



(43) International Publication Date
11 May 2017 (11.05.2017)

(10) International Publication Number
WO 2017/078783 A1

(51) International Patent Classification:
H04W 76/02 (2009.01) *H04W 76/04* (2009.01)
H04W 4/00 (2009.01)

(21) International Application Number:
PCT/US2016/025626

(22) International Filing Date:
1 April 2016 (01.04.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/252,329 6 November 2015 (06.11.2015) US

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

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

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(54) Title: METHODS AND DEVICES FOR COMMUNICATION VIA SIDELINK

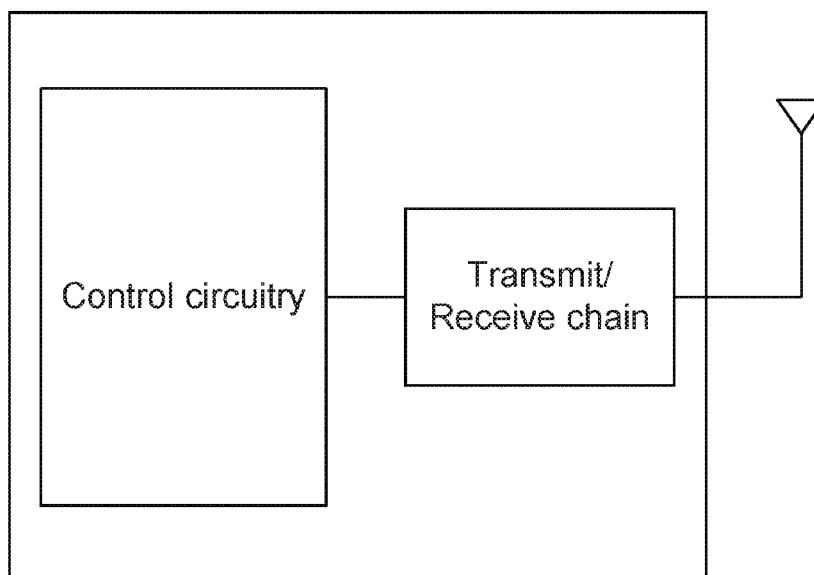


Fig. 10

(57) Abstract: An apparatus for use in a user equipment (UE), the apparatus includes control circuitry to control communication via sidelink within a narrow bandwidth, the communication via the sidelink to use a single transmit, receive or transceiver chain; and the transmit, receive or transceiver chain.



WO 2017/078783 A1



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG). **Published:**

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

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

METHODS AND DEVICES FOR COMMUNICATION VIA SIDELINK

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority from U.S. Provisional Patent Application
5 No. 62/252,329, filed November 6, 2015, and entitled "METHODS AND DEVICES FOR
LOW POWER AND LOW COST 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.

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BACKGROUND

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

BRIEF DESCRIPTION OF THE DRAWINGS

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Figure 1 illustrates Release 12 D2D broadcast communication.

Figure 2 illustrates a pool configuration example for Mode-2.

Figure 3 illustrates frequency resource pool configuration.

Figure 4 illustrates an example of Time Resource Patterns (TRP).

Figure 5 illustrates a call flow for Proximity Services (ProSe) user equipment
20 (UE)-Network Relay.

Figure 6 illustrates a configuration of D2D discontinuous reception (DRX) cycles.

Figure 7 illustrates a transmit/receive (TX/RX) resource scheduling example by a
master UE.

Figure 8 illustrates a physical layer operation of Slave and Master devices (note
25 that sidelink control information (SCI) and sidelink synchronization signals (SL-SS)
transmission periods may not be of the same length).

Figure 9 illustrates example components of an electronic device according to some
examples.

Figure 10 illustrates a UE in accordance with some embodiments.

30 Figure 11 illustrates hardware resources in accordance with, or suitable for use
with, some embodiments.

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

The Internet of Things (IoT) is one of the key transformation paradigms of the upcoming 5G communication era. Connection of massive number of devices to network is one of the main problems to be addressed by the 5G wireless technologies. The amount of devices that require 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 will require connection to the network.

One of the methods to manage/control traffic and wireless access for the massive number of devices is to further densify the amount of access points. However, deployment of dedicated wireless access nodes requires additional investments (operating expenditure (OPEX) and capital expenditure (CAPEX)). In order to avoid this excessive cost, wireless relays may be used. Moreover, user equipment/terminals may be used for relaying the traffic of other devices, thus aggregating the traffic from nodes in proximity.

The existing wireless technologies such as Bluetooth (802.15.1), Wi-Fi (802.11), 802.15.4 (ZigBee, WirelessHART, ISA100.11a) and their evolution may be used to connect a massive number of devices classes. Nowadays these technologies serve as wireless “bridges” to get connection towards a network. However, this approach may not fulfill all the diverse requirements that may arise, and suffers from a lack of network control, thus a new unified approach based on a single technology is beneficial for seamless IoT integration.

Moreover, many of IoT use cases may be supported in a near term owing to ongoing transformation of LTE technology and new functionalities. Currently, there are

standardization activities to support clean-slate operation of IoT/machine-type communications (MTC) devices re-using LTE technology and spectrum as much as possible. The focus is to enable operation of a very large number of devices with long range, low energy (years of operation with a coin cell battery), low rate communication in licensed spectrum. However, the work does not cover possibility of direct communication between devices, for example, an IoT device cannot transmit/receive traffic to/from another UE, either high end or another IoT device. Enabling direct communication for these devices may open many more applications for LTE based IoT, such as smart home, wearable body sensors, industry automation/control, etc. Depending on application/service, the user data may not target internet services (for example, end up in the network), but rather be intended for the local server, for example, a user's smartphone or application, while IoT type of devices are likely to use a connection to the network.

A factor of using direct communication for IoT is energy efficiency for low end devices due to utilization of the proximity in case of short-range communication with another device.

In order to facilitate efficient wireless communication for IoT use cases, 3rd Generation Partnership Project (3GPP) LTE may be extended to efficiently support direct low power communication between devices. Currently, LTE Release 12-13 supports basic functionality of direct communication and discovery. The goal of the Release 12 was to enable basic functionality aimed at Public Safety and partially General/Consumer use cases, with Release 13 to introduce enhancements to support L3 relaying, inter-carrier/inter-public land mobile network (PLMN) discovery, prioritized resource access and out-of-coverage discovery.

Herein, further enhancements to Sidelink/D2D communications are analyzed to support low power, low cost direct communication/discovery. The following general aspects are discussed:

- Background of the existing LTE ProSe;
- Proposed wearable device classification for different use cases; and
- Enhancements to support different device categories (e.g. wearable device classifications).

Herein, we identify design bottlenecks of the Release 12-13 D2D/ProSe that limit energy efficiency and cost efficiency, and provide design enhancements to remove these

bottlenecks. According to some examples, low power and low cost D2D communications for wearable/IoT devices may be enabled. Enhancements may provide reduced UE active time and simplified architecture for cost and energy efficient implementations.

5 There are existing wireless technologies designed for low power, low cost, short-range communication, such as Bluetooth Low Energy, ZigBee etc. These technologies use unlicensed spectrum and their own protocol stacks. Cellular service providers and operators cannot control these devices, and thus, cannot guarantee service quality, while not having any revenue from these services. According to some examples, we propose to integrate such capabilities of direct low power, low cost communication into LTE. Note,
10 that direct communication is already supported in LTE release 12-13, however, it is not optimized for such use cases.

A new device, supporting enhanced low power, low cost LTE D2D communication may benefit from predictable performance controlled by the network, may have capability to access the network directly, and may be even lower power and lower cost than existing
15 technologies.

1 Background of LTE Release 12-13 D2D/Sidelink

Examples herein may provide key technology components to enable low power, low cost direct communication between devices based on LTE D2D/Sidelink technology.
20 For convenience of explanation, we provide a background of the LTE Rel.12-13 sidelink operation. Note, that terms D2D (device-to-device), SL (sidelink) and ProSe (Proximity Services) are used interchangeably herein.

1.1 Common Design Aspects

LTE D2D/Sidelink as much as possible reuses LTE uplink physical layer, for
25 example, SC-FDMA (single carrier frequency division multiple access) waveform, physical uplink shared channel (PUSCH) interleaving, common turbo or convolutional coding, TBS (transport block size) and MCS (modulation and coding) tables, DMRSs (demodulation reference signals). The transmission is allowed only in dedicated or uplink (UL) resources (dedicated D2D carrier or UL carrier in frequency-division duplex (FDD)
30 and UL subframes in time-division duplex (TDD)). The transmission resources are allocated by configuring resource pools. Transmission resource pool configurations are signaled in dedicated system information blocks (SIBs) (SIB 18 and 19) and define

frequency (physical resource blocks set) and time (subframe set) resources used for each sidelink channel.

1.2 Discovery

The D2D discovery procedure was introduced in order to enable proximity triggered services deployed at application layers. For these purposes, transmission/reception of a special periodic discovery announcement was specified. The transmission is allowed only inside a discovery resource pool, which is allocated periodically, with minimum occasion periodicity of 320 ms, and 10240 ms maximum periodicity. Each transmission spans 2 physical resource blocks (PRBs) in the frequency domain and X subframes in the time domain (where X is configurable between 1 and 4). There are also two different resource allocation modes: Type-1 is autonomous resource selection (random resource selection), and Type-2B is Evolved Node B (eNB or eNodeB) controlled resource selection, where resources for transmission are configured by radio resource control (RRC) signaling.

In Rel.13, the discovery periodicity was reduced to the level of communication pool periodicity i.e. 40/80/160/320 ms in FDD and corresponding values for TDD.

1.3 Communication

The D2D data communication was specified targeting only Public Safety operation in different scenarios within network coverage, partial network coverage or out of network coverage. The main Public Safety application was voice service (voice over IP (VoIP)). That led to the design being optimized for robust long-range voice communication with semi-persistent randomized resource allocation. A two-step data transmission procedure was adopted: 1) Transmit control information (Sidelink Control Information (SCI) or Scheduling Assignment (SA)) inside a physical sidelink control channel (PSCCH) resource pool pointing to the subsequent data transmission with the specified physical layer parameters, 2) Data transmission inside a physical sidelink shared channel (PSSCH) resource pool following the transmission of control information. An example of this arrangement is shown in Figure 1. Figure 1 shows signaling in a network including an eNB 115, D2D transmitter 120 and D2D receiver 130. The 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 scheduling control information in PSCCH and data in PSSCH. The D2D transmitter obtains SCI and D2D data resources from the resource grant 135. The D2D transmitter 120 then transmits SCI 140 in PSCCH to the D2D receiver 130, in accordance with the allocated resources.

The D2D receiver 130 receives the SCI 140 by blind decoding over the PSCCH and from this acquires information about the subsequent data transmission from the D2D transmitter 120. The D2D transmitter 120 then transmits the D2D data 145 in PSSCH according to the SCI previously sent to the D2D receiver 130, and as allocated by the eNB. The D2D receiver receives the D2D data in accordance with the previously received SCI 140.

Depending on how the resources for transmission are acquired, there are two 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 1, 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 2 shows an example of a pool configuration for Mode-2 using FDD. The SA cycle 210 of Figure 2 has a cycle length of 1024 ms, having an offset 212 from system frame number (SFN) 0 215. 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 3 shows an example the frequency configuration of the resource pool for Mode-2, in accordance with the example of Figure 2. In Figure 3, frequency is shown vertically and time is shown horizontally. The parameters saStartPRB 310, saNumPRB 315 and saEndPRB 320 define the physical resource blocks (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.

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 3, each block in the horizontal direction represents a subframe in a logical resource pool. In elements 302 and 304 of Figure 3, each block in the horizontal direction represents a symbols 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 1 shows how the TRP bitmap is applied inside the resource pool. Figure 4 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 4, the TRP bitmap has a length of eight subframes and is repeated each eight subframes of the logical data pool.

1.4 Layer-3 Relay

The Layer-3 relaying support was introduced in LTE Release 13; the following general flow is supported:

A Relay UE 520 performs initial E-UTRAN attachment procedure 550, which involves signaling to/from mobility management entity (MME) 530 and home subscriber server (HSS) 540 as per usual E-UTRAN attachment procedure. Then, the relay discovery and selection procedure 560 is performed according to Model A or Model B discovery.

5 After the relay discovery and successful selection performed, the Remote UE 510 and Relay UE 520 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 is performed.

10 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 Release 12 broadcast functionality with some enhancements in order to efficiently discover and select relays.

2 Support of Wearable Device Communication

15 2.1 Different Wearable Device Categories

First, potential device categories that may serve identified use cases may be described. Regardless of possible cellular capabilities of the device, the following D2D capability categories may be identified:

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

20 **Table 1. Wearable devices categories**

2.2 Energy Efficiency Limiting Factors of LTE D2D

The Release 12-13 D2D was specified targeting selected use cases for Public Safety and Consumer scenarios. The aim to maximize coverage/range and robustness to
25 interference led to insufficient consideration of energy efficiency of the agreed L1/L2 procedures. The following limiting factors may lead to non-optimized power consumption of a D2D UE when operating using Rel.12-13 procedures:

- **Long duty cycles.** Currently, there are no discontinuous reception (DRX) cycles specified for sidelink. The D2D UE may need to monitor all configured RX pools (at least PSCCH) and filter them at higher layers. For D2D communication, at most 320ms duty cycle may be configured.
- 5 • **Complicated synchronization.** According to previous studies, the initial frequency error and clock drift may lead to large frequency offsets, especially at higher carrier frequencies. That frequency offsets may be estimated using advanced detection algorithms (including decoding-aided approaches), which bring higher cost and energy consumption. Thus, revision of the synchronization signals and procedure may lead to reduced complexity and reduced energy consumption.
- 10 • **Blind decoding of SCI.** In LTE Rel.12, a UE may be mandated to perform up to 50 blind decodings of SCI per subframe depending on PSCCH resource pool configuration. That may substantially complicate receiver implementation and revision may be beneficial for low power, low cost use cases.
- 15 • **Multi-transmission time interval (TTI) processing.** In LTE Rel.12, a UE may be mandated to send 2 TTIs of PSCCH (SCI) and 4 TTIs of PSSCH (Data). Relaxing this may save both transmission and reception energy consumption in the case of short-range communication where such link budget is not needed.
- **Cell-specific power control.** Power settings in Rel.12-13 are cell-specific (not UE, or UE-pair specific) and may not provide energy efficient short-range communication due to excessive transmission power settings.
- 20 • **Large number of sidelink processes.** There are 16 sidelink processes specified for a D2D UE, that may be too large a capability for a low cost device. The number of sidelink processes may be reduced (e.g. to 1 or 2) to save cost. In Rel.12-13, 25456 bits may be received simultaneously per TTI.
- 25 • **Peak-to-average power ratio (PAPR).** Modulation/waveform may be further revised to support ~0 dB PAPR and efficient low cost implementation of an integrated power amplifier. The SC-FDMA waveform used in UL and SL may be further revised in order to enable lower cost and higher energy efficiency.
- 30 • **High layer connection establishment overhead.** Currently, in order to establish UE-to-Network relaying, the relay discovery, one-to-one connection establishment and IP assignment should be made. This may lead to several hundreds of milliseconds end-to-end latency to establish connection and quite large overhead

for a short state update message.

2.3 Considerations on Simplified Uu Interface for the Low Cost Device

One approach is to reuse MTC, narrow-band IoT (NB-IoT), cellular IoT (CIoT) device architecture to enable low cost, energy efficient direct connectivity with a cellular network. The mentioned technologies use reduced capabilities and revised procedures in order to fit target device complexity, chip size and power consumption. One way to facilitate the dual mode LTE + D2D low cost operation is to seamlessly integrate these two technologies in a single device.

2.4 Proposed Enhancements

Summarizing the potential use cases and categories of wearable devices, there are two general disruptive design objectives for the wearable devices:

1. Enable low energy, low cost, low data rate D2D communication to support wearable devices category 1; and
2. Enable low energy, high data rate, regular cost D2D communication to support wearable devices category 2.

These two design vectors may be considered for wearable communication design. Another issue is to organize interworking between D2D and cellular air-interfaces and seamlessly integrate inherited relaying functions in order to forward the wearable traffic to the network. All these different design objectives are discussed in this sub-clause.

2.4.1 Enhancements to Support Wearable Device Category 1

In this subsection, technology components to facilitate low power D2D communication evolving the existing LTE Release 12-13 sidelink are discussed.

- Simplified Physical Layer

Another important energy and cost efficiency aspect is the physical layer design. Most of the low power, low cost wireless communication systems adopt schemes that allow very simple, low complexity implementation with very high energy efficiency traded for spectral efficiency. The following physical layer design aspects are considered:

1. **Narrow bandwidth.** Operation bandwidth of the communication system may directly affect implementation cost. The narrowband design may provide co-existence of many devices inside a particular allocated spectrum bandwidth, high

energy per bit in power-limited systems (e.g. uplink transmission case), low complexity transceiver design, etc. However, the narrower the bandwidth, the longer the transmission of a particular packet in time, thus the longer the activity period of the involved transceivers. This dependence may be carefully taken into account when considering target data rates and energy efficiency / complexity tradeoffs. In some embodiments, the narrow bandwidth may be one/six/twelve LTE PRB(s) (180 kHz / 1080 kHz / 2160 kHz).

2. **Single antenna / RX chain.** A single RX chain may be used in some embodiments for low cost, low power devices and may be taken as a baseline for wearable devices.

3. **Simple and common coding.** Channel coder may be selected in order to provide sufficient performance with low complexity for the target applications. The coder may be common for all channels (broadcast, control, shared/data) in order to reuse it for all purposes. The convolutional turbo coding (CTC) coder used for PUSCH/PDSCH/PSSCH may be reused for these purposes.

4. **Waveform and modulation.** Since the transmit waveform selection greatly impacts RF implementation cost and efficiency, it should be carefully selected for the Categories 1. Currently, SC-FDMA waveform with up to QAM16 modulation is used in LTE sidelink. This provides lower PAPR than non-precoded OFDM used in downlink (DL) and leads to up to several dB PAPR. The non-zero PAPR impacts the PA efficiency and raises implementation challenges to deal with non-linear distortions. However, other waveforms, such as e.g. FDMA GFSK/GMSK (used in GSM, BT LE and other low complexity wireless communications systems) may provide 0-dB PAPR that allows very energy efficient and inexpensive PA implementation using the integrated architecture.

5. **Synchronization.** Synchronization is established before transmitting and receiving data packets in Rel.12-13 D2D communication. The synchronization procedure is decoupled from data TX/RX and is assumed as a background process. This procedure may or may not be changed for the low power D2D, and some aspects may be revised:

- a. **Synchronization sequence design (primary sidelink synchronization signals (PSSS) and secondary sidelink synchronization signals (SSSS)).** Zadoff–Chu (ZC) sequences selected for PSSS may have ambiguity issues on large initial carrier frequency offsets. Advanced estimation and

detection algorithms (potentially involving hypothesis testing with multiple decoding of physical sidelink broadcast channel (PSBCH)) may solve this issue. The cost and power consumption of such implementation may appear not so low. The need to involve a decoder for synchronization signal detection restricts possible power saving approaches when most of baseband is in sleeping mode during the acquisition. As for SSSS, the ID space of 168 different sequences may be reduced (even to 1) in order to reduce SSSS detection complexity.

- b. **Procedure.** Currently, the synchronization signals are sent every 40ms by a UE acting as a synchronization source. For the wearable communication, the synchronization establishments may be considered jointly

The Category 1 devices that do not have cellular capabilities may be always synchronized using SL-SS and PSBCH transmitted by a master UE. If the device has cellular capabilities, it may acquire synchronization in DL cellular carrier when operating in D2D, however, the benefits of this approach may be weighed against additional energy consumption.

6. **Hybrid automatic repeat request (HARQ).** In the legacy Rel.12-13 D2D there is no physical layer acknowledgement/negative-acknowledgement (ACK/NACK) to acknowledge media access control (MAC) transport block reception. In case of erroneous MAC PDU reception, a large portion will be resent due to lack of physical layer HARQ because only transport control protocol (TCP) ARQ is used for acknowledging reception. Some embodiments described herein provide a selective ACK approach when a group of transport blocks are acknowledged or only erroneous transmissions of a group of transport blocks are acknowledged.

7. **TDD-like operation without duplexers and duplexers.** In order to further simplify the transceiver, the operation procedures for low cost devices may ensure the UE transmits and receives in different time instances with additional turn-around gap between TX and RX states. This may avoid the need for duplexers and duplexers.

- Reduced RX Capabilities

The receiving capabilities of current D2D UEs are not very high compared to high-end cellular UE categories, however they may be further reduced to extract additional cost and energy savings:

1. **Reduce number of SCI blind decodings.** Currently, a D2D UE needs to perform up to 50 SCI blind decodings, which substantially complicates PSCCH processing. For the wearable use cases, the number of active links may typically be small (1 for communication with the master UE and 0-2 for communication with other wearable UEs). Thus, the wearable UE may be configured with reduced blind decoding (BD) capabilities, which implies that the network is to configure narrow band PSCCH resource pools for wearable communication.
2. **Reduce number of sidelink receive processes.** Currently, there are 16 sidelink receive processes assumed to be handled simultaneously by a D2D UE. That was implied by the broadcast nature of D2D physical layer, where most packets are assumed to be filtered out on higher layers. This is definitely a very high capability for a wearable device, and complicates the implementation. Similar to the SCI, the number of sidelink receive processes may be reduced to 1-3, particularly where communication with a single master device is a primary use case.
3. **Reduced maximum TBS/MCS supported level.** High order modulations may require more advanced receiver processing and larger soft buffer size than that for the low order modulations. The low order modulation (e.g. QPSK) may be sufficient for the target data rates of the wearable devices category 1.
4. **Single TTI transmission.** Processing of only single TTI may be sufficient for short-range communication.

• Power Control

The legacy Rel.12 D2D power control provides efficient co-existence regulation mechanism with cellular UL transmissions by setting P0 and alpha parameters with fractional compensation of eNB-UE pathloss. That protects UL if proper open loop power control parameters are selected. If alpha is configured to be 0, then fixed power transmission (including max power) is possible. However, this may not be efficient for short-range low power communication because the power level does not take into account UE-UE channel attenuation and may lead to excessive transmission energy consumption.

For the purpose of optimizing transmission power, the following solution may be considered:

Fractional power control based on compensation of UE-UE pathloss. The master UE may estimate the pathloss of the UE-UE link and do the following:

5 **Option 1.** Calculate transmission power for the wearable device and signal it in a control message.

Option 2. Signal a quantized pathloss value that will be applied by a wearable UE for calculation of transmission power.

10 i. Note, that the master UE may just signal a target range class, which corresponds to a few different fixed power levels of a wearable UE, e.g. one of the available four different power levels [10, 0, -10, -20] dBm may be signaled by a 2-bit message.

- Split of UE Functions

15 In the wearable use case, two different UE roles may be assumed:

- 1) Wearable / Remote / Dependent UE – *Slave UE*;
- 2) Hub / Relay / Head UE – *Master UE*.

Since the operation functions are different for these two roles, efficient split of functions may be considered. There are three general approaches for functions split:

- 20 1) **Physical layer split.** The physical layer functional split allows different frame format, waveform, transmission timing, measurements, channels etc. This approach is similar to DL and UL split in traditional cellular systems. However, for the wearable communication system, the functional split may take into account possible peer-to-peer communication between Slave devices. Having this in mind, it is advantageous to
- 25 minimize the physical layer functional split/difference according to some embodiments.
- 2) **MAC layer split.** This assumes symmetrical physical layer but controlled by L2 control signaling multiplexed into shared channel transmissions. This L2 control signaling may be a new D2D Radio Resource Control (RRC) protocol.
- 30 3) **Higher layer split.** Similar to MAC layer split, but even higher layer control is deployed.

If the function split is enabled, then the following functions may be left to a Master UE in order to simplify implementation of the Slave UE:

- 1) Transmission of synchronization signals. The Master may act as a synchronization source in order to save the Slave's energy. The SL-SS identity, encoded into synchronization signals may be interpreted as a pico-net or PAN (personal area network) ID. This ID may be configured by upper layers.
 - 5 2) Measurements. The Master UE may do measurements related to channel quality of the Master-Slave communication link in order to optimize performance:
 - a. Pathloss, reference signal received power (RSRP), reference signal received quality (RSRQ): these measurements may be done in order to adjust for example transmission power.
 - 10 b. Channel quality indication (CQI) and/or channel state information (CSI): The Master UE may estimate CQI in order to assign optimal MCS level for a given data rate.
 - 3) Transmission and reception timeline scheduling (i.e. TDD configuration).
 - 4) A Master UE controls resources for both transmission and reception. In some

15 embodiments, this may be done by introducing a new SCI format with additional field for scheduling of reception resources.
- Dedicated Resource Pool

In order to protect short-range, low power wearable device transmission and

20 incorporate the proposed enhancements, a separate resource pool may be configured for these purposes.
 - Connection-less Operation

The IoT low cost device (Category 1) target use case may exchange state

information with a device or network. That behavior may produce bursty, infrequent and

25 low data rate traffic, which does not require long connection with device/network.

Therefore, the connection-oriented operation may be deprioritized for these device

categories. The connection-less operation assumes a reduced or minimized number of

steps in order to deliver data. The following may be considered for facilitating connection-

less transmission.
 - 30 • ***Self-contained data transmissions.*** A wearable UE may send a small data packet by a single physical layer transmission. This assumes a predefined application service identity multiplexed into MAC PDU. Similar operation

may be deployed as in D2D discovery. In this case, the Slave UE's context may be stored at the Master UE for a long period.

- **Reduce RAT-specific connection establishment procedures.** Only IP acquisition step may be needed to reduce connection overhead. Further, IP header compression mechanisms may be used.

- Configurable low duty cycles

The main energy saving factor that may be used to enable low power D2D, is the reduction of time in active TX/RX state for a D2D UE. In that sense, the absence of low duty cycle configurations in D2D communication may limit potential power consumption savings. Currently, SCI period, which is the granularity of UE TX/RX activity time, may be configured from the following values: [40, 80, 160, 320] subframes for FDD and TDD configurations #1-5, [70, 140, 280] subframes for the TDD configuration #0 and [60, 120, 240] subframes for the TDD configuration #6. That is, the maximum SCI period is 320ms, which implies a D2D UE is to wake up its transceiver at most every 320ms in order to TX/RX D2D data. These values are not suitable for operation scenarios where much more infrequent transmissions are expected. For the purposes of enabling the much lower duty cycles, the following solutions are proposed:

Option 1: Allow larger SCI/PSCCH periods configuration. In this case, additional values of larger SCI periods may be specified. For example, [640, 1280, 2560, 5120, 10240] subframes SCI period may be added for FDD and TDD configurations #1-5, [560, 1120, 2240, 4480, 8960] subframes for the TDD configuration #0 and [240, 480, 960, 1920, 3840, 7680] subframes for the TDD configuration #6. This option only allows extending duty cycle on the System Frame Number counter upper bound, which is 1024 frames (10240ms). In order to enable even larger SCI periods, the hyper-frame approach used for enhanced DRX procedures may be reused.

Option 2: Introduce DRX/DTX/Paging cycles on top of SCI periods. Currently, there is no notion of DRX cycles and there is no paging procedure for reaching a D2D UE. Upper layers trigger the activity of D2D UEs that may lead to connection re-establishment if bursty/infrequent traffic appears on D2D link. Sidelink DRX cycles may be configured in terms of SCI periods similar to frame-level configuration for cellular operation. The DRX active period means that during it a UE listens for all PSCCH occasions. The inactivity timer may count the number of empty PSCCH occasions and switch a UE to inactive state when a configured number is exceeded.

Fig 6 illustrates an approach of configuring short 610 and long 620 DRX cycles. When configured, a UE when in active state tries to decode each PSCCH region of each SA/data period 630 to find transmissions of interest (e.g. a paging request). If a transmission of interest was found, then an inactivity timer remains zero (or unchanged). If there were no transmissions of interest (i.e. transmissions intended for current UE), then the inactivity timer/counter is incremented in each empty SA/data period 630 (i.e. in each SA/data period 630 with no transmission of interest). When the inactivity timer reaches a configured inactivity timer threshold, then the short DRX cycles 610 starts, meaning that a UE does not need to monitor a number of consecutive SA/data periods 630 during this cycle. During short DRX, a UE wakes up each short DRX cycle 610 to try to decode PSCCH. A long DRX cycle 620 is activated after a PSCCH of interest is not found during a configured number of attempts during short DRX. The UE then wakes up each long DRX cycle 620 to try to decode PSCCH.

- Sub-SCI Period Communication

The idea is to minimize or reduce possible activity time to sub-SCI period values. This may be achieved by special time-division multiplexing (TDM) between master and slave transmission resources. In order to achieve this, a Master UE may schedule both TX and RX resources. For example, the Master, when allocating transmission resources, may send SCI for both transmission and reception, therefore knowing when the slave will answer during the SCI period.

Figure 7 shows TX and RX activity of a master UE 710 and slave UE 750 in a SCI period 700. The master UE 710 sends scheduling information in PSCCH 715, the scheduling information including SCI 720 for data transmission by the master 710 (when the slave 750 is to receive), and SCI 725 for transmission by the slave 750 (when the master is to receive). The master then transmits in data 730 to the slave 750, as scheduled. The slave 750, having received the scheduling information from the master 710 listens 735 in accordance with the SCI 720 and receives the data 730 from the master. The slave transmits data 740 in accordance with the SCI 725 received from the master 710, the data being received 745 by the master 710.

This may allow the activity time to be reduced to a single SCI period. In this case, the slave UE may not need to send SCI prior to its answer to the Master.

- Summary of Enhancements and Overall State Diagram

Summarizing the discussed enhancements, the following practical enhancements may be introduced in order to support Category 1 wearable devices:

- Fixed reduced operation bandwidth (for example, 180/1080/2160 kHz);
- Single TX/RX chain, single operation carrier;
- 5 • Common coder for control and data (for example, CTC);
- Zero-dB PAPR revised modulation and waveform;
- Functional split for Master and Slave UEs (introduce D2D RRC);
- Revised synchronization design (at least to deal with reduced operation bandwidth);
- Significantly reduced number of blind decodings and sidelink RX processes (1-3);
- 10 • D2D DRX and paging cycles;
- Sub-SCI period communication;
- Dedicated resource pool for wearable communication;

An exemplary physical layer operation time flow is shown in Figure 8. The Master UE 810 may transmit 830-1 SL-SS and PSBCH. These may be detected by the
 15 Slave UE 820 allowing the Slave 820 to detect the Master and acquire synchronization and resource configuration 840. This may occur within a particular SCI period (period x in Figure 8). In the next SCI period (period x+1) the Slave UE 820 may transmit a connection request 850, or alternatively, may transmit a data packet 850 where the data to be transmitted is sufficiently small. In the next SCI period (period x+2) the Master UE
 20 810 may transmit a response 860 providing a resource allocation. Alternatively, the Master UE may transmit data 860 to the Slave UE 820. Where the Slave UE 820 receives a resource allocation, the allocated resource may be used subsequently by the Slave UE 820 to transmit data. In Figure 8, the Master UE 810 is illustrated with SL-SS and PSBCH 830-1, 830-2, 830-3, 830-4 being aligned with the SCI period. However, in practice SL-
 25 SS and PSBCH need not be aligned with the SCI period.

According to some examples, the following steps may be carried out for transmission of data by a slave UE are:

1. Slave UE 820 wakes up;
2. Slave UE 820 searches for the Master UE 810 with a configured SL-SS ID
 30 which may be treated as a pico-net ID or PAN ID;
3. Slave UE 820 acquires 840 synchronization and resource configuration;
4. Slave UE 820 transmits connection request 850 (for streaming) or transmits a data packet 850;

5. Master UE 810 listens for Slave UE's 820 request 850 or data 850.

6. Master UE 810 responds 860 with resource allocation, MCS, TX power.

In some examples the SCI period may be configured to a small value, e.g. 8 ms in order to allow low latency and short-lived connection that will benefit energy

5 consumption. Another option is to allow sub-SCI period communication that is discussed separately in a dedicated sub-section.

In case a Master UE has data or control for the Slave UE, the paging procedure may be specified. For these purposes, a special paging request may be sent in PSBCH or SCI+PSSCH transmission. A Slave UE may apply long paging cycles to monitor paging
10 resources infrequently.

2.4.2 Enhancements to Support Wearable Device Category 2

The main difference of Category 2 compared with Category 1 is that the D2D capabilities are high, for example, low latency, high data rate traffic is targeted. The battery assumption is changed and a medium capacity rechargeable battery may be
15 assumed with up to several days operation lifetime. The cost is of less concern than Category 1 since these categories target other market segments and are likely to be implemented in mid-high end wearable devices.

Many of enhancements, discussed for Wearable Device Category 1 are applicable for Category 2, excluding the reduced transceiver capabilities which limit the data rate and
20 spectral efficiency, such as narrow bandwidth and maximum supported modulation. The wearable device category 2 may support regular LTE bandwidth and high order modulations in order to provide high data rate transmission.

Thus, considering regular cost and high data rate with reasonable energy efficiency, the following enhancements comparing to the Release 12-13 are proposed.

25 • Enhanced Power Control

Similar to category 1, the UE-UE link specific power control setting should be applied in order to deal with UE-UE channel attenuation and provide consistent power level.

• HARQ Feedback

30 For more efficient link operation with fine latency, the Layer-1&2 HARQ mechanism may be supported oppositely to Rel.12-13 D2D, where no physical layer acknowledgement is deployed.

• Peak Data Rate Increase

Current LTE D2D communication support ~6.3 MBPS data rate due to several restrictions: maximum TBS is set to 25456, maximum supported modulation is QAM16, every transport block (TB) is sent by 4 TTIs, no MIMO (single antenna transmission). Therefore, removing these restrictions may facilitate up to ~35 MPBS in 10 MHz band with a single antenna transmission and even higher using MIMO techniques.

- Feedback Based Link Adaptation & CQI/CSI

Currently, there are no channel quality feedbacks supported for D2D. Thus, pessimistic MCS is selected for transmission. Enabling mechanisms to measure and report channel quality indication will significantly improve spectral efficiency of a D2D link.

- Resource Control

In autonomous resource allocation mode (Mode-2), currently, resources for transmission are selected randomly by each transmitting UE. In order to avoid resource collisions between transmission and reception on a D2D link, a more controlled resource allocation may be used. For these purposes, the Master UE may control both transmission and reception on a D2D link.

- Protocol Enhancements

Master / Slave functional split similar to Wearable Category 1 should be considered for Category 2.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 9 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.

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

implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

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 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 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 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 evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 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 be 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 evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 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 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 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 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 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 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 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.

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 division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

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 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 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.

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).

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.

Figure 10 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. The transmit/receive chain may be a single transceiver chain.

5 In embodiments in which the electronic device illustrated in Figure 9 is used to implement the UE illustrated in Figure 10, 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.

10 Figure 11 is a block diagram illustrating components, according to some example 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 11 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
15 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
20 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.

 The communication resources 1130 may include interconnection and/or network interface components or other suitable devices to communicate with one or more
25 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
30 components.

 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 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
5 memory/storage devices 1120, the peripheral devices 1104, and the databases 1106 are examples of computer-readable and machine-readable media.

EXAMPLES

10 Example 1. An apparatus for use in a user equipment (UE), the apparatus comprising:
control circuitry to control communication via sidelink within a narrow bandwidth,
the communication via the sidelink to use a single transmit, receive or transceiver chain;
and
the transmit, receive or transceiver chain.

15

In Example 2, the subject matter of Example 1 or any of the Examples described herein may further include: wherein the narrow bandwidth is selected from:

twelve physical resource blocks (PRBs),
six physical resource blocks,
20 one physical resource block,
2160 kHz,
1080 kHz, or
180 kHz.

25 In Example 3, the subject matter of Example 1-2 or any of the Examples described herein may further include: wherein the control circuitry is to perform no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

30 Example 4. An apparatus for use in a user equipment (UE), the apparatus comprising:
control circuitry to control communication via sidelink, wherein
the control circuitry is to perform no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

In Example 5, the subject matter of Example 1-4 or any of the Examples described herein may further include: wherein the control circuitry is restricted to handle less than 16 simultaneous sidelink receive processes.

5

Example 6. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication via sidelink, wherein the control circuitry is restricted to handle less than 16 simultaneous sidelink receive processes.

10

In Example 7, the subject matter of Example 5-6 or any of the Examples described herein may further include: wherein the control circuitry is restricted to handle no more than three simultaneous sidelink receive processes.

15 In Example 8, the subject matter of Example 1-7 or any of the Examples described herein may further include: wherein the control circuitry is arranged to use a transport block size (TBS) and modulation coding scheme (MCS) such that Quadrature Phase Shift Keying (QPSK) is used and the TBS has a maximum of 1000 bits.

20 Example 9. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication via sidelink, wherein the control circuitry is arranged to use a transport block size (TBS) and modulation coding scheme (MCS) such that Quadrature Phase Shift Keying (QPSK) is used and the transport block size (TBS) has a maximum of 1000 bits.

25

In Example 10, the subject matter of Example 1-7 or any of the Examples described herein may further include: wherein the control circuitry is:

arranged to use a transport block size (TBS) greater than 25456 bits, and/or
arranged to use fewer than 3 transmission time interval (TTIs) for each transport

30 block (TB)

Example 11. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication via sidelink, wherein at least one of: the control circuitry is arranged to use a transport block size (TBS) greater than

25456 bits, and/or

the control circuitry is arranged to use fewer than 3 transmission time interval (TTIs) for each transport block (TB).

- 5 In Example 12, the subject matter of Example 1-11 or any of the Examples described herein may further include: wherein the control circuitry is to cause transmission and/or reception of:

only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or

- 10 only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

Example 13. An apparatus for use in a user equipment (UE), the apparatus comprising:

control circuitry to control communication via sidelink, wherein

- 15 the control circuitry is to cause transmission and/or reception of:

only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or

only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

20

In Example 14, the subject matter of Example 1-13 or any of the Examples described herein may further include: wherein the control circuitry is to cause the UE to operate as a Master in the communication via the sidelink, and

- 25 the UE is to communicate with another UE via the sidelink, the another UE to operate as a Slave.

Example 15. An apparatus for use in a user equipment (UE), the apparatus comprising:

control circuitry to control communication with another UE via sidelink, wherein

- 30 the control circuitry is to cause the UE to operate as a Master in the communication via the sidelink, and the another UE is to operate as a Slave.

In Example 16, the subject matter of Example 14-15 or any of the Examples described herein may further include: wherein the control circuitry is to cause transmission of sidelink synchronization signals (SL-SS).

In Example 17, the subject matter of Example 16 or any of the Examples described herein may further include: wherein the SL-SS include an SL-SS identity.

- 5 In Example 18, the subject matter of Example 14-17 or any of the Examples described herein may further include: wherein the control circuitry is to perform a measurement related to channel quality of the sidelink between the Master and Slave.

- 10 In Example 19, the subject matter of Example 18 or any of the Examples described herein may further include: the measurement includes one or more of pathloss, reference signal received power (RSRP) or reference signal received quality (RSRQ).

- 15 In Example 20, the subject matter of Example 19 or any of the Examples described herein may further include: wherein the control circuitry is to adjust a transmission power of the Master and/or Slave based on the measurement.

- 20 In Example 21, the subject matter of Example 18-20 or any of the Examples described herein may further include: wherein the control circuitry is arranged to estimate, based on the measurement, one or more of channel quality indication (CQI) and/or channel state information (CSI).

- 25 In Example 22, the subject matter of Example 21 or any of the Examples described herein may further include: wherein the control circuitry is to adjust a modulation coding scheme (MCS) of the Master and/or Slave based on the estimate.

- In Example 23, the subject matter of Example 14-22 or any of the Examples described herein may further include: wherein the control circuitry is to:

- 30 estimate a pathloss of the sidelink between the Master and Slave;
calculate a transmission power to be used by the Slave based on the estimated pathloss; and
cause the UE to signal the calculated transmission power to the Slave in a control message.

In Example 24, the subject matter of Example 14-22 or any of the Examples described

herein may further include: wherein the control circuitry is to:

estimate a pathloss of the sidelink between the Master and Slave;

cause the UE to signal a quantized pathloss value, based on the estimated pathloss, to the Slave.

5

In Example 25, the subject matter of Example 14-22 or any of the Examples described herein may further include: wherein the control circuitry is to:

estimate a pathloss of the sidelink between the Master and Slave;

10 cause the UE to signal to the Slave a target range class that corresponds to one of a plurality of fixed transmission power levels for the Slave.

In Example 26, the subject matter of Example 14-25 or any of the Examples described herein may further include: wherein the control circuitry is to schedule transmission and reception by the Slave.

15

In Example 27, the subject matter of Example 26 or any of the Examples described herein may further include: wherein the control circuitry is to schedule the transmission and reception by the Slave such that the Slave is not scheduled to transmit and receive simultaneously.

20

In Example 28, the subject matter of Example 26-27 or any of the Examples described herein may further include: wherein the control circuitry is to cause transmission, via the sidelink, of control information including parameters for the transmission and reception schedule.

25

In Example 29, the subject matter of Example 14-28 or any of the Examples described herein may further include: wherein the control circuitry is arranged to allocate resource for transmission by the Master and reception by the Master.

30 In Example 30, the subject matter of Example 29 or any of the Examples described herein may further include: wherein the control circuitry is arranged to cause transmission of sidelink control information (SCI) including a field indicating the allocated reception resource for reception by the Master.

In Example 31, the subject matter of Example 14-30 or any of the Examples described herein may further include: wherein the control circuitry is arranged to allocate resource for transmission by the Slave and reception by the Slave.

5 In Example 32, the subject matter of Example 31 or any of the Examples described herein may further include: wherein the control circuitry is arranged to cause transmission of sidelink control information (SCI) including a field indicating the allocated reception resource for reception by the Slave.

10 In Example 33, the subject matter of Example 14-32 or any of the Examples described herein may further include wherein the control circuitry is to schedule transmit and receive resources within a single sidelink control information (SCI) period.

In Example 34, the subject matter of Example 1-13 or any of the Examples described
15 herein may further include: wherein the control circuitry is to cause the UE to operate as a Slave in the communication via the sidelink, and
the UE is to communicate with another UE via the sidelink, the another UE to operate as a Master.

20 Example 35. An apparatus for use in a user equipment (UE), the apparatus comprising:
control circuitry to control communication with another UE via sidelink, wherein
the control circuitry is to cause the UE to operate as a Slave in the communication via the
sidelink, and the another UE is to operate as a Master.

25 In Example 36, the subject matter of Example 34-35 or any of the Examples described herein may further include: wherein the control circuitry is to process sidelink synchronization signals (SL-SS) from the Master.

In Example 37, the subject matter of Example 36 or any of the Examples described herein
30 may further include: wherein the SL-SS include an SL-SS identity, and the control circuitry is to interpret the SL-SS as a pico-net or personal area network (PAN) ID.

In Example 38, the subject matter of Example 34-37 or any of the Examples described herein may further include: wherein the control circuitry is to:

receive a signal from the Master; and
adjust a transmission power of the UE based on the signal.

5 In Example 39, the subject matter of Example 38 or any of the Examples described herein may further include: wherein the signal includes a control message to control power for the UE.

10 In Example 40, the subject matter of Example 38 or any of the Examples described herein may further include: wherein the signal includes a quantized path loss value.

In Example 41, the subject matter of Example 38 or any of the Examples described herein may further include: wherein the signal includes a target range class that corresponds to one of a plurality of fixed transmission power levels for the UE.

15 In Example 42, the subject matter of Example 34-41 or any of the Examples described herein may further include: wherein the control circuitry is to:
receive a signal from the Master; and
set a modulation coding scheme (MCS) for transmission based on the signal.

20 In Example 43, the subject matter of Example 34-42 or any of the Examples described herein may further include wherein the control circuitry is to receive control information from the Master and extract parameters for transmission and reception.

25 In Example 44, the subject matter of Example 34-43 or any of the Examples described herein may further include: wherein the control circuitry is arranged to receive, from the Master, sidelink control information (SCI) including a field indicating allocated reception resource, the allocated reception resource for transmission by the apparatus and reception by the Master.

30 In Example 45, the subject matter of Example 34-44 or any of the Examples described herein may further include: wherein the control circuitry is to:
receive sidelink control information (SCI) associated with a SCI period, and
obtain transmit and receive resources from the SCI, wherein
the transmit and receive resources are within the SCI period.

In Example 46, the subject matter of Example 14-45 or any of the Examples described herein may further include: wherein the Master is to use different transmission frame format, waveform, transmission timing, measurements and/or channels from the Slave.

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In Example 47, the subject matter of Example 14-45 or any of the Examples described herein may further include: wherein the physical layer of the Slave is symmetrical with the physical layer of the Master.

10 In Example 48, the subject matter of Example 14-47 or any of the Examples described herein may further include: wherein the Master acts as a synchronization source.

In Example 49, the subject matter of Example 1-48 or any of the Examples described herein may further include: wherein the control circuitry is to:

15 estimate a pathloss for the sidelink and
set a transmission power based on the estimated pathloss.

Example 50. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication via sidelink, the control circuitry to:

20 estimate a pathloss for the sidelink and
set a transmission power of the UE in the sidelink based on the estimated pathloss.

In Example 51, the subject matter of Example 1-48 or any of the Examples described herein may further include: wherein the control circuitry is to:

25 estimate a pathloss for the sidelink and
provide an indication of the estimated pathloss and/or a transmission power based on the estimated pathloss to another UE communicating via the UE-UE link.

Example 52. An apparatus for use in a user equipment (UE), the apparatus comprising:

30 control circuitry to control communication via sidelink, the communication via the sidelink with another UE, the control circuitry to:
estimate a pathloss for the sidelink and
provide an indication of the estimated pathloss and/or a transmission power based on the estimated pathloss to another UE communicating via the UE-UE link.

In Example 53, the subject matter of Example 1-52 or any of the Examples described herein may further include: wherein the control circuitry is to at least one of:

- 5 cause transmission of an acknowledgement (ACK) in response to receipt of a media access control (MAC) Protocol data unit (PDU),
- cause transmission of a negative acknowledgement (NACK) in response to erroneous receipt of a MAC PDU,
- receive an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or
- 10 cause retransmission of a MAC PDU in response to receipt of a NACK relating to an earlier transmission of the MAC PDU.

Example 54. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication via sidelink, the control circuitry to at least one of:

- 15 cause transmission of an acknowledgement (ACK) in response to receipt of a media access control (MAC) Protocol data unit (PDU),
- cause transmission of a negative acknowledgement (NACK) in response to erroneous receipt of a MAC PDU,
- 20 receive an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or
- cause retransmission of a MAC PDU in response to receipt of a NACK relating to an earlier transmission of the MAC PDU.

25 In Example 55, the subject matter of Example 1-54 or any of the Examples described herein may further include: wherein the control circuitry is to:

- perform a measurement related to channel quality of the sidelink; and
- provide information based on the channel quality to the another UE.

30 Example 56. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication with another UE via sidelink, the control circuitry to:

- perform a measurement related to channel quality of the sidelink; and
- provide information based on the channel quality to the another UE.

In Example 57, the subject matter of Example 1-56 or any of the Examples described herein may further include: wherein the control circuitry is to:

- perform a measurement related to channel quality of the sidelink; and
- 5 set a power for transmission in the sidelink based on the channel quality to the another UE.

Example 58. An apparatus for use in a user equipment (UE), the apparatus comprising: control circuitry to control communication with another UE via sidelink, the control
10 circuitry to:

- perform a measurement related to channel quality of the sidelink; and
- set a power for transmission in the sidelink based on the channel quality to the another UE.

15 In Example 59, the subject matter of Example 1-58 or any of the Examples described herein may further include: further comprising a channel coder to use common coding for broadcast, control, and shared channels.

In Example 60, the subject matter of Example 59 or any of the Examples described herein
20 may further include: wherein the common coding comprises a convolutional turbo code (CTC).

In Example 61, the subject matter of Example 59-60 or any of the Examples described herein may further include: wherein the channel coder is to use the common coding for:
25 a physical sidelink broadcast channel (PSBCH), a physical sidelink control channel (PSCCH) and a physical sidelink shared channel (PSSCH).

In Example 62, the subject matter of Example 1-61 or any of the Examples described herein may further include: wherein the control circuitry is to use a zero-decibel (dB)
30 peak-to-average power ratio (PAPR) transmit waveform.

In Example 63, the subject matter of Example 62 or any of the Examples described herein may further include: wherein the zero-dB PAPR transmit waveform is selected from:
frequency division multiple access (FDMA) with frequency-shift keying (FSK)

modulation,

FDMA with Gaussian frequency shift keying (GFSK), or
FDMA Gaussian Minimum Shift Keying (GMSK).

- 5 In Example 64, the subject matter of Example 1-63 or any of the Examples described herein may further include: wherein the transmit, receive or transceiver chain is a transceiver chain and the control circuitry is to control the transceiver chain such that transmission and reception occur only in different time instances.
- 10 In Example 65, the subject matter of Example 64 or any of the Examples described herein may further include: wherein the control circuitry is to control the transceiver chain such that there is a turn-around gap between transmission time instances and reception time instances.
- 15 In Example 66, the subject matter of Example 1-65 or any of the Examples described herein may further include: wherein the control circuitry is to cause delivery of data via the sidelink according to a connectionless operation.

In Example 67, the subject matter of Example 66 or any of the Examples described herein
20 may further include: wherein delivering the data includes sending the data in a data packet by a single physical layer transmission.

In Example 68, the subject matter of Example 1-67 or any of the Examples described herein may further include wherein the sidelink control information (SCI) period is greater
25 than 320 subframes.

In Example 69, the subject matter of Example 68 or any of the Examples described herein may further include wherein the SCI period is selected from 640, 1280, 2560, 5120 or 10240 subframes.

30

In Example 70, the subject matter of Example 68 or any of the Examples described herein may further include: wherein the SCI period is selected from 560, 1120, 2240, 4480 or 8960 subframes.

In Example 71, the subject matter of Example 68 or any of the Examples described herein may further include: wherein the SCI period is selected from 480, 960, 1920, 3840 or 7680 subframes.

- 5 In Example 72, the subject matter of Example 1-67 or any of the Examples described herein may further include: wherein discontinuous reception (DRX) and paging cycles are used in the sidelink.

- 10 In Example 73, the subject matter of Example 72 or any of the Examples described herein may further include: wherein the UE is configured with DRX and paging cycles as multiple of a sidelink control information (SCI) period.

- 15 In Example 74, the subject matter of Example 1-73 or any of the Examples described herein may further include: wherein the control circuitry is to cause the UE to operate in a spectrum resource pool dedicated for low power communication devices.

Example 75. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- 20 utilizing a single transceiver chain of the UE to provide the D2D communication in a narrowband spectrum.

- 25 In Example 76, the subject matter of Example 75 or any of the Examples described herein may further include: wherein the narrowband spectrum is composed of one, six, or twelve physical resource blocks (PRBs).

- 30 In Example 77, the subject matter of Example 75-76 or any of the Examples described herein may further include: performing no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

Example 78. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- performing no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH)

subframe.

In Example 79, the subject matter of Examples 75-78 or any of the Examples described herein may further include:

- 5 restricting a number of sidelink control information blind decoding attempts during processing of physical side link control channel (PSCCH).

Example 80. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- 10 restricting a number of sidelink control information blind decoding attempts during processing of physical side link control channel (PSCCH).

In Example 81, the subject matter of Example 80 or any of the Examples described herein may further include: restricting the number to no more than 3 attempts in a subframe.

15

In Example 82, the subject matter of Example 75-81 or any of the Examples described herein may further include: restricting operation of the UE to handle less than 16 simultaneous sidelink receive processes.

- 20 Example 83. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

 restricting operation of the UE to handle less than 16 simultaneous sidelink receive processes.

- 25 In Example 84, the subject matter of Examples 75-83 or any of the Examples described herein may further include:

 restricting operation of the UE to no more than three sidelink receive processes.

In Example 85, the subject matter of Example 75-84 or any of the Examples described
30 herein may further include: communicating via sidelink using Quadrature Phase Shift Keying (QPSK) and the transport block size (TBS) has a maximum of 1000 bits.

Example 86. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

communicating via sidelink using Quadrature Phase Shift Keying (QPSK) and the transport block size (TBS) has a maximum of 1000 bits.

5 In Example 87, the subject matter of Example 75-84 or any of the Examples described herein may further include:

using a transport block size (TBS) greater than 25456 bits, and/or
using fewer than 3 transmission time interval (TTIs) for each transport block (TB).

10 Example 88. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising at least one of:
using a transport block size (TBS) greater than 25456 bits, and/or
using fewer than 3 transmission time interval (TTIs) for each transport block (TB).

15 In Example 89, the subject matter of Example 75-88 or any of the Examples described herein may further include: transmitting and/or receiving:
only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or
only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

20

Example 90. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

transmitting only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or
25 only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

In Example 91, the subject matter of Examples 75-90 or any of the Examples described herein may further include:

operating the UE as a master or slave of a D2D link.
30

Example 92. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

operating the UE as a master or slave of a D2D link.

In Example 93, the subject matter of Example 91-92 or any of the Examples described herein may further include: the master allocates resource for transmission and reception.

5 In Example 94, the subject matter of Example 91-93 or any of the Examples described herein may further include: wherein the master sends sidelink control information (SCI) for transmission and SCI for reception.

10 In Example 95, the subject matter of Example 91-94 or any of the Examples described herein may further include: wherein the master performs radio measurements for controlling modulation and coding scheme (MCS), allocation size, power settings for both transmission by the master and transmission by the slave.

15 In Example 96, the subject matter of Example 91-95 or any of the Examples described herein may further include: wherein the master broadcasts synchronization signals accompanied by broadcast channel, a personal area network (PAN) identity encoded into the synchronization signals.

20 In Example 97, the subject matter of Example 91-96 or any of the Examples described herein may further include: wherein the master estimates transmission power for the slave and reports it to the slave.

In Example 98, the subject matter of Example 91-97 or any of the Examples described herein may further include: wherein the slave synchronizes to the master.

25 In Example 99, the subject matter of Example 91-98 or any of the Examples described herein may further include: wherein the slave decodes control information from the master and extracts parameters for transmission and reception.

30 In Example 100, the subject matter of Example 91-99 or any of the Examples described herein may further include: operating the UE as the master.

In Example 101, the subject matter of Example 100 or any of the Examples described herein may further include: allocating resource for transmission and reception by the slave.

In Example 102, the subject matter of Example 100-101 or any of the Examples described herein may further include: allocating resource for transmission and reception by the master.

- 5 In Example 103, the subject matter of Example 100-102 or any of the Examples described herein may further include: transmitting a sidelink synchronization signals (SL-SS).

In Example 104, the subject matter of Example 103 or any of the Examples described herein may further include: wherein the SL-SS include an SL-SS identity.

10

In Example 105, the subject matter of Example 100-104 or any of the Examples described herein may further include: measuring a channel quality between the master and slave.

- 15 In Example 106, the subject matter of Example 105 or any of the Examples described herein may further include: wherein measuring the channel quality includes measuring one or more of pathloss, reference signal received power (RSRP) or reference signal received quality (RSRQ).

- 20 In Example 107, the subject matter of Example 106 or any of the Examples described herein may further include: setting a transmit power of the master based on the measurement.

- 25 In Example 108, the subject matter of Example 106 or any of the Examples described herein may further include: sending information based on the measurement to the slave to set a transmit power of the slave.

- In Example 109, the subject matter of Example 105-108 or any of the Examples described herein may further include: estimating, based on the measurement, one or more of channel quality indication (CQI) and/or channel state information (CSI).

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In Example 110, the subject matter of Example 109 or any of the Examples described herein may further include: adjusting a modulation coding scheme (MCS) of the Master and/or Slave based on the estimate.

In Example 111, the subject matter of Example 100-110 or any of the Examples described herein may further include: scheduling transmission and reception by the slave.

5 In Example 112, the subject matter of Example 111 or any of the Examples described herein may further include: wherein the scheduling is such that transmission and reception by the slave are not simultaneous.

10 In Example 113, the subject matter of Example 111-112 or any of the Examples described herein may further include: transmitting control information including parameters for the transmission and reception schedule.

15 In Example 114, the subject matter of Example 100-113 or any of the Examples described herein may further include: scheduling transmit and receive resources within a single sidelink control information (SCI) period.

In Example 115, the subject matter of Example 100-114 or any of the Examples described herein may further include:

20 estimating a pathloss of the sidelink between the master and slave;
 calculating a transmission power to be used by the slave based on the estimated pathloss; and
 signaling the calculated transmission power to the Slave in a control message.

In Example 116, the subject matter of Example 100-114 or any of the Examples described herein may further include:

25 estimating a pathloss of the sidelink between the Master and Slave;
 signaling to the slave a quantized pathloss value to control a transmission power of the slave, based on the estimated pathloss.

30 In Example 117, the subject matter of Example 100-114 or any of the Examples described herein may further include:

 estimating a pathloss of the sidelink between the Master and Slave;
 signaling to the slave a target range class that corresponds to one of a plurality of fixed transmission power levels for the Slave.

In Example 118, the subject matter of Example 91-99 or any of the Examples described herein may further include: operating the UE as the slave.

5 In Example 119, the subject matter of Example 118 or any of the Examples described herein may further include: receiving from the master an allocation of resource for transmission and reception by the slave.

10 In Example 120, the subject matter of Example 118-119 or any of the Examples described herein may further include: receiving and processing from the master a sidelink synchronization signals (SL-SS).

In Example 121, the subject matter of Example 120 or any of the Examples described herein may further include: wherein the SL-SS include an SL-SS identity.

15 In Example 122, the subject matter of Example 118-121 or any of the Examples described herein may further include:

receiving information from the master relating to a channel quality between the master and slave, and

20 setting a transmission power for communication with the master based on the received information.

In Example 123, the subject matter of Example 118-122 or any of the Examples described herein may further include:

25 receiving information from the master and setting a modulation coding scheme (MCS) for transmission based on the signal.

In Example 124, the subject matter of Example 118-123 or any of the Examples described herein may further include: receiving control information from the master and extracting parameters for transmission and reception.

30

In Example 125, the subject matter of Example 118-124 or any of the Examples described herein may further include:

receiving sidelink control information (SCI) for a SCI period, and
obtaining transmit and receive resources from the SCI, wherein

the transmit and receive resources are within the SCI period.

In Example 126, the subject matter of Example 118-125 or any of the Examples described herein may further include:

- 5 receiving a signal from the master; and
- adjusting a transmission power of the UE based on the signal.

In Example 127, the subject matter of Example 126 or any of the Examples described herein may further include: wherein receiving a signal from the master includes receiving
10 a control message to control transmission power for the slave.

In Example 128, the subject matter of Example 126 or any of the Examples described herein may further include: wherein the signal includes a quantized path loss value.

15 In Example 129, the subject matter of Example 126 or any of the Examples described herein may further include: wherein the signal includes a target range class that corresponds to one of a plurality of fixed transmission power levels for the UE.

In Example 130, the subject matter of Example 91-129 or any of the Examples described
20 herein may further include: wherein the master and slave use different transmission frame format, waveform, transmission timing, measurements and/or channels.

In Example 131, the subject matter of Example 91-129 or any of the Examples described herein may further include: wherein the physical layer of the slave is symmetrical with the
25 physical layer of the master.

In Example 132, the subject matter of Example 75-131 or any of the Examples described herein may further include:

- estimating a pathloss for the sidelink and
- 30 setting a transmission power based on the estimated pathloss.

Example 133. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

 estimating a pathloss for the sidelink and

setting a transmission power based on the estimated pathloss.

In Example 134, the subject matter of Example 75-131 or any of the Examples described herein may further include:

- 5 estimating a pathloss for the sidelink and
 providing an indication of the estimated pathloss and/or a transmission power based on the estimated pathloss to another UE communicating via the UE-UE link.

10 Example 135. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- estimating a pathloss for the sidelink and
 providing an indication of the estimated pathloss and/or a transmission power based on the estimated pathloss to another UE communicating via the UE-UE link.

15 In Example 136, the subject matter of Examples 75-135 or any of the Examples described herein may further include: at least one of:

- transmitting an acknowledgement (ACK) in response to receipt of a media access control (MAC) Protocol data unit (PDU),
- transmitting a negative acknowledgement (NACK) in response to erroneous receipt
20 of a MAC PDU,
- receiving an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or
- retransmitting a MAC PDU in response to receipt of a NACK relating to an earlier transmission of the MAC PDU.

25

Example 137. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- transmitting an acknowledgement (ACK) in response to receipt of a media access control (MAC) Protocol data unit (PDU),
- 30 transmitting a negative acknowledgement (NACK) in response to erroneous receipt of a MAC PDU,
- receiving an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or
- retransmitting a MAC PDU in response to receipt of a NACK relating to an earlier

transmission of the MAC PDU.

In example 138, the subject matter of Example 75-137 or any of the Examples described herein may further include:

- 5 performing a measurement related to channel quality of the sidelink; and
providing information based on the channel quality to the another UE.

Example 139. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- 10 performing a measurement related to channel quality of the sidelink; and
providing information based on the channel quality to the another UE.

In example 140, the subject matter of Example 75-139 or any of the Examples described herein may further include:

- 15 performing a measurement related to channel quality of the sidelink; and
setting a power for transmission in the sidelink based on the channel quality to the
another UE.

Example 141. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- 20 performing a measurement related to channel quality of the sidelink; and
setting a power for transmission in the sidelink based on the channel quality to the
another UE.

- 25 In Example 142, the subject matter of Examples 75-141 or any of the Examples described
herein may further include: encoding information for transmission via broadcast, control,
and shared channels using a common channel coding.

- In Example 143, the subject matter of Examples 142 or any of the Examples described
30 herein may further include wherein the common channel coding comprises a convolutional
turbo code.

In Example 144, the subject matter of Examples 142-143 or any of the Examples described herein may further include: the broadcast, control, and shared channels include a

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

5 In Example 145, the subject matter of Examples 75-144 or any of the Examples described herein may further include: utilizing a zero-decibel (dB) peak-to-average power ratio (PAPR) transmit waveform.

10 In Example 146, the subject matter of Examples 145 or any of the Examples described herein may further include: wherein the zero-dB PAPR transmit waveform is frequency division multiple access with frequency-shift keying (FSK) modulation.

15 In Example 147, the subject matter of Examples 75-146 or any of the Examples described herein may further include: the transceiver chain transmits and receives only at different times.

In Example 148, the subject matter of Example 75-147 or any of the Examples described herein may further include: delivering data in a connectionless operation via sidelink.

20 In Example 149, the subject matter of Example 148 or any of the Examples described herein may further include: wherein delivering the data in a connectionless operation includes sending the data in a data packet by a single physical layer transmission.

25 In Example 150, the subject matter of Examples 75-149 or any of the Examples described herein may further include: wherein the UE is configured with sidelink control information (SCI) periods larger than 320 ms.

In Example 151, the subject matter of Examples 75-149 or any of the Examples described herein may further include:

30 utilizing discontinuous reception (DRX) and paging cycles for operation in sidelink.

In Example 152, the subject matter of Example 151 or any of the Examples described herein may further include: wherein the UE is configured with DRX and paging cycles as multiple of a sidelink control information (SCI) period.

In Example 153, the subject matter of Examples 75-152 or any of the Examples described herein may further include:

5 operating the UE in a spectrum resource pool dedicated for low power communication.

In Example 154, the subject matter of Example 75-153 or any of the Examples described herein may further include:

10 utilizing a dedicated resource configured by a network for low-power D2D communication.

Example 155. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

15 utilizing a single transceiver chain of the UE to provide the D2D communication in a narrowband spectrum.

In Example 156, the subject matter of Example 155 or any of the Examples described herein may further include: wherein the narrowband spectrum is composed of one, six, or
20 twelve physical resource blocks (PRBs).

In Example 157, the subject matter of Example 155-156 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to perform no more than three sidelink control information (SCI) blind decoding
25 attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

Example 158. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to
30 communicate using device-to-device (D2D) communication, the method comprising:

 performing no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

In Example 159, the subject matter of Examples 155-158 or any of the Examples described herein may further include:

5 the machine executable instructions to restrict a number of sidelink control information blind decoding attempts during processing of physical side link control channel (PSCCH).

Example 160. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

10 the machine executable instructions to restrict a number of sidelink control information blind decoding attempts during processing of physical side link control channel (PSCCH).

In Example 161, the subject matter of Examples 159-160 or any of the Examples described herein may further include: the machine executable instructions to restrict the number to no more than 3 attempts in a subframe.

In Example 162, the subject matter of Example 155-161 or any of the Examples described herein may further include: the machine executable instructions to restrict operation of the UE to handle less than 16 simultaneous sidelink receive processes.

Example 163. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

25 restricting operation of the UE to handle less than 16 simultaneous sidelink receive processes.

In Example 164, the subject matter of Examples 155-163 or any of the Examples described herein may further include:

30 the machine executable instructions to restrict operation of the UE to no more than three sidelink receive processes.

In Example 165, the subject matter of Example 155-164 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more

processor to communicate via sidelink using Quadrature Phase Shift Keying (QPSK) and such that the transport block size (TBS) has a maximum of 1000 bits.

Example 166. Machine executable instructions arranged, when executed by one or more

5 processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

communicating via sidelink using Quadrature Phase Shift Keying (QPSK) and the transport block size (TBS) has a maximum of 1000 bits.

10 In Example 167, the subject matter of Example 155-164 or any of the Examples described herein may further include: the machine executable instructions to

using a transport block size (TBS) greater than 25456 bits, and/or

using fewer than 3 transmission time interval (TTIs) for each transport block (TB).

15 Example 168. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising at least one of:

using a transport block size (TBS) greater than 25456 bits, and/or

20 using fewer than 3 transmission time interval (TTIs) for each transport block (TB).

In Example 169, the subject matter of Example 155-168 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to transmit and/or receive:

25 only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or

only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

30 Example 170. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

transmitting only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or

only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

5 In Example 171, the subject matter of Examples 155-170 or any of the Examples described herein may further include:

the machine executable instructions to cause the UE to operate as a master or slave of a D2D link.

10 Example 172. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:
operating the UE as a master or slave of a D2D link.

15 In Example 173, the subject matter of Example 171-172 or any of the Examples described herein may further include: the master to allocate resource for transmission and reception.

In Example 174, the subject matter of Example 171-173 or any of the Examples described herein may further include: wherein the master to send sidelink control information (SCI) for transmission and SCI for reception.

20 In Example 175, the subject matter of Example 171-174 or any of the Examples described herein may further include: wherein the master to perform radio measurements for controlling modulation and coding scheme (MCS), allocation size, power settings for both transmission by the master and transmission by the slave.

25 In Example 176, the subject matter of Example 171-175 or any of the Examples described herein may further include: wherein the master to broadcasts synchronization signals accompanied by broadcast channel, a personal area network (PAN) identity encoded into the synchronization signals.

30 In Example 177, the subject matter of Example 171-176 or any of the Examples described herein may further include: wherein the master to estimate transmission power for the slave and report it to the slave.

In Example 178, the subject matter of Example 171-177 or any of the Examples described herein may further include: wherein the slave to synchronize to the master.

5 In Example 179, the subject matter of Example 171-178 or any of the Examples described herein may further include: wherein the slave to decode control information from the master and extract parameters for transmission and reception.

10 In Example 180, the subject matter of Example 171-179 or any of the Examples described herein may further include: the machine executable instructions to cause the UE to operate as the master.

15 In Example 181, the subject matter of Example 180 or any of the Examples described herein may further include: the machine executable instructions to allocate resource for transmission and reception by the slave.

In Example 182, the subject matter of Example 180-181 or any of the Examples described herein may further include: the machine executable instructions to allocate resource for transmission and reception by the master.

20 In Example 183, the subject matter of Example 180-182 or any of the Examples described herein may further include: the machine executable instructions to cause transmission of a sidelink synchronization signals (SL-SS).

25 In Example 184, the subject matter of Example 183 or any of the Examples described herein may further include: wherein the SL-SS is to include an SL-SS identity.

In Example 185, the subject matter of Example 180-184 or any of the Examples described herein may further include: the machine executable instructions to cause measurement of a channel quality between the master and slave.

30 In Example 186, the subject matter of Example 185 or any of the Examples described herein may further include: wherein measuring the channel quality includes measuring one or more of pathloss, reference signal received power (RSRP) or reference signal received quality (RSRQ).

In Example 187, the subject matter of Example 186 or any of the Examples described herein may further include: the machine executable instructions to set a transmit power of the master based on the measurement.

5

In Example 188, the subject matter of Example 186 or any of the Examples described herein may further include: the machine executable instructions to cause information based on the measurement to be sent to the slave to set a transmit power of the slave.

10 In Example 189, the subject matter of Example 185-188 or any of the Examples described herein may further include: the machine executable instructions to estimate, based on the measurement, one or more of channel quality indication (CQI) and/or channel state information (CSI).

15 In Example 190, the subject matter of Example 189 or any of the Examples described herein may further include: the machine executable instructions to adjust a modulation coding scheme (MCS) of the Master and/or Slave based on the estimate.

20 In Example 191, the subject matter of Example 180-190 or any of the Examples described herein may further include: the machine executable instructions to schedule transmission and reception by the slave.

25 In Example 192, the subject matter of Example 191 or any of the Examples described herein may further include: wherein the scheduling is such that transmission and reception by the slave are not simultaneous.

In Example 193, the subject matter of Example 191-192 or any of the Examples described herein may further include: the machine executable instructions to cause transmission of control information including parameters for the transmission and reception schedule.

30

In Example 194, the subject matter of Example 180-193 or any of the Examples described herein may further include: the machine executable instructions to schedule transmit and receive resources within a single sidelink control information (SCI) period.

In Example 195, the subject matter of Example 180-194 or any of the Examples described herein may further include machine executable instructions to cause the one or more processor to:

- estimate a pathloss of the sidelink between the master and slave;
- 5 calculate a transmission power to be used by the slave based on the estimated pathloss; and
- signal the calculated transmission power to the Slave in a control message.

10 In Example 196, the subject matter of Example 180-194 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to:

- estimate a pathloss of the sidelink between the Master and Slave;
- signal to the slave a quantized pathloss value to control a transmission power of the slave, based on the estimated pathloss.

15

In Example 197, the subject matter of Example 180-194 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to

- estimate a pathloss of the sidelink between the Master and Slave;
- 20 signal to the slave a target range class that corresponds to one of a plurality of fixed transmission power levels for the Slave.

25 In Example 198, the subject matter of Example 171-179 or any of the Examples described herein may further include: the machine executable instructions to cause the UE to operate as the slave.

30 In Example 199, the subject matter of Example 198 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to receive from the master an allocation of resource for transmission and reception by the slave.

In Example 200, the subject matter of Example 198-199 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to receive and process from the master sidelink synchronization signals (SL-SS).

In Example 201, the subject matter of Example 200 or any of the Examples described herein may further include: wherein the SL-SS includes an SL-SS identity.

- 5 In Example 202, the subject matter of Example 198-201 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to:

receive information from the master relating to a channel quality between the master and slave, and

- 10 set a transmission power for communication with the mater based on the received information.

In Example 203, the subject matter of Example 198-202 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more

- 15 processor to:

receive information from the master and

set a modulation coding scheme (MCS) for transmission based on the signal.

In Example 204, the subject matter of Example 198-203 or any of the Examples described

- 20 herein may further include: the machine executable instructions to cause the one or more processor to receive control information from the master and extract parameters for transmission and reception.

In Example 205, the subject matter of Example 198-204 or any of the Examples described

- 25 herein may further include: the machine executable instructions to cause the one or more processor to:

receive sidelink control information (SCI) for a SCI period, and

obtain transmit and receive resources from the SCI, wherein

the transmit and receive resources are within the SCI period.

- 30

In Example 206, the subject matter of Example 198-205 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to:

receive a signal from the master; and

adjust a transmission power of the UE based on the signal.

In Example 207, the subject matter of Example 206 or any of the Examples described herein may further include: wherein receiving a signal from the master includes receiving
5 a control message to control transmission power for the slave.

In Example 208, the subject matter of Example 206 or any of the Examples described herein may further include: wherein the signal includes a quantized path loss value.

10 In Example 209, the subject matter of Example 206 or any of the Examples described herein may further include: wherein the signal includes a target range class that corresponds to one of a plurality of fixed transmission power levels for the UE.

In Example 210, the subject matter of Example 155-209 or any of the Examples described
15 herein may further include: wherein the master and slave to use different transmission frame format, waveform, transmission timing, measurements and/or channels.

In Example 211, the subject matter of Example 155-209 or any of the Examples described herein may further include: wherein the physical layer of the slave is symmetrical with the
20 physical layer of the master.

In Example 212, the subject matter of Example 155-211 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to:

25 estimate a pathloss for the sidelink and
set a transmission power based on the estimated pathloss.

Example 213. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to
30 communicate using device-to-device (D2D) communication, the method comprising:
estimating a pathloss for the sidelink and
setting a transmission power based on the estimated pathloss.

In Example 214, the subject matter of Example 155-211 or any of the Examples described

herein may further include: the machine executable instructions to cause the one or more processor to:

- estimate a pathloss for the sidelink and
- provide an indication of the estimated pathloss and/or a transmission power based
- 5 on the estimated pathloss to another UE communicating via the UE-UE link.

Example 215. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- 10 estimating a pathloss for the sidelink and
- providing an indication of the estimated pathloss and/or a transmission power
- based on the estimated pathloss to another UE communicating via the UE-UE link.

In Example 216, the subject matter of Examples 155-215 or any of the Examples

15 described herein may further include: the machine executable instructions to at least one of:

- transmit an acknowledgement (ACK) in response to receipt of a media access control (MAC) Protocol data unit (PDU),
- transmit a negative acknowledgement (NACK) in response to erroneous receipt of
- 20 a MAC PDU,
- receive an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or
- retransmit a MAC PDU in response to receipt of a NACK relating to an earlier transmission of the MAC PDU.

25

Example 217. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:

- transmitting an acknowledgement (ACK) in response to receipt of a media access
- 30 control (MAC) Protocol data unit (PDU),
- transmitting a negative acknowledgement (NACK) in response to erroneous receipt of a MAC PDU,
- receiving an ACK in response to transmission of a MAC PDU and refrain from causing retransmission of the MAC PDU, or

retransmitting a MAC PDU in response to receipt of a NACK relating to an earlier transmission of the MAC PDU.

5 In example 218, the subject matter of Example 155-217 or any of the Examples described herein may further include: the machine executable instructions to:
perform a measurement related to channel quality of the sidelink; and
provide information based on the channel quality to the another UE.

10 Example 219. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:
performing a measurement related to channel quality of the sidelink; and
providing information based on the channel quality to the another UE.

15 In example 220, the subject matter of Example 155-219 or any of the Examples described herein may further include: the machine executable instructions to:
perform a measurement related to channel quality of the sidelink; and
set a power for transmission in the sidelink based on the channel quality to the
another UE.

20 Example 221. Machine executable instructions arranged, when executed by one or more processor, to implement a method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:
performing a measurement related to channel quality of the sidelink; and
25 setting a power for transmission in the sidelink based on the channel quality to the
another UE.

In Example 222, the subject matter of Examples 155-221 or any of the Examples described herein may further include: machine executable instructions to encode
30 information for transmission via broadcast, control, and shared channels using a common channel coding.

In Example 223, the subject matter of Examples 222 or any of the Examples described herein may further include wherein the common channel coding comprises a convolutional

turbo code.

In Example 224, the subject matter of Examples 222-223 or any of the Examples described herein may further include: the broadcast, control, and shared channels include a
5 PSBCH (physical sidelink broadcast channel), a PSCCH (physical sidelink control channel) and a PSSCH (physical sidelink shared channel).

In Example 225, the subject matter of Examples 155-224 or any of the Examples described herein may further include: wherein the machine executable instructions to
10 utilize a zero-decibel (dB) peak-to-average power ratio (PAPR) transmit waveform.

In Example 226, the subject matter of Examples 225 or any of the Examples described herein may further include: wherein the zero-dB PAPR transmit waveform is frequency division multiple access with frequency-shift keying (FSK) modulation.
15

In Example 227, the subject matter of Examples 155-226 or any of the Examples described herein may further include: machine executable instructions to cause the transceiver chain to transmit and receive only at different times.

20 In Example 228, the subject matter of Examples 155-227 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to deliver data in a connectionless operation via sidelink.

In Example 229, the subject matter of Example 228 or any of the Examples described
25 herein may further include: wherein delivering the data in a connectionless operation includes sending the data in a data packet by a single physical layer transmission.

In Example 230, the subject matter of Examples 155-229 or any of the Examples described herein may further include: the machine executable instructions to configure the
30 UE with sidelink control information (SCI) periods larger than 320 ms.

In Example 231, the subject matter of Examples 155-229 or any of the Examples described herein may further include:

the machine executable instructions to utilize discontinuous reception (DRX) and

paging cycles for operation in sidelink.

In Example 232, the subject matter of Example 231 or any of the Examples described herein may further include: the machine executable instructions to configure the UE with
5 DRX and paging cycles as multiple of a sidelink control information (SCI) period.

In Example 233, the subject matter of Examples 155-232 or any of the Examples described herein may further include:

the machine executable instructions to cause the UE to operate in a spectrum
10 resource pool dedicated for low power communication.

In Example 234, the subject matter of Example 155-233 or any of the Examples described herein may further include: the machine executable instructions to cause the one or more processor to cause the UE to utilize a dedicated resource configured by a network for low-
15 power D2D communication.

Example 235. One or more computer-readable media comprising the machine executable instructions of any one of Examples 155-234.

20 In Example 236, the subject matter of Example 235, wherein the one or more computer-readable media are non-transitory media.

Example 237. An apparatus for use in a user equipment (UE), the apparatus comprising:
means to control communication via sidelink using a single transmit, receive or
25 transceiver chain within a narrow bandwidth.

Example 238. An apparatus for use in a user equipment (UE), the apparatus comprising:
means to control communication via sidelink, by performing no more than three
sidelink control information (SCI) blind decoding attempts in a subframe during
30 processing of a physical sidelink control channel (PSCCH) subframe.

Example 239. An apparatus for use in a user equipment (UE), the apparatus comprising:
means to restrict communication via sidelink to handle less than 16 simultaneous
sidelink receive processes.

Example 240. An apparatus for use in a user equipment (UE), the apparatus comprising:
means to communicate via sidelink using Quadrature Phase Shift Keying (QPSK)
and a transport block size (TBS) having a maximum of 1000 bits

5

Example 241. An apparatus for use in a user equipment (UE), the apparatus comprising:
means to transmit and/or receive:

only a single transmission time interval (TTI) of physical sidelink control channel
(PSCCH) per transport block (TB), and/or

10 only a single TTI of physical sidelink shared channel (PSSCH) per transport block
(TB).

Example 242. An apparatus for use in a user equipment (UE), the apparatus comprising:

15 means to operate the UE as a Master in communication with another UE via a
sidelink, the another UE to operate as a Slave.

Example 243. An apparatus for use in a user equipment (UE), the apparatus comprising:

means operate the UE as a Slave in communication with another UE via a sidelink,
the another UE to operate as a Master.

20

Example 244. A UE comprising the apparatus of any one of examples 1-74 or 237-243 or
any of the Examples described herein, and further comprising one or more of: a display, a
camera, a sensor, an input/output (I/O) interface.

25 Example 245. An apparatus comprising means to perform one or more elements of a
method described in or related to any of examples 75-154, or any other method or process
described herein.

Example 246. One or more computer-readable media comprising instructions to cause an
30 electronic device, upon execution of the instructions by one or more processors of the
electronic device, to perform one or more elements of a method described in or related to
any of examples 75-154, or any other method or process described herein, or to operate as
the device of any one of examples 1 to 74.

Example 247. An apparatus comprising logic, modules, and/or circuitry to perform one or more elements of a method described in or related to any of examples 75-154, or any other method or process described herein.

5 Example 248. An apparatus comprising:

one or more processors; and

one or more computer readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples 75-154, or portions thereof.

10

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

15

CLAIMS

1. An apparatus for use in a user equipment (UE), the apparatus comprising:

control circuitry to control communication via sidelink within a narrow bandwidth,
5 the communication via the sidelink to use a single transmit, receive or transceiver chain;
and
the transmit, receive or transceiver chain.

2. The apparatus of claim 1, wherein the narrow bandwidth is selected from:

10 twelve physical resource blocks (PRBs),
six physical resource blocks,
one physical resource block,
2160 kHz,
1080 kHz, or
15 180 kHz.

3. The apparatus of claim 1, wherein the control circuitry is to perform no more than three
sidelink control information (SCI) blind decoding attempts in a subframe during
processing of a physical sidelink control channel (PSCCH) subframe.

20

4. The apparatus of claim 1, wherein the control circuitry is restricted to handle less than
16 simultaneous sidelink receive processes.

5. The apparatus of claim 4, wherein the control circuitry is restricted to handle no more
25 than three simultaneous sidelink receive processes.

6. The apparatus of claim 1, wherein the control circuitry is arranged to use a transport
block size (TBS) and modulation coding scheme (MCS) such that Quadrature Phase Shift
Keying (QPSK) is used and the TBS has a maximum of 1000 bits.

30

7. The apparatus of claim 1, wherein the control circuitry is to cause transmission and/or
reception of:

only a single transmission time interval (TTI) of physical sidelink control channel
(PSCCH) per transport block (TB), and/or

only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

8. The apparatus of claim 1, wherein the control circuitry is to cause the UE to operate as a Master in the communication via the sidelink, and
the UE is to communicate with another UE via the sidelink, the another UE to operate as a Slave.

9. The apparatus of claim 1, wherein the control circuitry is to cause the UE to operate as a Slave in the communication via the sidelink, and
the UE is to communicate with another UE via the sidelink, the another UE to operate as a Master.

10. A UE comprising the apparatus of any one of claims 1 to 9, and further comprising one or more of: a display, a camera, a sensor, an input/output (I/O) interface.

11. A method of operating a low-power user equipment (UE) to communicate using device-to-device (D2D) communication, the method comprising:
utilizing a single transceiver chain of the UE to provide the D2D communication in a narrowband spectrum.

12. The method of claim 11, wherein the narrowband spectrum is composed of one, six, or twelve physical resource blocks (PRBs).

13. The method of claim 11, further comprising performing no more than three sidelink control information (SCI) blind decoding attempts in a subframe during processing of a physical sidelink control channel (PSCCH) subframe.

14. The method of claim 11, further comprising restricting operation of the UE to handle less than 16 simultaneous sidelink receive processes.

15. The method of claim 11, further comprising:
restricting operation of the UE to no more than three sidelink receive processes.

16. The method of claim 11, further comprising communicating via sidelink using Quadrature Phase Shift Keying (QPSK) and the transport block size (TBS) has a maximum of 1000 bits.

- 5 17. The method of claim 11, further comprising transmitting and/or receiving:
only a single transmission time interval (TTI) of physical sidelink control channel (PSCCH) per transport block (TB), and/or
only a single TTI of physical sidelink shared channel (PSSCH) per transport block (TB).

10

18. The method of claim 11, further comprising:
operating the UE as a master or slave of a D2D link.

15

19. The method of claim 18, wherein the master allocates resource for transmission and reception.

20. The method of claim 18, wherein the master sends sidelink control information (SCI) for transmission and SCI for reception.

20

21. The method of claim 18, wherein the master performs radio measurements for controlling modulation and coding scheme (MCS), allocation size, power settings for both transmission by the master and transmission by the slave.

25

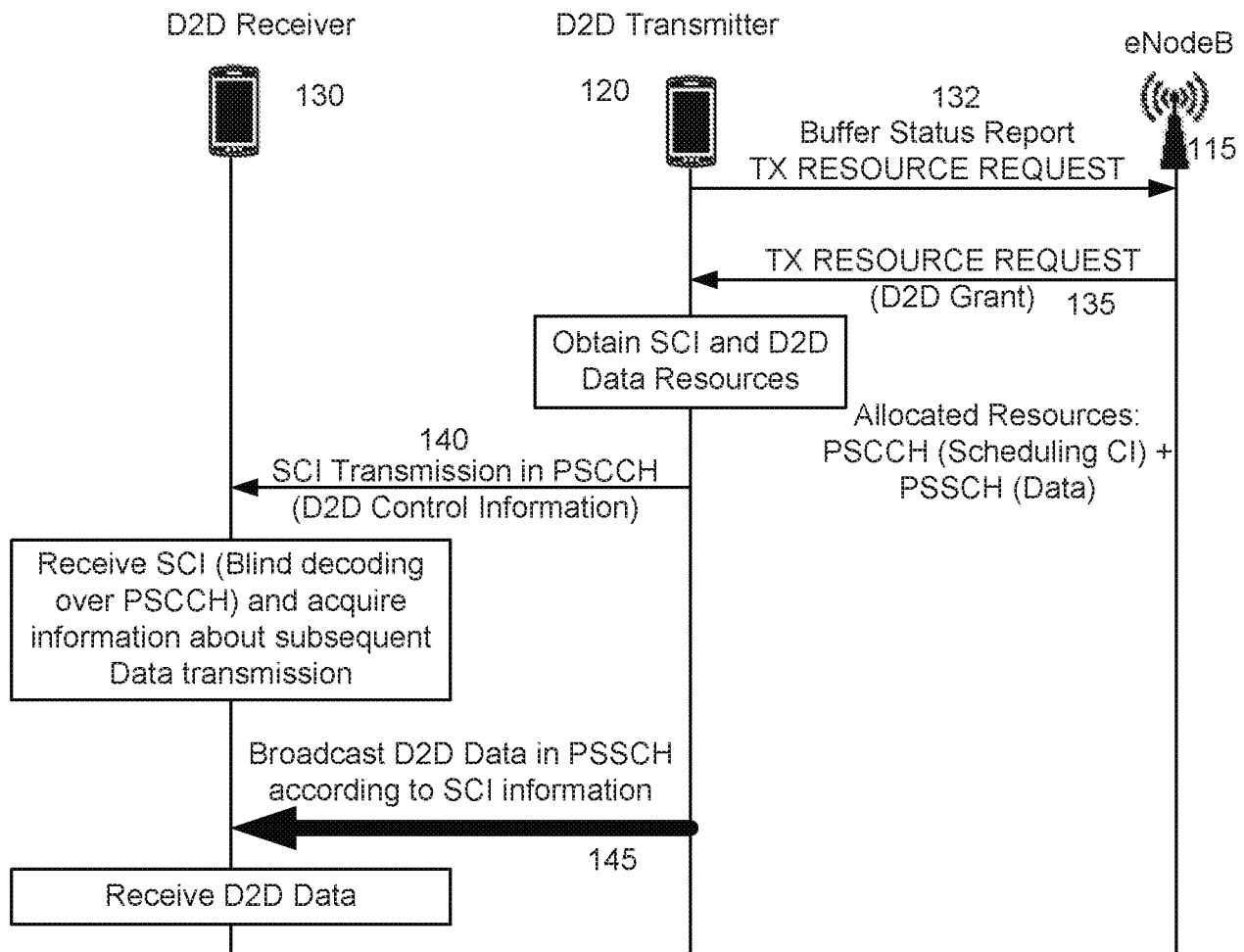
22. . The method of claim 18, wherein the master broadcasts synchronization signals accompanied by broadcast channel, a personal area network (PAN) identity encoded into the synchronization signals.

23. The method of claim 18, wherein the master estimates transmission power for the slave and reports it to the slave.

30

24. The method of claim 18, wherein the slave synchronizes to the master.

25. One or more computer-readable media comprising the instructions Machine executable instructions of any one of Examples 11 to 24.

**Fig. 1**

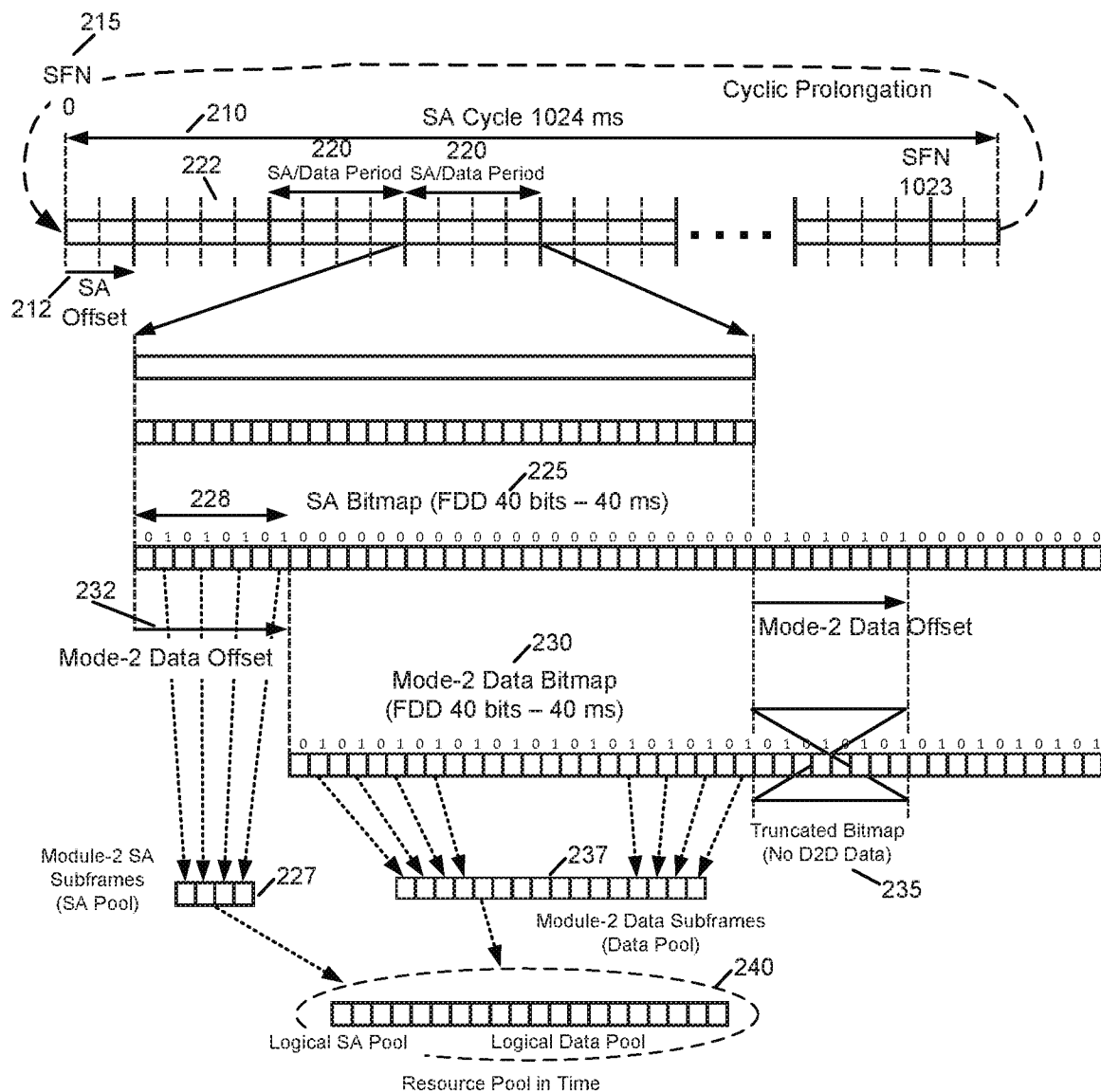


Fig. 2

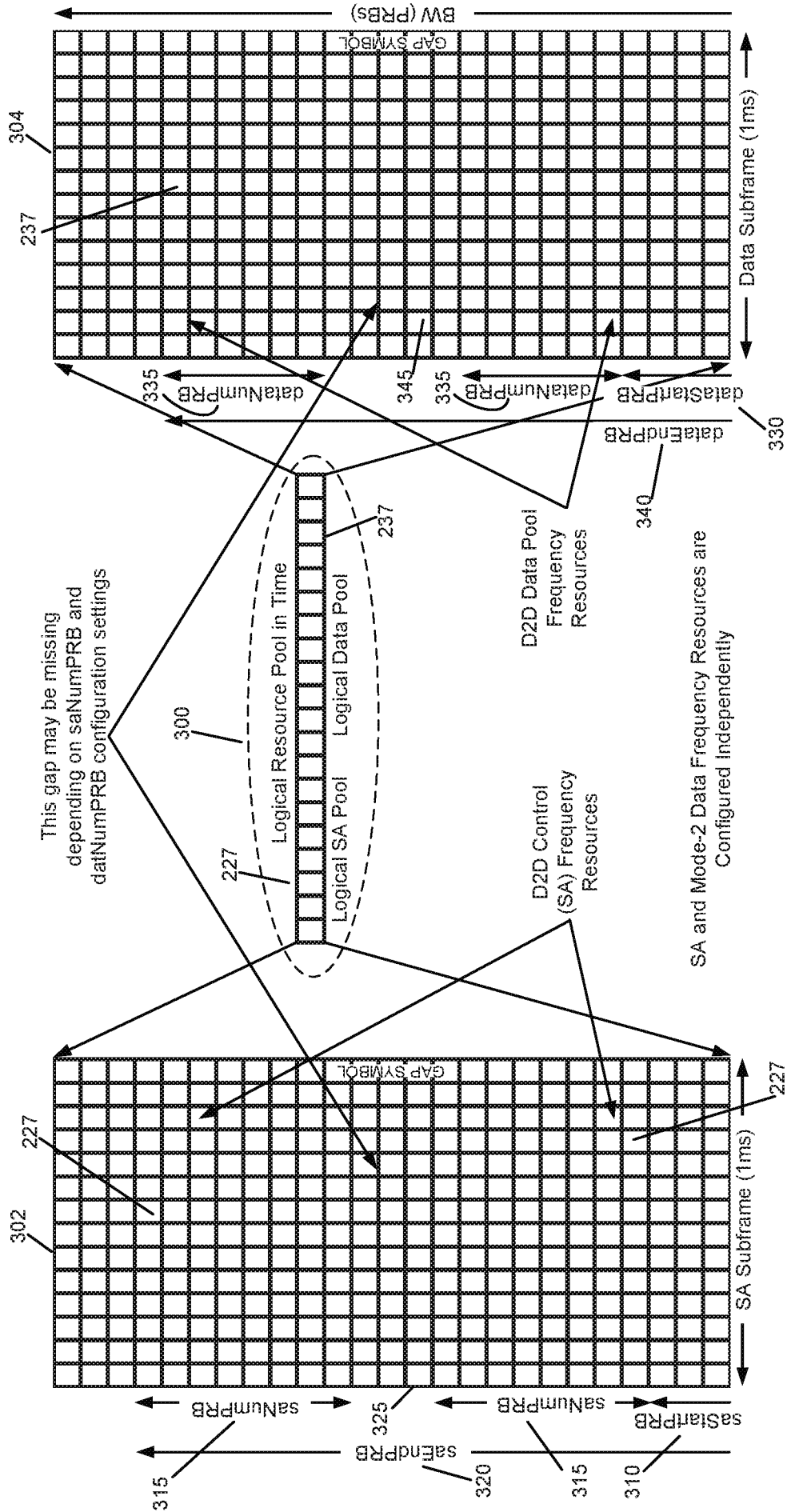


Fig. 3

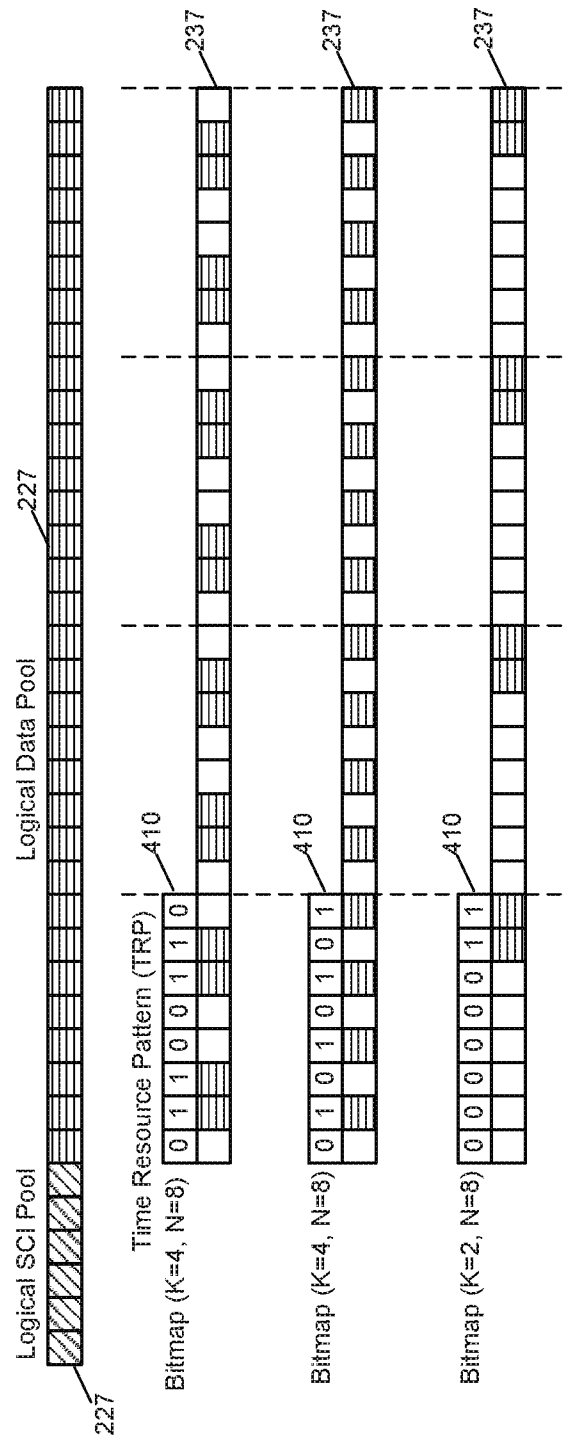


Fig. 4

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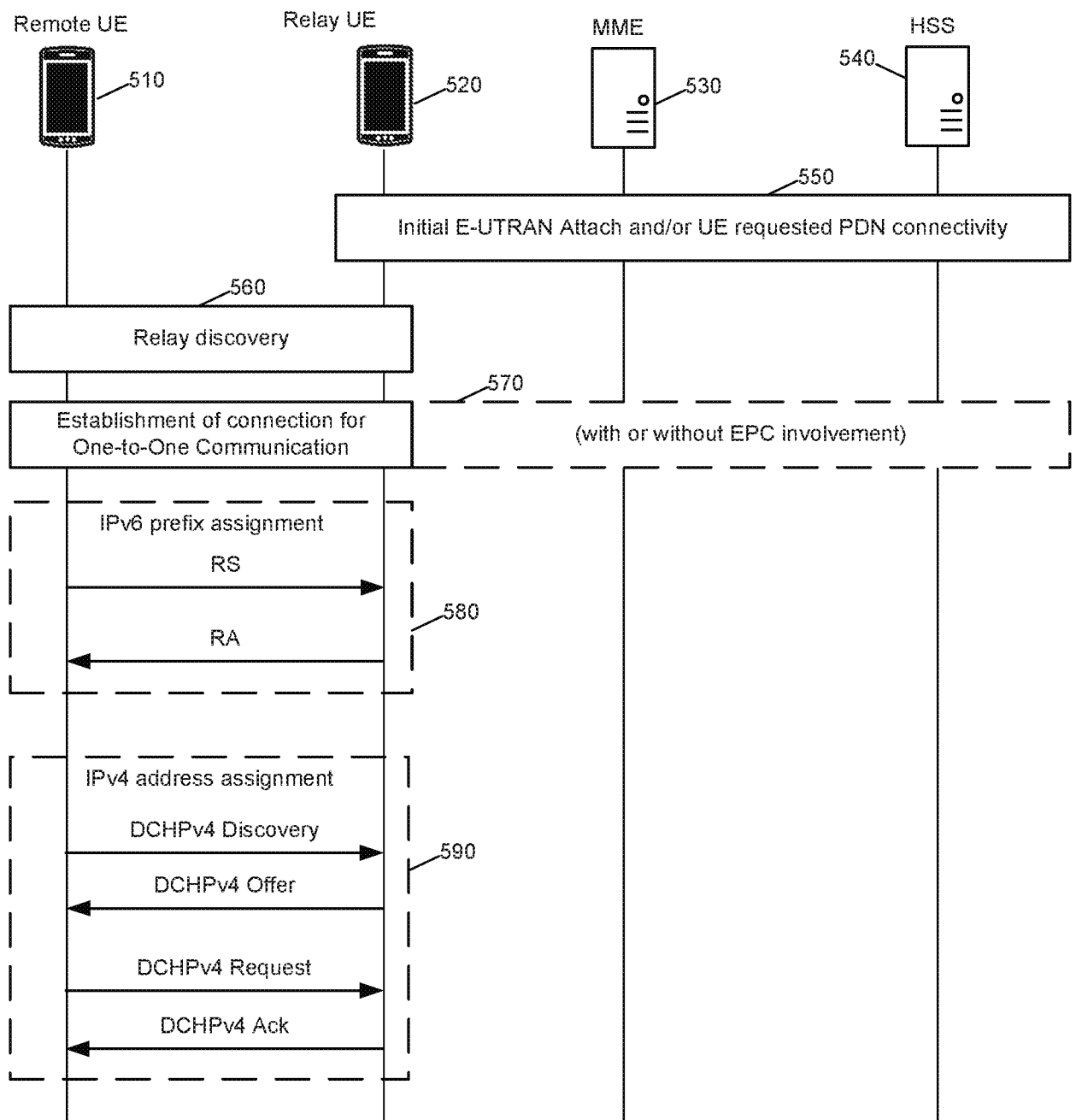
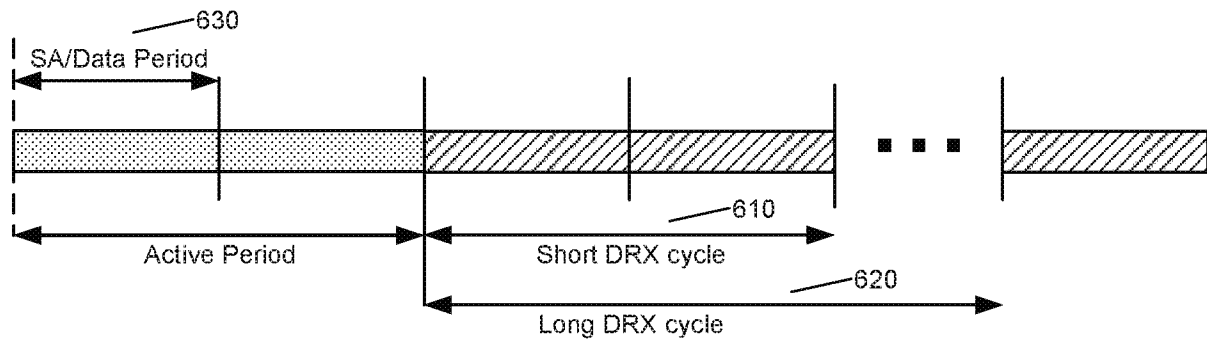
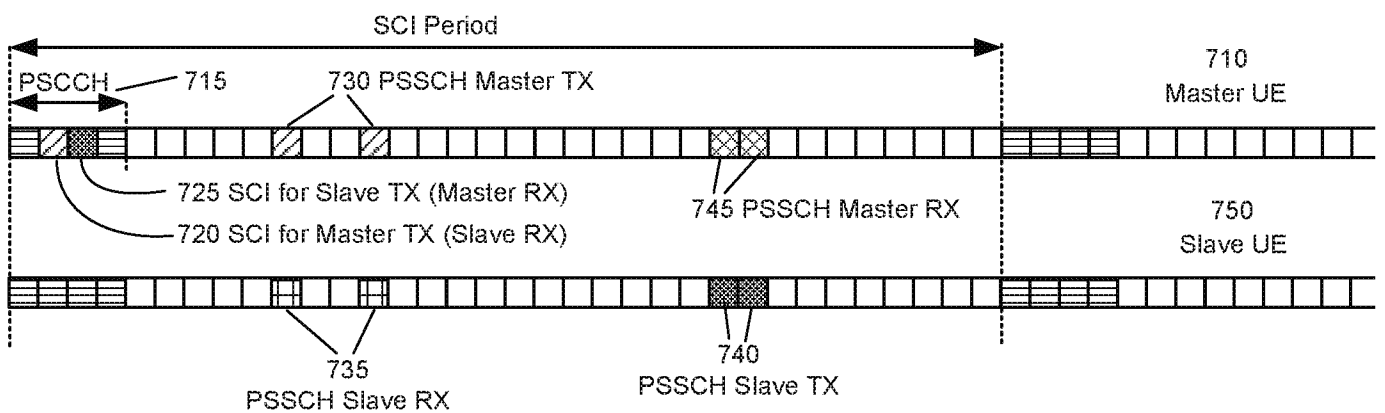
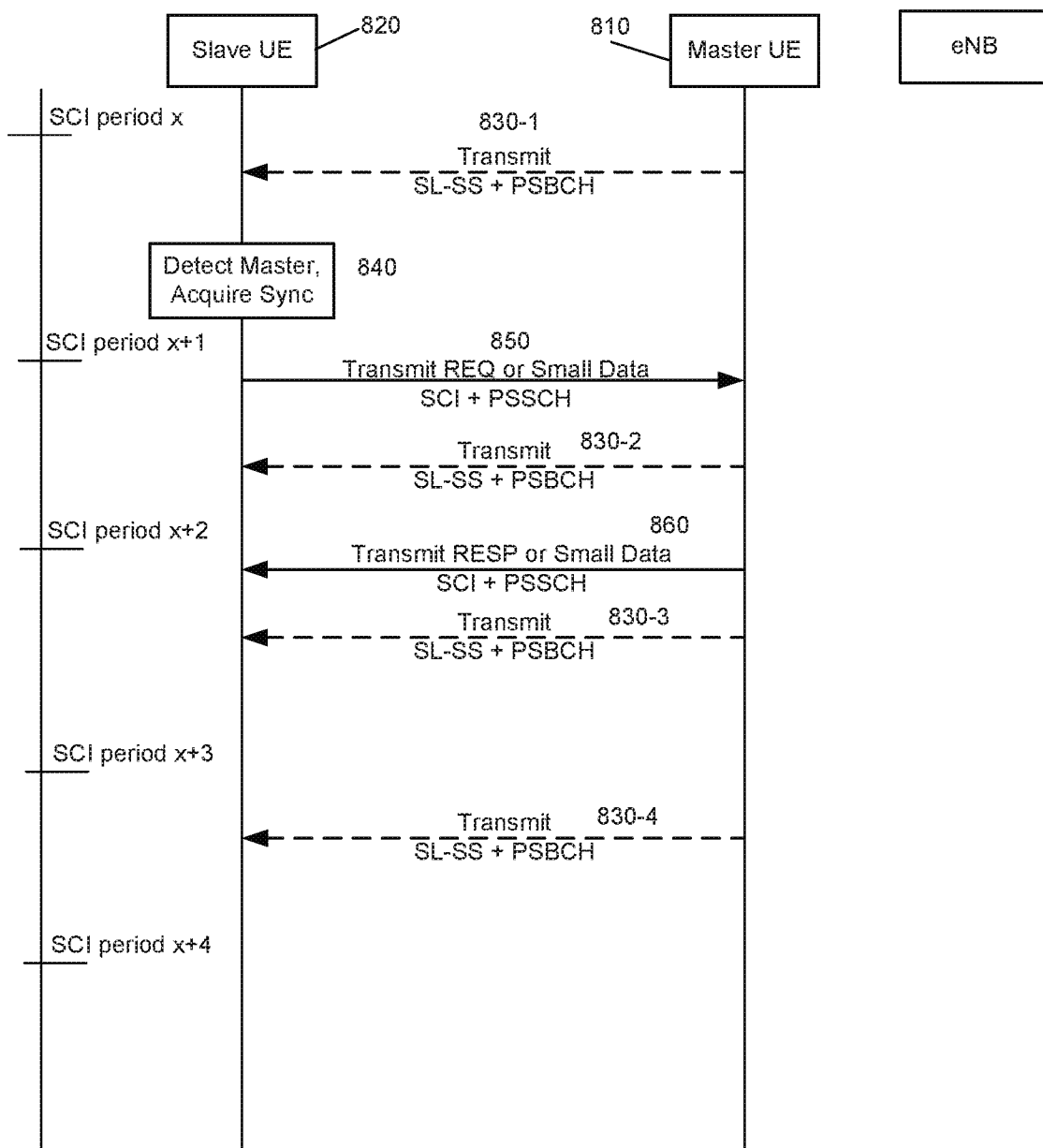


Fig. 5

**Fig. 6****Fig. 7**

**Fig. 8**

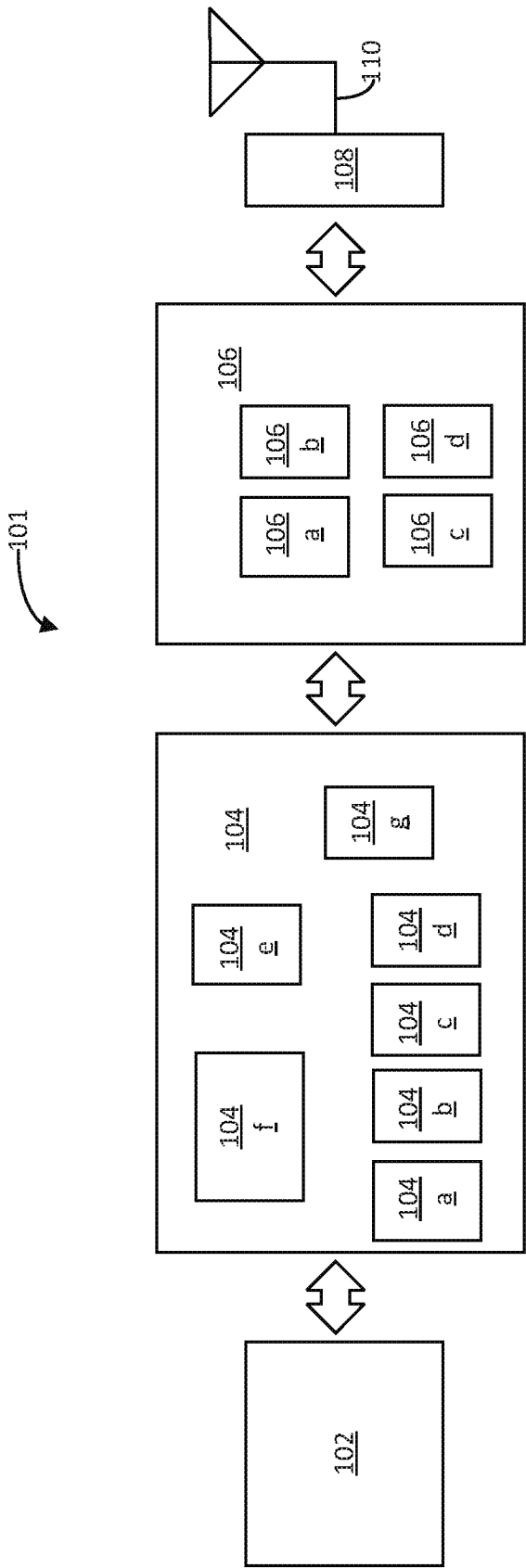


Fig. 9

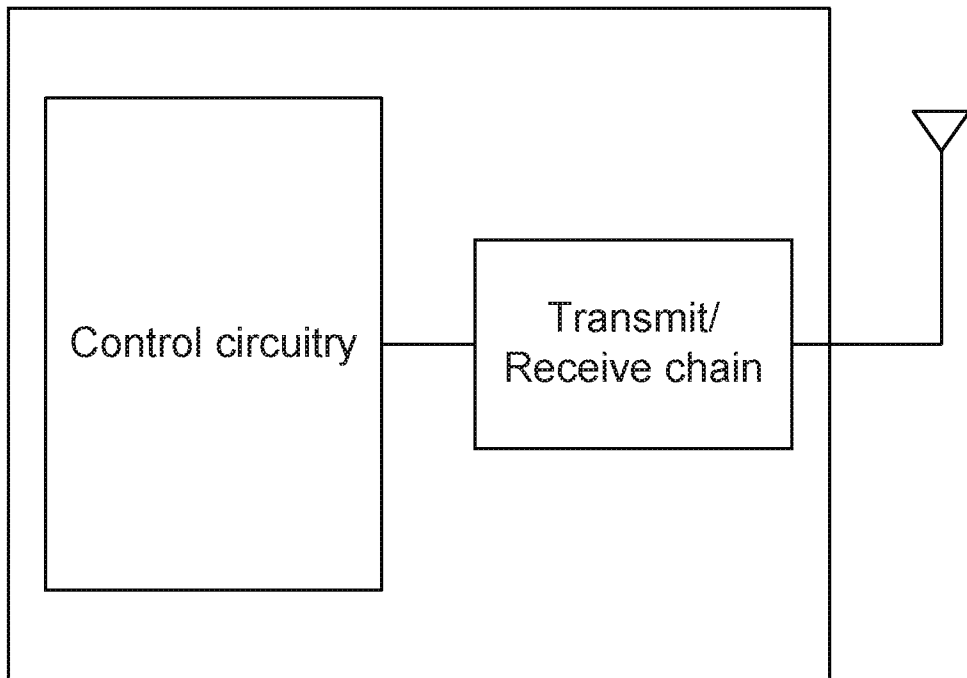


Fig. 10

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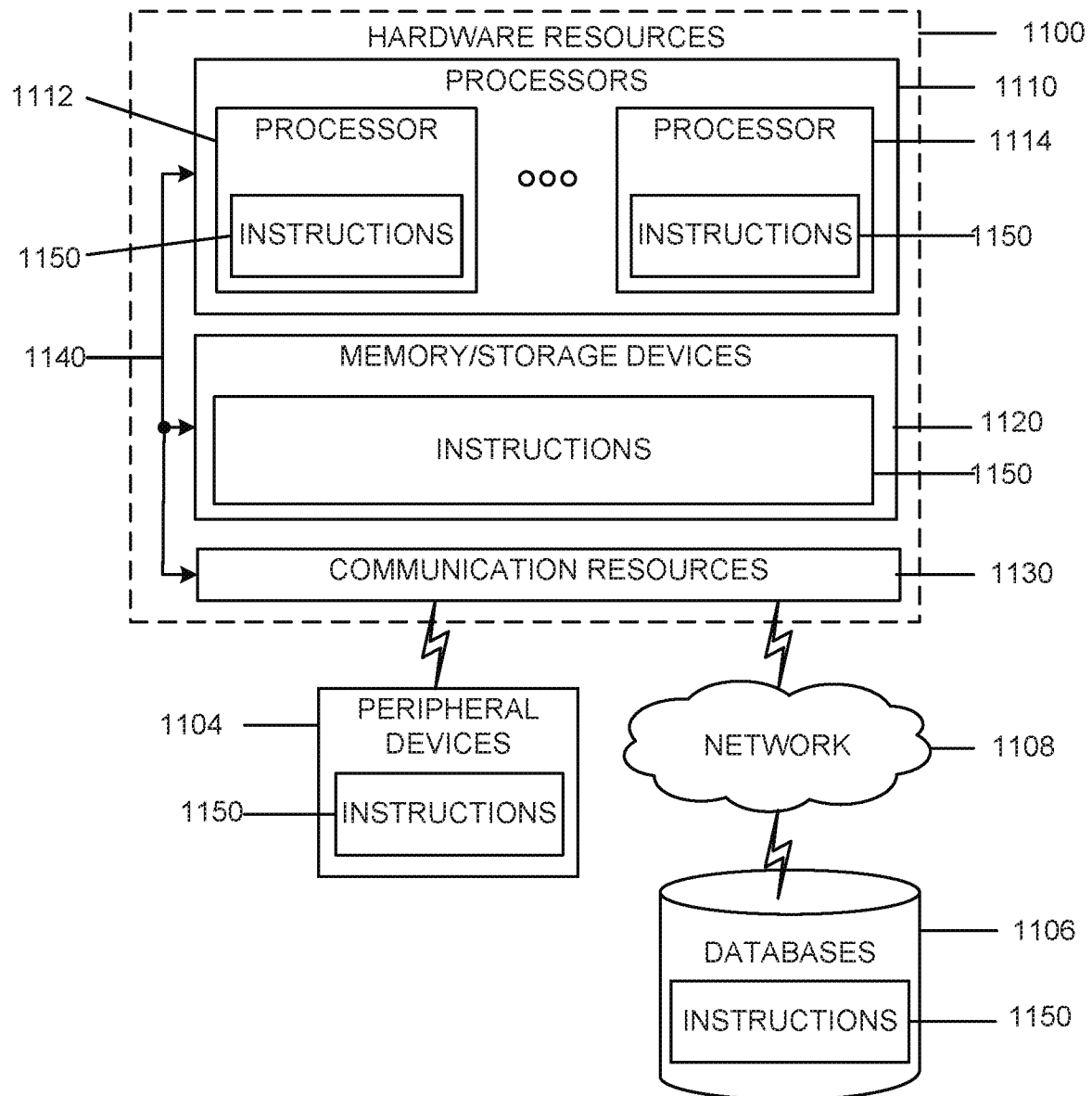


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/025626

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W76/02 H04W4/00
ADD. H04W76/04

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/045472 A1 (NEC CORP [JP])	1,11
Y	27 March 2014 (2014-03-27)	2,12
A	paragraphs [0061] - [0067], [0119] - [0121]; figure 1	10,25
	----- -/--	



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

11 July 2016

Date of mailing of the international search report

08/09/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/025626

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	"Way Forward on the LS for new UE category and additional coverage improvement to RAN2", 3GPP DRAFT; R1-133922 WAY FORWARD ON THE LS FOR NEW UE CATEGORY AND ADDITIONAL COVERAGE IMPROVEMENT TO RAN2, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOL , vol. RAN WG1, no. Barcelona, Spain; 20130819 - 20130823 23 August 2013 (2013-08-23), XP050716969, Retrieved from the Internet: URL: http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_74/Docs/ [retrieved on 2013-08-23]	2,12
A	Last two bullet points; page 1 -----	10,25

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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, 2, 11, 12(completely); 10, 25(partially)

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, 2, 11, 12(completely); 10, 25(partially)

Using reduced number of RB allocation to reduce bandwidth used by UE

2. claims: 3, 13(completely); 10, 25(partially)

Reducing power consumption of UE by limiting control channel decoding

3. claims: 4, 5, 14, 15(completely); 10, 25(partially)

Reducing UE receive processing load by limiting the number of RX processes

4. claims: 6, 16(completely); 10, 25(partially)

Reducing data processing requirements by limiting TBS size and the use of channel modulation/coding options

5. claims: 7, 17(completely); 10, 25(partially)

Reducing UE transceiver on time by restricting to single TTI duration per transport block

6. claims: 8, 9, 18-24(completely); 10, 25(partially)

Operating of the UE the UE-UE link in master/slave mode, including features of operation in specific sub-modes (claims 20-23)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/025626

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014045472 A1	27-03-2014	EP 2898740 A1	29-07-2015
		US 2015230249 A1	13-08-2015
		WO 2014045472 A1	27-03-2014
