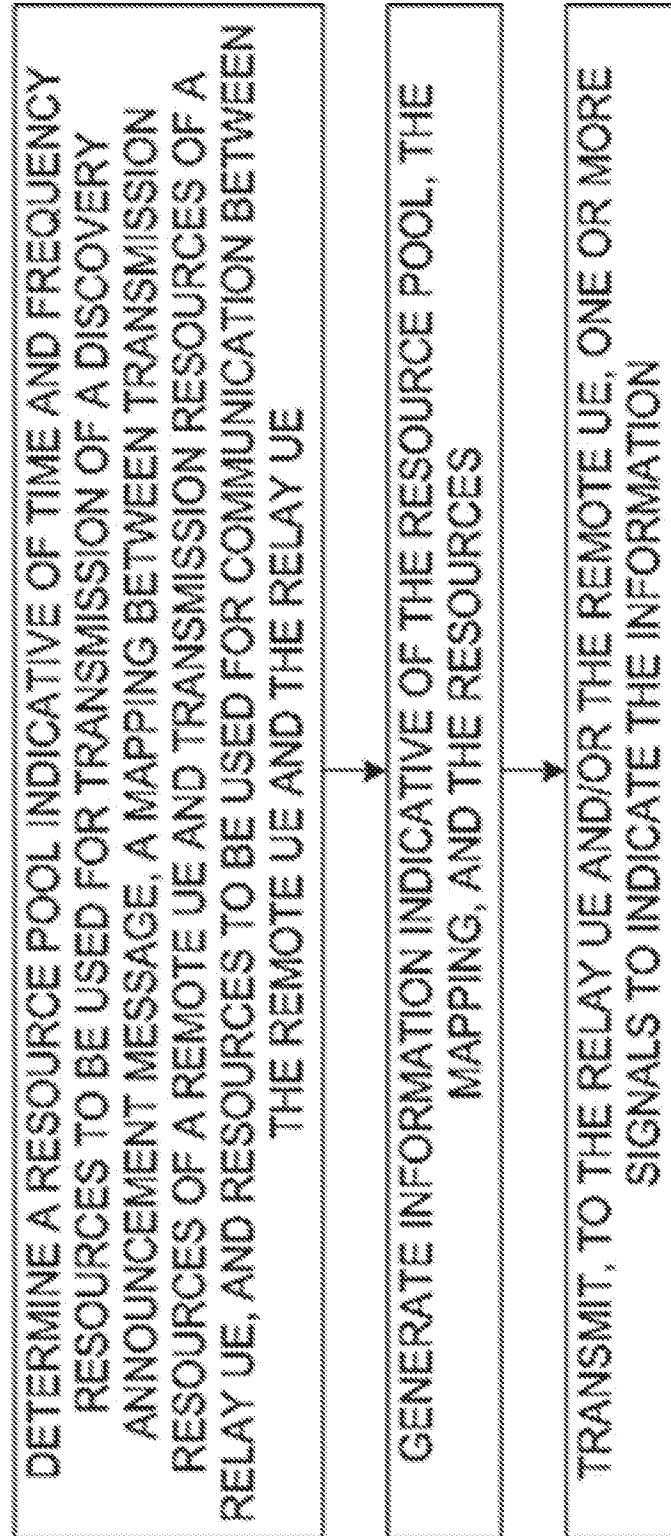


Figure 16

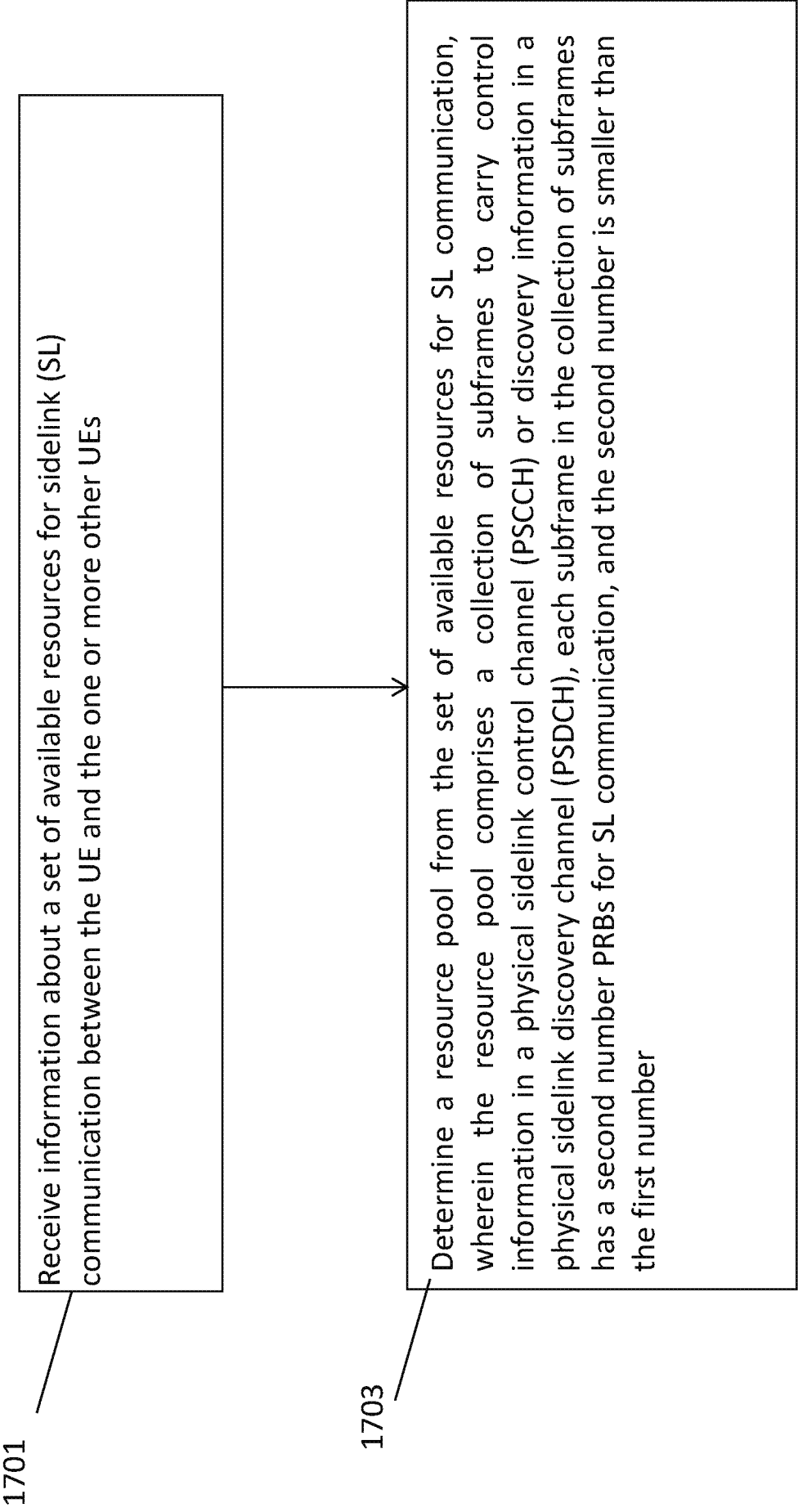


Figure 17

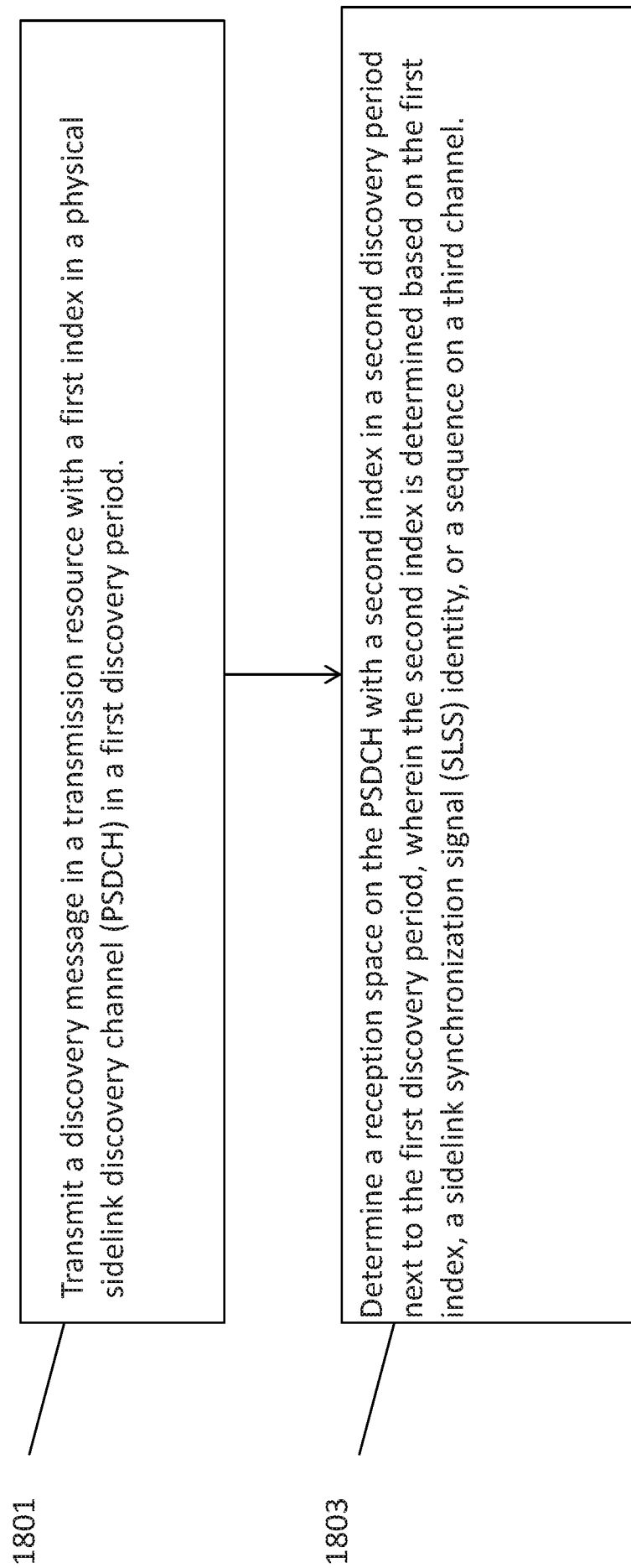


Figure 18

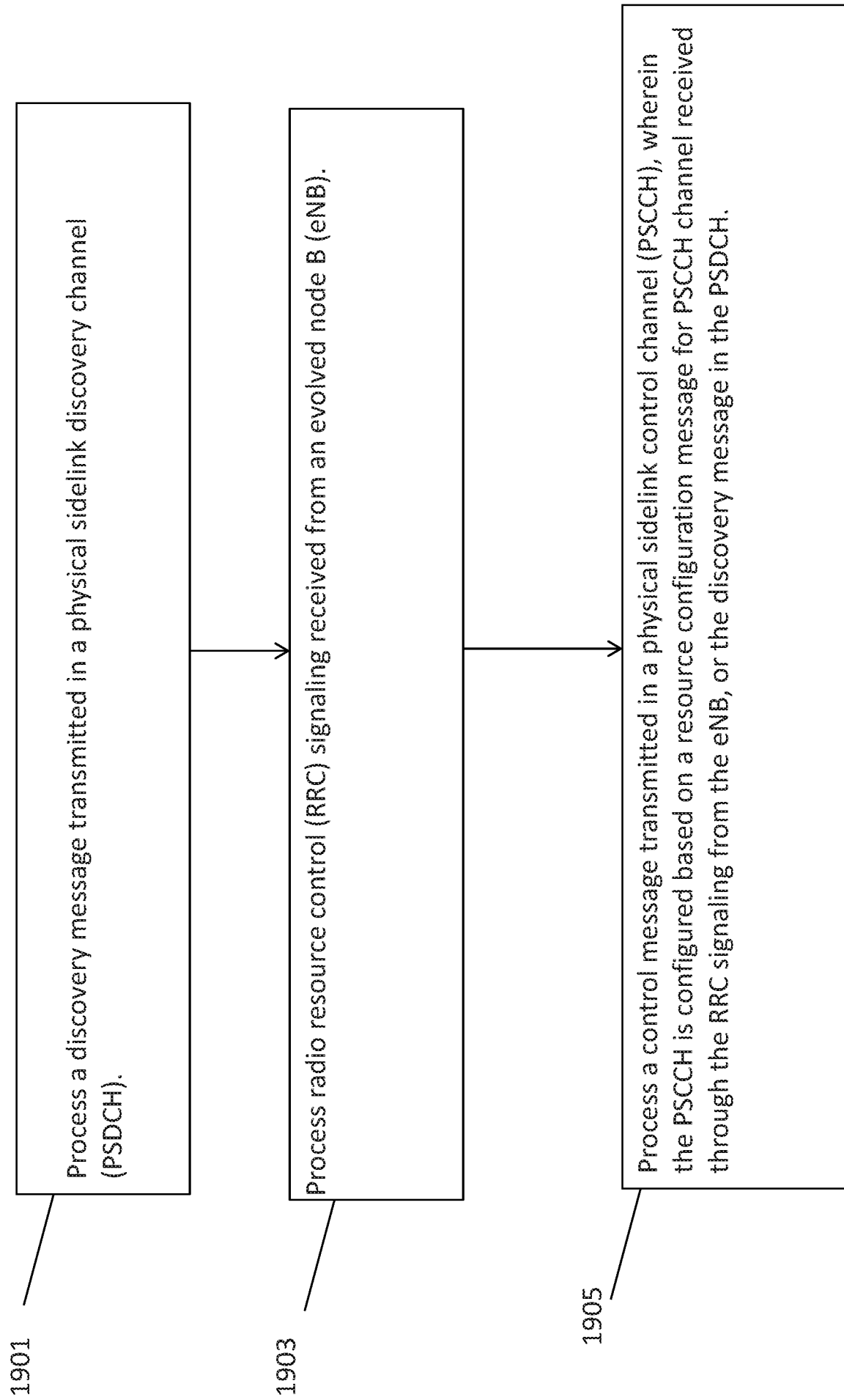


Figure 19

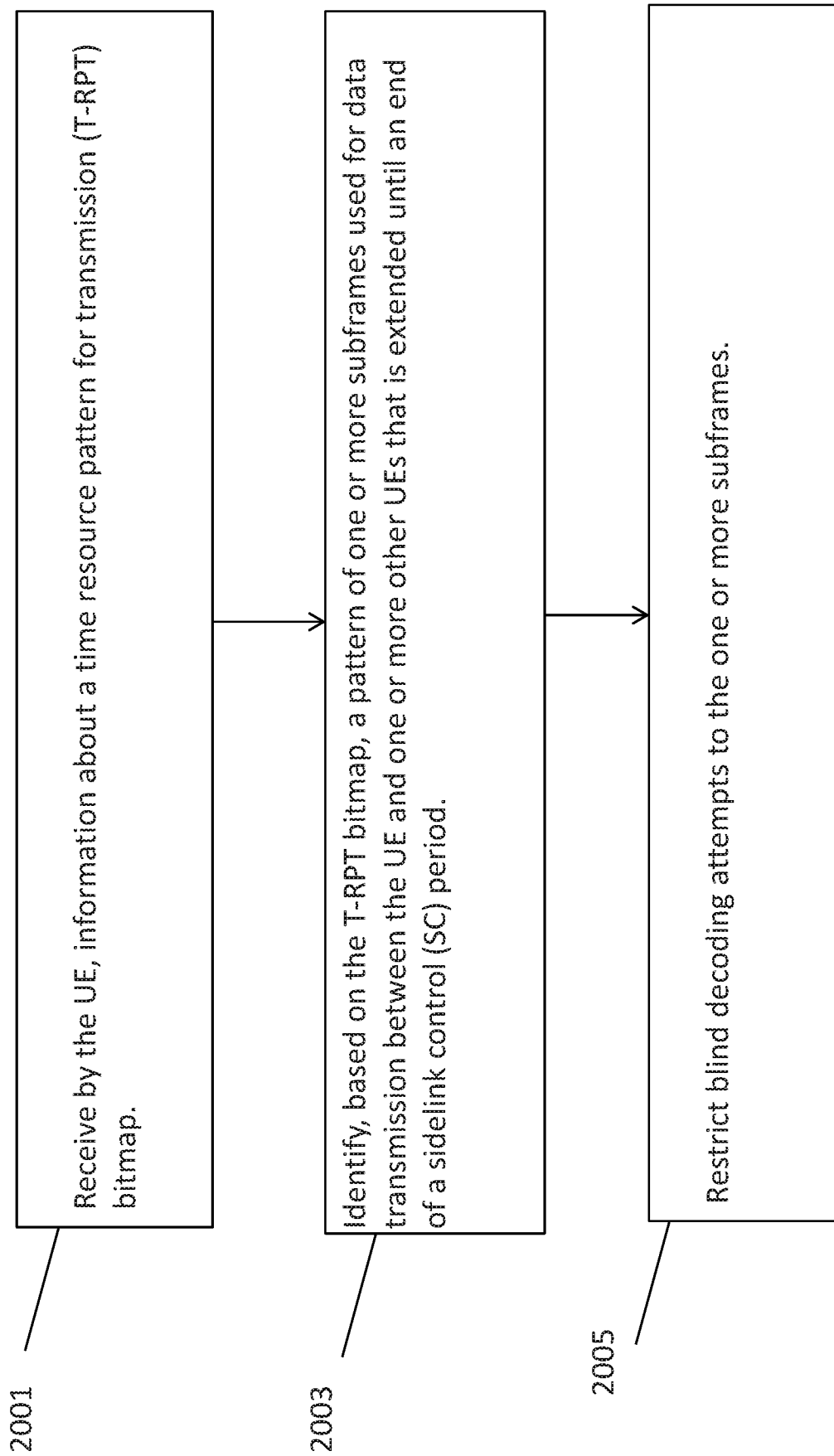


Figure 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/039652

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W72/04

ADD. H04W4/00 H04W8/00

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)

H04W

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/002087 A1 (NTT DOCOMO INC [JP]) 8 January 2015 (2015-01-08) paragraphs [0029], [0038]; figures 6,10,16 & EP 3 018 957 A1 (NTT DOCOMO INC [JP]) 11 May 2016 (2016-05-11) -----	1-6
X	WO 2016/022849 A1 (INTERDIGITAL PATENT HOLDINGS [US]) 11 February 2016 (2016-02-11) columns 1,2 -----	1,2,4-6



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

29 November 2016

Date of mailing of the international search report

16/02/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Palencia Gutiérrez

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/039652

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-6

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-6

Resource pool configuration

2. claims: 7-13

Reception space determination

3. claims: 14-19

Configuration of the PSCCH

4. claims: 20-25

Blind decoding restriction based on time resource pattern

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/039652

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015002087 A1	08-01-2015	EP 3018957 A1	11-05-2016
		JP 2015012590 A	19-01-2015
		US 2016262142 A1	08-09-2016
		WO 2015002087 A1	08-01-2015

WO 2016022849 A1	11-02-2016	NONE	
