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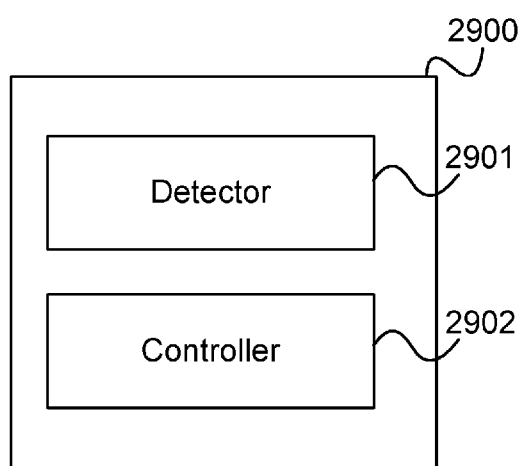
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FIG 29



(57) Abstract: A communication terminal is described comprising a transceiver configured to support radio synchronization, discovery and communication with a cellular radio communication network via a first frequency band using a first bandwidth and a controller configured to control the transceiver to directly communicate with another communication terminal via a second frequency band using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free.



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COMMUNICATION TERMINAL AND METHOD FOR INITIATING A COMMUNICATION**Technical Field**

[0001] Exemplary implementations described herein generally relate to communication terminals and methods for initiating a communication.

Background

[0002] A cellular mobile communication system may allow direct communication between mobile communication devices which bypasses the cellular mobile communication system's base stations (i.e. device-to-device communication). However, such direct communication may impact regular operation of the mobile communication system, i.e. communication via its base stations or it is not possible due to a lack of communication resources, e.g. when the cellular mobile communication system is heavily loaded or communication terminals are too far apart as direct communication was designed for short range. Accordingly, approaches are desirable which allow a usage of direct communication in a wide range of scenarios, including unlicensed bands and narrow bandwidth.

Brief Description of the Drawings

[0003] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various aspects are described with reference to the following drawings, in which:

Figure 1 shows a communication system, e.g. an LTE (Long Term Evolution) communication system as specified by 3GPP (Third Generation Partnership Project).

Figure 2 shows a communication arrangement illustrating D2D (device-to-device) communication.

Figure 3 shows a table summarizing the main regulatory requirements.

Figure 4 shows a communication arrangement illustrating DNB-U communication.

Figure 5 illustrates the functionality of a DNB-U Synch device.

Figure 6 shows a communication arrangement.

Figure 7 shows a message flow diagram illustrating a message flow according to 3GPP ProSe Discovery.

Figure 8 shows a message flow diagram illustrating an example of a two-stage discovery procedure in out-of-coverage scenario for a general consumer.

Figure 9 shows a signal diagram illustrating a frequency hopping pattern for synchronization signal transmission.

Figure 10 illustrates a synchronization procedure.

Figure 11 illustrates a synchronization procedure according to a first option.

Figure 12 illustrates a synchronization procedure according to a second option.

Figure 13 illustrates a synchronization procedure according to a first option for another use case.

Figure 14 illustrates a synchronization procedure according to a second option for another use case.

Figure 15 shows a signal diagram illustrating a first example of a synchronization framework.

Figure 16 shows a signal diagram illustrating a second example of a synchronization framework.

Figure 17 shows an NPSS sequence in NB-IOT.

Figure 18 shows a U-NPSS structure according to a first example.

Figure 19 shows an NSSS sequence in NB-IOT.

Figure 20 shows a U-NPSS structure according to a second example.

Figure 21 shows diagrams each showing time to acquire 90% probability of detection depending on SNR illustrating the performance that can be achieved by the U-NPSS of the first example.

Figure 22 shows the synchronization sequence of in a legacy D2D system.

Figure 23 shows a mapping of a U-NPSS sequence into a signal PRB design.

Figure 24 illustrates a second example for U-NSSS design.

Figure 25 illustrates a third example for U-NSSS design.

Figure 26 shows a mapping of a U-NPSS sequence into time and frequency.

Figure 27 shows a diagram illustrating a two stage approach for synchronization, discovery and communication.

Figure 28 shows a diagram illustrating a three stage approach for synchronization, discovery and communication.

Figure 29 shows a communication terminal.

Figure 30 shows a flow diagram illustrating a method for initiating a communication.

Description of Exemplary Implementations

[0004] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and aspects of this disclosure in which the invention may be practiced. Other aspects may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various aspects of this disclosure are not necessarily mutually exclusive, as some aspects of this disclosure can be combined with one or more other aspects of this disclosure to form new aspects.

[0005] Figure 1 shows a communication system 100, e.g. an LTE (Long Term Evolution) communication system as specified by 3GPP (Third Generation Partnership Project).

[0006] The communication system 100 includes a radio access network (e.g. an E-UTRAN, Evolved UMTS (Universal Mobile Communications System) Terrestrial Radio Access Network according to LTE) 101 and a core network (e.g. an EPC, Evolved Packet Core, according LTE)

102. The radio access network 101 may include base (transceiver) stations (e.g. eNodeBs, eNBs, according to LTE) 103. Each base station 103 provides radio coverage for one or more mobile radio cells 104 of the radio access network 101.

[0007] A mobile terminal (also referred to as UE, user equipment, or MS, mobile station) 105 located in one of the mobile radio cells 104 (in this example the leftmost radio cell 104) may communicate with the core network 102 and with other mobile terminals 105 via the base station providing coverage in (in other words operating) the mobile radio cell.

[0008] Control and user data are transmitted between a base station 103 and a mobile terminal 105 located in the mobile radio cell 104 operated by the base station 103 over the air interface 106 on the basis of a multiple access method.

[0009] The base stations 103 are interconnected with each other by means of a first interface 107, e.g. an X2 interface. The base stations 103 are also connected by means of a second interface 108, e.g. an S1 interface, to the core network, e.g. to an MME (Mobility Management Entity) 109, and a Serving Gateway (S-GW) 110. For example, the MME 109 is responsible for controlling the mobility of mobile terminals located in the coverage area of E-UTRAN, while the S-GW 110 is responsible for handling the transmission of user data between mobile terminals 105 and core network 102.

[0010] In Release 12 and 13 3GPP has introduced "Device to Device (D2D)" communication with the aim to allow a specific mobile device (i.e. UE) such as mobile terminal 105 to discover other mobile devices in its proximity and eventually communicate with each other (Proximity based Services, ProSe) directly, i.e. bypassing the base stations 103.

[0011] Figure 2 shows a communication arrangement 200 illustrating D2D (device-to-device) communication.

[0012] In the example of Figure 2, first mobile devices (UEs) 201 located in a coverage area 202 of an E-UTRAN are served by a base station 203 and perform uplink (UL) and downlink (DL) communication with the base station 203. Second mobile devices 204, which are also located in the coverage area 202, use device-to-device communication (D2D). A third

mobile device 205 located in the coverage area 202 uses both direct communication with one of the second mobile devices 204 and also communicates with the base station 203.

[0013] Fourth mobile devices 206 are located outside of the coverage area 202 and use direct communication to communicate with each other.

[0014] D2D ProSe has been optimized for proximity scenarios targeting a maximum coupling loss of $\sim 130\text{dB}$. D2D ProSe is mainly based on LTE radio access technology where the uplink spectrum and the uplink waveform is used for direct communication between the mobile devices such that D2D operates in the operator licensed spectrum.

[0015] Even though D2D allows direct communication between mobile devices in scenarios where the devices are within the network coverage or outside the network coverage, certain specific use cases might not be optimally covered. In particular the D2D feature may not optimally cover cases when the range to be covered is sufficiently large, e.g. 2km. As an example one use case could be when a set of users are skiing in different sectors of a ski resort and would like to communicate either via voice or text messages.

[0016] Another example could be when users are in a highly dense environment (such as a stadium) and due to high load the network is congested. Users then might still want to communicate in a direct manner. However, in this particular scenario the operator frequency (i.e. the licensed spectrum) might be congested that there are no radio resources for D2D and hence no D2D communication (at least for normal communications – this might not be the case for public safety type of communications) between mobile devices would be possible according to D2D.

[0017] To address this issue and to cover use cases as the ones mentioned above, approaches are provided as described in the following which introduce the possibility for mobile devices (i.e. UEs or more generally subscriber terminals of a cellular mobile communication system) to have direct communication in unlicensed band and which allow for a long range of direct communication between the mobile devices.

[0018] Typical unlicensed bands which may be used for direct communication are the ISM band, e.g. at 900MHz in US and 800 MHz band in Europe or e.g. 800-900MHz or 2.4GHz. Further, shared bands such as TVWS (Television White Space) bands, Licensed Shared Access bands (currently defined for 2.3-2.4 GHz but may be applied to other bands as well) and Spectrum Access System bands (currently defined for 3.55-3.7 GHz but may be applied to other bands as well) may be used.

[0019] Figure 3 shows a table 300 summarizing the main regulatory requirements. It can be seen from table 300 that it is not possible to deploy a wide bandwidth in those frequency bands. The bandwidths span between 250 kHz and 500 kHz. Hence, D2D as typically operated in LTE band is not suitable to operate in the unlicensed spectrum.

[0020] Recently, 3GPP has introduced narrow bandwidth based cellular technologies specifically to serve Internet of Things (IoT)-related use cases. The following cellular technologies recently standardized in 3GPP are meant to operate in licensed spectrum:

- Enhanced Coverage GSM based on GPRS standard in the context of Rel-13
- The evolution of the LTE MTC solution (commonly called Cat M1) which is based on an evolution of the legacy Cat 0.
- Narrowband IOT which is a not backward compatible radio access technology which is specifically optimized in order to satisfy the requirements required for typical IoT solutions (commonly called Cat NB1).

All those technologies are intended to allow for connection of the IoT devices to the cellular network even in deep coverage conditions. Cat NB1 and Cat M1 are developed to maximize the coverage level (e.g. thanks to repetitions) for delay tolerant applications.

[0021] According to the approaches described in the following, to cover direct communication use cases such as the ones above a direct (unicast or multicast) communication in a narrowband unlicensed band capable of supporting voice and message exchange with an extended coverage is provided. Moreover, in-coverage and out-of-coverage scenarios may be supported.

[0022] It should be noted that connectivity standards such as WLAN (Wireless Local Area Network) and Bluetooth do not support the range and bandwidth requirements for use cases as the ones above and that cellular standards such as GSM (Global System for Mobile Communications) and EDGE (Enhanced Data Rates for GSM Evolution) do not support direct communications, and do not support communication in unlicensed bands, D2D ProSE is complex and does not support unlicensed bands and has short range (up to 1km), NB-IOT: 3GPP precludes the support of voice and does not support unlicensed spectrum and LAA (License Assisted access) and MuLTEfire do not support direct communication.

[0023] According to various approaches, wide range Direct NarrowBand communication in Unlicensed Spectrum (DNB-U) is provided for a mobile device including providing one or more of the following functionalities for the mobile device

- Discovering, making itself discoverable, synchronizing and communicating with one or more other mobile devices in range supporting DNB-U (e.g. similarly to what can be achieved by LTE) at least when the mobile devices are out of the network coverage,
- Discovering, making itself discoverable, synchronizing and communicating with one or more other mobile devices in range supporting DNB-U (e.g. similarly to what can be achieved by LTE) at least when the mobile devices are in partial or full network coverage for example when the network is highly loaded,
- Supporting the possibility to automatically or manually disconnect from an LTE cellular communication network and enable DNB-U.

[0024] The DNB-U is for example a narrowband low-rate data transmission, e.g. with at least 2km range. For example, LTE narrowband PHY (physical layer) can be used for this type of communication and data rate.

[0025] In particular, in the following, procedures to form (or to connect to) a DNB-U network are described, a framework for DNB-U including the discovery procedure and a synchronization procedure when forming or entering a DNB-U network is given.

[0026] Figure 4 shows a communication arrangement 400 illustrating DNB-U communication.

[0027] In the example of figure 4, first mobile devices (UEs) 401 located in a coverage area 402 of an E-UTRAN are served by a base station 403 and perform uplink (UL) and downlink (DL) communication with the base station 403. A second mobile device 404, which is also located in the coverage area 402, uses direct communication (D2D) in licensed band, i.e. in the band of the E-UTRAN to communicate with a third mobile device 405 located in the coverage area 402 which uses both direct communication with the second mobile devices 404 and also communicates with the base station 403.

[0028] Fourth mobile devices 406 are also located within the coverage area 402 and are moved, e.g. due to high load of the E-UTRAN, to unlicensed spectrum (as illustrated by arrow 407) and use DNB-U for communicating with each other.

[0029] Fifth mobile devices 408 are located outside of the coverage area 402 and use DNB-U to communicate with each other.

[0030] According to various approaches, DNB-U functionality is implemented in a mobile device rendering it capable of enabling a direct communication in unlicensed bands in case of out-of-coverage, in-coverage and partial coverage and/or a highly loaded cellular network.

[0031] In the out-of-coverage scenario, the mobile device (e.g. a UE) may determine to be out-of-coverage based on that its LTE modem does not detect any PLMN (Public Land Mobile Network) during frequency scan, or based on that it detects a radio link failure. In this case the mobile device may

- Automatically activate DNB-U to check whether other mobile devices are in the range with or without specific authorization from its user.
- Notify the loss of coverage to its user and wait for manual activation of DNB-U by its user.

[0032] In the in-coverage scenario, the following situations may occur

1. The mobile device (e.g. UE) may be in a cellular network coverage area but it cannot access the cellular network. This can happen if
 - the network has barring enabled and
 - the UE detects barring is enabled by reading system information (e.g. SIB1, SIB2 and SIB14) or
 - the cellular network rejects an RRC (Radio Resource Control) connection request with a specific wait time; or
 - the device detects a roaming cellular network but its user has disabled mobile data during roaming
2. The mobile device is in a cellular network coverage area but the cellular network is congested.
 - The mobile device can detect this situation based on any of the following:
 - measuring the RSRP (Reference Signal Received Power) or RSRQ (Reference Signal Received Quality) in a radio cell in which it is located,
 - detecting the cell load e.g. the amount of PRBs (Physical Resource Blocks) scheduled to UEs in the cellular network) in a radio cell in which it is located or based on any other condition,
 - determining the ratio of requested grants and actually scheduled grants of the mobile device.

The detection is not limited to the above and the mobile device may use the various detection approaches in any combination.

[0033] In both situations 1 and 2, the mobile device may

- Automatically activate DNB-U to check whether other mobile devices are in the range with or without specific authorization from its user.
- Notify the impossibility to use the regular (cellular) network to its user and wait for manual activation of DNB-U by the user.

[0034] The functionalities and procedures described below cover both the cases when a device wants to establish a unicast or multicast communication.

[0035] For synchronization, a mobile device may act as DNB-U Synch device as it is described in the following with reference to figure 5.

[0036] Figure 5 illustrates the functionality of a DNB-U Synch device 500.

[0037] The DNB-U Sync device 500 is a mobile device which is responsible for at least delivering discovery signals 502 to allow other devices 501 to synchronize and providing a direct link cell identity (D-ID) 503. How long and on which frequency it sends the discovery signals 502 depends on the used approach and is explained in further below.

[0038] The discovery signals 502 may be used for discovery and for example as well as for time and/or frequency synchronization. Alternatively, the discovery signal 502 are only for discovery of communication tiers and synchronization is done based on subsequently transmitted specific synchronization training sequences.

[0039] In addition, the DNB-U Sync device 500 may also share information 504 about which mobile devices are within his coverage (within some km). The DNB-U Sync device 500 may share this information via multicast communication (open at least within certain groups; the forming of groups of mobile devices is described further below).

[0040] In the following, an approach for selection and reselection of or from a DNB-U sync device is described.

[0041] In a specific location many mobile devices can temporarily operate as DNB-U Sync devices. As such, many mobile devices may send discovery signals 502 in order to be discoverable by other devices in a specific range (details of which are given further below). In the following, an approach is described for a mobile device to choose which DNB-U Synch device to synchronize to.

[0042] A set of "groups" may be configured in each mobile device. The groups may be either predefined by the cellular network (e.g. groups corresponding to public security) or they are defined by the users when communication with the cellular network is available (e.g. a

communication with a server or cloud), e.g. in order to generate an additional group or introduce additional mobile devices into a specific group a mobile device accesses a cloud or server.

[0043] Each group is associated with a specific priority and this for example can be changed manually by the mobile device's user up to a certain extent (e.g. public security has always highest priority and cannot be modified). Further, there may be a hierarchy of groups, i.e., terminals of a lower hierarchy group may only access their own group (type) while terminals of a higher hierarchy group may access to more groups.

[0044] For each of these groups a specific security key is created and within the group there is the possibility to communicate in a secure manner.

[0045] An example of priority groups is (in order of descending priority)

- Priority Group 1: public safety devices
- Priority Group 2: mobile devices with best reception quality (e.g. highest RSRP (Reference Signal Received Power)) at the mobile device
- Private priority group 3: preferred set of devices (from list of contacts, friends)
- Private priority group 4: additional predefined group of devices

[0046] For example, a mobile device only initiates direct communication with another mobile device of a communication group if there is no mobile device of a priority group with a higher priority with which the mobile device is to communicate.

[0047] A mobile device may define further priority groups and any order of the above mentioned priority groups can be considered (e.g. up to a certain extent). Many private priority groups can be created, and the priority associated to this can be manually changed according to the needs.

[0048] It should be noted that private groups can correspond to one or more devices which would cover unicast and multicast communications.

[0049] A reselection may take place if the e.g. a timer associated to the DNB-U Sync device expires, if the DNB-U Sync device does not have any active communication, if it becomes out of

coverage (RSRP of the DNB-U synch device is lower than a certain threshold), or if another DNB-U sync device appears that belongs to a higher priority group than the current one.

[0050] Regarding device discovery and for a device to be discoverable, once DNB-U is activated in a mobile device, the mobile device may become discoverable for other mobile devices supporting DNB-U in a certain range and the mobile device may try to discover other mobile devices which might be communicating already. The user can (manually or automatically) activate the possibility to discover other mobile devices or being discoverable. In case the possibility to discover other devices is activated in the mobile device this means that it allows the overall modem subcomponent or specific part of it to enter into a listening mode which scans periodically a specific frequency range (or a multitude of frequency ranges) in order to detect other mobile devices for DNB-U. In case the possibility to be discoverable for other mobile device in the mobile device this means that it allows the transmission of specific synchronization sequences and, for example, the DNB-U Synch device shares information about its presence within its network.

[0051] In the following it is assumed that a mobile device activates the functionality to be discoverable and the functionality to discover other mobile devices. Moreover it is assumed that it sends synchronization signals in predefined frequency channels i.e. at a central frequency $F_{\text{synch}}=180\text{KHz}$ located in e.g. the middle of the 900MHz frequency band in the US or a specific chunk of the ISM 800MHz band in Europe. The above mentioned location for the synchronization signal (middle chunk) is only provided as example and other locations may be used. However, in order to simplify the implementation a specific location may be preconfigured in the mobile device (and e.g. in each mobile device supporting DNB-U).

[0052] In the following, the following naming convention is used:

- “DNB-U Sync min set” is the minimum set of information the DNB-U Sync device 500 sends in order for other mobile devices to synchronize. The DNB-U Sync min set for example includes at least a DNBU-Primary Synchronization Sequence, a DNBU-Secondary Synchronization Sequence, and may include other information such as user

ID, priority group related information, reference signals and possibly any other broadcast information. Broadcast information may include also additional services the particular device can offer like e.g. printing capability, internet access, or relay functionality.

- "DNB-U Sync window" which corresponds to a duration D (e.g. in milliseconds) during which the mobile device transmits several instances of the DNB-U Sync min set.
- "DNB-U Sync periodicity" which allows controlling how often a mobile device can use a DNB-U Sync window.

The corresponding configuration may be predefined.

[0053] Regarding DNB-U Discovery Frequencies, in the following an approach based on a Primary DNB-U Sync Frequency (F_A) and one or more Secondary DNB-U Sync Frequencies F_B , F_C , ... is described.

[0054] A first possibility is the configuration of a single Secondary DNB-U Sync frequency. Alternatively, a multitude of secondary DNB-U Sync frequencies can be configured. Both the Primary DNB-U Sync frequency and the Secondary DNB-U Sync frequency are frequencies that a mobile device may use in order to transmit/receive synchronization signals to make itself discoverable and to discover the presence of other mobile devices. The mobile device may also use those two (or more) frequencies in different conditions. In the following, two exemplary approaches for the discovery of other mobile devices and becoming discoverable are given.

[0055] According to a first example for an approach for discovery and becoming discoverable, the DNB-U Sync device 500 does not send periodic discovery/synchronization signals but stops transmitting if there is not an active communication or if no mobile device enters the proximity of the DNB-U Sync device 500 for a maximum duration (e.g. until a timer expires).

[0056] As an example the case is considered that when a first mobile device activates DNB-U in a location where no other mobile devices are communicating or sending synchronization signals. After enabling DNB-U, the first mobile device senses the spectrum (listens for the

frequency where synchronization signals should be sent, e.g. F_A , F_B and possibly further frequencies) by applying an equivalent of a Listen Before Talk protocol to detect whether other mobile devices are already transmitting synchronization signals or whether other communications are ongoing (collision avoidance). If this is not the case the mobile device A starts sending the DNB-U Sync min set within a certain DNB-U sync window on frequency F_A . The DNB-U sync window may be predefined and less than the Dwell Time (according to respective regulatory requirements) and less than the duty cycle (according to respective regulatory requirements). The design of the synchronization sequence may for example be chosen to achieve at least approximately 2km range in typical use cases.

[0057] A second mobile device located in the vicinity after sensing the frequency F_A can synchronize with the first mobile device which becomes a DNB-U Sync device. After this synchronization procedure the first mobile device and the second mobile device can communicate. The DNB-U Sync device keeps sending the DNB-U Sync min set periodically to allow other mobile devices to synchronize, however in order to free frequency F_A for other mobile devices, the first mobile device may use a the secondary frequency F_B to keep sending synchronization signals. The first mobile device maintains this for a maximum timing $T_{\max}$ after the end of the direct communication which takes place according to a specific frequency hopping pattern whenever it is needed (e.g. in 900MHz frequency band). When $T_{\max}$ elapses the DNB-U Sync device stops sending the DNB-U min set and enters sleep mode.

[0058] If the first mobile device enters a sleep mode, it may not be capable to detect the presence of later (synchronization) signals from other mobile devices unless it wakes up periodically to scan the specific frequency where synchronization signals should be sent (F_A and F_B etc.). Several options can be considered.

[0059] For example, according to one approach, a mobile device wakes up with a certain periodicity and it tries to detect the presence of synchronization signals. In a different exemplary implementation the mobile device has a particular architecture such that only specific components of the mobile device are waked up to detect the presence of

synchronization signals to limit power consumptions. Alternatively, the mobile device is equipped with a specific wake up receiver which could detect the presence of synchronization signals and in response wake up the mobile device's (regular) receiver. This wake up receiver could e.g. detect the level of energy and the presence of a specific signature characteristic of the synchronization signal design. The wake up receiver would be capable of waking up the mobile device's receiver only when needed and hence it would allow for battery consumption reduction.

[0060] According to a second example for an approach for discovery and becoming discoverable, a mobile device keeps sending periodic discovery (i.e. synchronization) signals by adapting the periodicity to reduce battery consumption if there is not an active communication or if no other mobile device enters the proximity region for a maximum timer.

[0061] As in the above example, if a first mobile device enables DNB-U in a location where there are no other mobile devices it senses the spectrum (e.g. according to a Listen Before Talk procedure). Whenever possible the first mobile device starts the transmission of the DNB-U Sync min set with a certain Sync window and a certain periodicity. The conditions on the parameters needs to be respected as above.

[0062] When a second mobile device enters the direct communication network (i.e. the area in which the first mobile device transmits the discovery signals), after sensing the direct communication network, it is able to synchronize to the first mobile device (acting as the master device of the direct communication network). In order to limit the power consumption of the sync DNB-U device, each mobile device for example only acts as sync device for a limited amount of time (e.g. until a corresponding timer in the mobile device has expired).

[0063] In the following, approaches for a direct link establishment within the coverage area of a Sync DNB-U device, in particular the establishment of direct communication between devices none of which being a Sync device are described with reference to figure 6.

[0064] Figure 6 shows a communication arrangement 600.

[0065] The communication arrangement 600 includes seven mobile devices 601 to 607 (referred to as devices A, B, C, M, N, X and Y). The first mobile device 601 (device A) acts as DNB-U Sync device and the mobile devices B, C, X, and Y are synchronized to the DNB-U Sync device A.

[0066] For example, device B wants to communicate with device C which are within the (direct communication) coverage area of the DNB-U Sync device A. Device B may be aware of the reachability of device C because the DNB-U Sync device A has shared information (in a specific group) about which users are active (e.g. synchronized) within its coverage area 608.

[0067] As another example, device Y may want to communicate with other devices which are not known in the list of the devices synchronized to device A (not in coverage 608 of device A), such as device M and device N. For example, on radio layer, only mobile devices with unicast direct links are known to the sync device A. Device X and Y are not known to device A as long as they are only listening to multi-cast data sent by device A.

[0068] In figure 6, a single arrow indicates a multi-cast connection and a double arrow line indicates a unicast connection.

[0069] In principle, any DNB-U device can become a Sync device. Thus, communication links may be provided between the mobile devices 601 to 607 using different sync devices. For example, first links 609 are provided using device A as sync device, second links 610 are provided using device B as sync device and third links 611 are provided using device Y as sync device.

[0070] A DNB-U Sync device can serve either as the only synchronization source for all mobile devices in its coverage or a multitude of Sync devices can be present.

[0071] According to one approach, when the devices do not support dual connectivity capability and hence would be capable to only communicate over one direct link at a time (for a one-to-one communication) in order to enable synchronization with multiple devices a synchronization timer is introduced. In this case, the timer allows that any communication

between, for example, devices B and A and between the devices C and A is completed before devices B and C start their own synchronization procedure according one of the following ways:

1. The DNB-U Sync device A knows the coarse location of other mobile devices (sector based) and informs device B and device C to establish a direct communication. In this case the devices B and C release the synchronization to device A and device B (or C) starts sending DNB-U min set after listening for clean spectrum.
2. Even if the Sync device (Device A) does not have (coarse) positioning information, it asks devices B and C to start a direct communication. In case devices B and C are not in coverage range the synchronization procedure fails and devices B and C are not able to communicate because of out of coverage.
3. The sync DNB-U device A acts as a relay of information and thus extends the coverage if the device to which the information is to be transmitted intended is within the coverage range 608 of device 8. However, this mode of operation leads to an increased power consumption in the sync device A.

[0072] According to an alternative approach, it is assumed that each device is capable of supporting dual connectivity when it has activated DNB-U. In this case dual connectivity of a mobile device, including one connection to a sync device and connection towards another mobile device with which the mobile device wants to communicate is possible. However, it should be noted that this approach leads to an increased battery consumption in the mobile device.

[0073] Discovery Procedure for Device to Device Type Communication in Out of Coverage

[0074] In the following, examples for a specific and detailed architectural design for direct discovery is given for the following feature use cases:

- Discovery Use Case 1: A UE out of cellular coverage would like to get alerted as soon as a specific UE or at least one member of a specific group is within proximity.
- Discovery Use Case 2: A UE out of cellular coverage would like to discover other UEs within proximity e.g. for the purpose of a subsequent private direct communication.

[0075] In ProSe Direct Discovery can be "open" or "restricted". Open is the case where there is no explicit permission needed from the UE being discovered, whereas restricted discovery only takes place with explicit permission from the UE that is being discovered. ProSe defines two Models of discovery:

- Model A ("I am here") – supports open and restricted
- Announcing UE: The UE announces certain information that could be used by UEs in proximity that have permission to discover.
- Monitoring UE: The UE that monitors certain information of interest in proximity of announcing UEs.
- Model B ("who is there?" / "are you there?") – support only restricted
- Discoverer UE: The UE transmits a request containing certain information about what it is interested to discover.
- Discoveree UE: The UE that receives the request message can respond with some information related to the discoverer's request.

[0076] ProSe Public Safety always uses restricted discovery. In ProSe Public Safety Discovery there are two types defined:

- Relay Discovery
- Group Member Discovery

[0077] Relay Discovery is supported via relay (a UE) that is connected to E-UTRAN and Group Member Discovery is defined within a group of UEs (Discovery Group ID). ProSe Public Safety Discovery messages are protected. Each ProSe-enabled Public Safety UE needs to obtain the security parameters from the ProSe Key Management Function before participating in ProSe direct discovery for public safety as shown in Figure 7.

[0078] Figure 7 shows a message flow diagram 700 illustrating a message flow according to 3GPP ProSe Discovery.

[0079] The message flow takes place between a UE 701, a ProSe Function (or multiple ProSe Function(s)) 702 and a PKMF (ProSe Key Management Function) 703.

[0080] In 704, the UE 701 is configured.

[0081] In 705, the UE 701 gets provisioned discovery parameters plus a PKMF address.

[0082] In 706, the UE 701 requests a key from the PKMF 703.

[0083] In 707, the PKMF 703 checks the UE's authorization.

[0084] In 708, the PKMF 703 sends a key response to the UE 701.

[0085] In 709, the PKMF 703 sends a MIKEY (Multimedia Internet Keying) message to the UE 701.

[0086] In 710, the UE 701 sends a MIKEY verification message to the PKMF 703.

[0087] In 711, the UE 701 is ready to send and receive a discovery message.

[0088] For each Discovery Group ID in group member discovery, the ProSe Key Management Function (PKMF) 703 provides the following security parameters:

- PSDK (Public Safety Discovery Key). The root key that is used for the protection of the Public Safety Discovery messages
- Optional: DUCK (Discovery User Confidentiality Key). This offers additional protection e.g. for hiding the User ID.

[0089] ProSe Public Safety Group Member Discovery assumes several parameters preconfigured in the UE like:

- Discovery Group ID
- PSDK (Public Safety Discovery Key) -> root key used in absence of the PKMF in case of out of Coverage

[0090] For certain scenarios of discovery of a group for direct communication (e.g. DNB-U) a preconfigured Discovery Group and PSDK are not feasible. Namely, the discovery use cases described above cannot be supported by 3GPP ProSe Discovery procedures. In consumer oriented uses cases, there is typically a need for being able to discover a user independently from its Discovery Group membership and also to create and manage groups dynamically. This means that definitions for the following procedures are typically necessary:

- Group initialization,

- Group management,
- Group expansion, and
- Group release

[0091] In the following examples for procedures and functionalities enabling general public UE discovery in out-of-coverage scenarios (e.g. for DNB-U communication) are described.

[0092] According to various examples, a two stage discovery procedure and dynamic group creation for a device to device type of communication in out-of-coverage areas is introduced. In the first stage of the discovery, only the minimum information is shared between two mobile terminals (e.g. UEs) to start communication without the sharing user ID. In the second stage, mutual authentication of the two mobile terminals is carried out including User ID and (e.g. all) group related credentials necessary for the group communication. This two-stage discovery approach enables discovery of any type of devices and it is not limited to public safety communication only and it protects confidentiality of users participating in the discovery procedure.

[0093] It should be noted that 3GPP ProSe defines discovery for in-coverage and out-of-coverage public safety only (no discovery procedure is defined for out-of-coverage consumer use cases in 3GPP ProSe).

[0094] Figure 8 shows a message flow diagram 800 illustrating an example of a two-stage discovery procedure in out-of-coverage scenario for a general consumer.

[0095] The message flow takes place between a first UE (UE A) 801 and a second UE (UE B) 802.

[0096] In 803, the UEs 801, 802 perform a basic discovery using an anonymized short form of the User ID. This may be seen as the first stage of the discovery procedure.

[0097] In 804, the UEs 801, 802 perform authentication based on identity based cryptography or digital certificates.

[0098] In 805, the UEs 801, 802 exchange group credentials. 804 and 805 can be seen as the second stage of the discovery procedure.

[0099] In 806, the UEs 801, 802 switch to group communication.

[00100] To be able to communicate in out-of-coverage scenarios with other UEs, first, the UE is configured with basic parameters to enable secure discovery. Parameters such as private keys, associated certificates or root certificate that may be needed for contacting other UEs in the same scenario are for example preconfigured in the UE and exchanged in this first stage. If Identity Based Cryptography is used for mutual authentication when UEs are out of network coverage, the UE is provisioned with a user identity and the following set of parameters defined by the IETF (Internet Engineering Task Force), for example:

- KPAK - KMS (Key Management Server) Public Authentication Key
- SSK – Secret Signing Key
- PVT – Public Validation Token.

[00101] A precondition is that a pre-affiliation of the UE's user is known (e.g. a set of communication terminals with which the user has previously communicated) which can be for example determined based for example on the contact list in the address book. Based on this user pre-affiliation, the UE may dynamically create a group (or multiple groups) when the UE is out of coverage. For example, two types of group organization can be supported:

- Group Type A: Distributed group with no leader, everybody can pull in (e.g. invite) a new group member
- Group Type B: Controlled group with a group administrator

[00102] As mentioned above a preconfigured discovery key is not feasible in DNB-U for certain use cases. Therefore, according to various examples, to achieve confidentiality of User IDs as part of the Discovery Announcement/ Solicitation message an anonymized short form of the User ID is introduced. This could be achieved by using e.g. only the last 4 digits of the MSIDN (e.g. *6789 instead of +49123456789). This could also include other formats of User IDs like SIP URI, app-layer identifier in the user@realm format, etc). A commonly known hash algorithm could be also used instead of the last digits/characters. Ideally an attacker should not be able to determine the User ID from the short form unambiguously.

[00103] For Group Type A, in 801, a basic discovery using hashed User IDs (e.g. SIP URI, telephone number, app-layer identifier in the user@realm format, etc.) or the last 4 digits MSISDN/User ID is performed. Each UE 801, 802 may start a discovery procedure by announcing e.g. a hashed value of its User ID and its DNB-U 2 ID or the last 4 digits of its MSISDN/User ID and its DNB-U 2 ID. In this example, it is assumed that the first UE (UE A) 801 starts the discovery procedure.

[00104] In 802, for authentication, the second UE (UE B) 802 receives the announcement of the first UE 801 and determines whether the hashed code matches the hashed value of UE A's User ID that is stored in UE B's address book or that the advertised last 4 digits matches the last 4 digits of UE A's MSISDN/User ID that is stored in UE B's address book. Based on this, UE B initiates a 1-to-1 Direct Communication with UE A. As part of the secure 1-to-1 link establishment the two UEs 801, 802 authenticate mutually by using Identity Based Cryptography or digital certificates.

[00105] In 803, Group Credential Exchanges are performed. Using application layer mechanisms one of the two UEs 801, 802 creates a new group, which implies creation of group information such as Group ID, Group IP multicast address, Group Key and group security credential. A UE that creates the group delivers the group parameters to another UE. In some scenarios one of the UEs may already be member of a group, in which case it simply provides the group parameters of the existing group to the other UE (with which a group should be formed). The UE that was provided with the group parameters stores those data for future direct group communication.

[00106] In 804, the UEs 801, 802 switch to group communication: At any point the two UEs may release the 1-to-1 link and switch to direct group communication using the group information.

[00107] In order to address Group Type B (i.e. group with a group administrator) the discovery procedure for Group Type A as described above can be followed, but for example with the following changes:

- UEs configure search for the hashed User ID or the last 4 digits of the MSIDN of the group admin only.
- Either Model A (Announcing / Monitoring) or Model B (Discoverer/ Discoveree) discovery, e.g. as defined in 3GPP, can be used.
- With Model A discovery the UE of the group admin announces the hashed value of the group admin's User ID or the last 4 digits of the MSIDN.
- With Model B discovery the group administrator's UE does not make any announcements and instead responds to Solicitation messages sent by other UEs. The Solicitation message includes two hashed identities: a hashed value of Discoverer's User ID and for a hashed value of the Target's User ID (i.e. in this case the hashed value of group administrator's User ID). Upon reception of the Solicitation message from another UE the group administrator's UE determines that it can accept the request (e.g. because the hashed value of Discoverer's User ID matches an entry in his address book) and sends a Response message to the other UE. At this point the other UE can initiate establishment of 1-to-1 link, during which the two UEs (administrator's UE and other UE) mutually authenticate. Also, the last 4 digits of the MSIDN can be included in Solicitation message.

[00108] Unlike 3GPP ProSe Discovery the discovery procedure described above enables a dynamical group principle, i.e. one user is not restricted to a static one group only.

[00109] As implementation example a discovery flow for a distributed group may for example be as follows:

[00110] 1. Group Initialization

a) Users affiliate with each other by adding the User ID (e.g. phone number or SIP URI) of the potential communication partner into the address book of their UEs. This could be for example, set of family members, sport, event group, etc.

b) Any user can start announcing its last 4 digits (derived from its own MSIDN/User ID).

According to different embodiments this can be done over the Discovery plane (D-plane) or the

Communication plane (C-plane). If done via C-plane, there is a need to define a DNB-U L2 ID that is understood by everyone as broadcast identifier (in contrast, the D-plane does not use any addresses, so everything sent in the D-plane is broadcast).

c) Once another UE receives the #-key (hash key) and is open for discovery, it initiates a 1-to-1 communication request, during which both parties mutually authenticate using digital certificates or Identity Based Cryptography (IBC).

d) The two users having performed the mutual authentication decide to create a group using app-layer means (e.g. similar to creating a chat room in an instant message service). Black-list users may be blocked automatically. Some users might be added automatically with no choice of not being added, e.g. family members. The creation of a group implies creation of: Group ID, multicast DNB-U L2 (layer 2) ID, multicast IP address and associated group security credential.

[00111] 2. Group Management

e) The two users can stop their 1-to-1 communication and instead continue to communicate with each other using DNB-U group communication.

[00112] 3. Group expansion

f) Both UEs may in parallel continue to advertise their hash key to attract additional users

g) When an additional user (e.g. a user C) detects either of the other two users (one of e.g. users A and B), it establishes a 1-to-1 link (with user A or user B) during which the additional user's UE is authenticated. At this point user A or user B can pull user C inside the group by simply providing the group parameters (Group ID, L2 ID, IP address, security credential) to user C's UE. A black-list may be synchronized between the users to avoid undesired users in the group, e.g. if user A blacklisted user C and user B wants to add user C or user C blacklisted user A and user B wants to add user C.

h) The UE of user C can release the 1-to-1 link and join the group using DNB-U group communication.

[00113] 4. Group release

i) The users can leave the group communication by sending a leave message that indicates that a particular user (associated with a user ID) has left the group.

[00114] Synchronization Procedures for a Direct Narrowband Communication System in Unlicensed Spectrum

[00115] One of the first procedure that a UE has to perform in order to connect to a DNB-U network is the synchronization.

[00116] In the following, detailed procedures for synchronization are described covering the following use cases:

- Synchronization Use Case 1: A given UE enables the DNB-U feature and wants to transmit data to a group and it does not receive any synchronization timing.
- Synchronization Use Case 2: A given UE enables the DNB-U feature and wants to transmit data to a group and it does receive at least one synchronization signal after scanning a set of anchor frequency/frequencies.
- Synchronization Use Case 3: A given UE enables the DNB-U feature and it does receive multiple synchronization signals after scanning a set of anchor frequencies.

[00117] The following examples specifically focus on the case where a UE with the DNB-U feature enabled has no concurrent support of DNB-U and an LTE network and hence no network assistance is possible. This can be compared to the case defined in D2D when the devices are in out of coverage.

[00118] In D2D the following synchronization procedure is considered according to 3GPP: In case of out of coverage a UE first needs to listen to a predefined frequency where synchronization sequences are transmitted in D2D. In order to perform this search the UE tries to cross-correlate a received sequence with a set of known Secondary Sidelink Synchronization Sequences (SLSS) which depend on a SideLink ID (SLSS ID).

[00119] The SLSS ID is in the range from 0 to 335 and is divided into two sets:

- $SLSS\ ID \in \{0, \dots, 167\}$: Either the transmitting UE is in coverage or gets the synchronization directly from a UE in coverage.

- SLSS ID $\in \{168, \dots, 335\}$: The UE is out-of-coverage and has no direct connection to a UE in coverage.

[00120] When the device (i.e. the UE) finds a synchronization source it gets its timing and frequency and is then able to demodulate the Master Information Block (MIB) sent by the synchronization source. In order to select the synchronization source the device uses a Sidelink Reference Signal Received Power (S-RSRP) applying L3 (layer 3) filtering with preconfigured filter coefficients. S-RSRP is measured on Demodulation Reference Signals (DMRS) which are embedded in the synchronization subframe. The possible synchronization sources for a UE are those for which the S-RSRP is above a certain preconfigured threshold and the UE selects them according to a priority (first those who are in coverage, then those who are linked to a UE which is in coverage and then the rest).

[00121] In certain cases the UE transmits itself the synchronization sequences (same primary and secondary synchronization sequences with potentially a difference SLSS ID and a different content for the MIB – the UE may use different subframes to transmit synchronization sequences compared to the synchronization source).

[00122] In case the UE has not found any synchronization source with S-RSRP above the predefined threshold it starts transmitting its own synchronization sequences and MIB in a preconfigured subframe.

[00123] However, the same synchronization procedure cannot be directly applied to DNB-U synchronization because of the following limitations:

- The presence of the synchronization sequences is always located in a certain predefined location within the system bandwidth (BW) in the licensed spectrum. Because of regulatory requirement this typically has to be modified for unlicensed spectrum synchronization.
- The definition of the SSLID used for D2D cannot be reused for the DNB-U system because in that case there is no need to discriminate whether a synchronization

source is in coverage or out of coverage because there is no network assistance.

This point is addressed further below in context of synchronization signal design.

- The synchronization source selection is based on the S-RSRP based on the DM-RS. This is undesirable for DNB-U because it would potentially introduce ping pong effect. This is an effect due to the propagation of the synchronization timing when the rule to select which synchronization source to select is only based on RSRP. In that case a large amount of cell reselection might happen.
- The choice to always re-transmit synchronization sequences might introduce too large interference and potentially also a large amount of cell reselection.

[00124] In the following, synchronization procedures for unlicensed device to device communication are described considering either (option 1) a single synchronization source or (option 2) a single synchronization source and multiple secondary synchronization sources. The basic principle can be seen to consist of the following steps: i) electing a synchronization source per predefined rules; ii) synchronizing to the elected user timing and frequency; optionally becoming a secondary synchronization source; iii) transmitting data using own or synchronization source timing iv) stopping being a synchronization source (manually or automatically in a semi static manner or in a dynamic manner). Additionally, a frequency hopping framework is described considering regional regulatory requirements in the unlicensed spectrum.

[00125] In more detail, the two options in terms of synchronization procedures described in the following are as follows:

1. Option 1: Single synchronization source
 - a. A single UE is elected as the synchronization source.
 - b. The UE can decide to stop being a synchronization source (manually or automatically in a semi static manner or in a dynamic manner).

- c. Another UE synchronized to the synchronization source uses the rx (receive) timing and frequency to transmit its data to one or more UEs assuming that the one or more UEs are synchronized to the same user.
 - d. A methodology to handle the cell border case is provided.
- 2. Option 2: Single synchronization source and multiple secondary synchronization source
 - a. According to certain rules a single UE is elected as synchronization source.
 - b. The UE can decide to stop being a synchronization source (manually (e.g. based on user input) or automatically in a semi static manner or in a dynamic manner).
 - c. Another UE synchronized to the synchronization source uses the rx (receive) timing and frequency to transmit its data and sends synchronization units as well according to certain rules. The rules to choose whether the synchronization signals have to be transmitted is different and the subframes where to transmit the synchronization sequences are different from option 1.

[00126] Option 1 can be seen to be simpler as it creates less interference but it has the drawback that at the cell boundaries the direct communication with neighbor users might be limited as UEs are synchronized to different synch sources.

[00127] Option 2 can be seen to be similar to the D2D procedure but it is optimized in order to take into account specific problems related to large amount of cell reselection and ping pong effect and to limit the propagation of the time and frequency error that has to be handled by the device in order to properly synchronize.

[00128] Both the options are based on the assumption that the medium is not always free such that potentially a carrier sensing is needed before transmitting the data and that a certain amount of frequency hopping is needed.

[00129] Regarding regulatory constraints, it should be noted that the FCC (Federal Communications Commission) states that

"For frequency hopping systems operating in the 902-928 MHz band: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping

frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period;" this transmission can use up to 30dBm Maximum Output Power. In case instead the 20dB bandwidth of the hopping channel is >250KHz (but less than 500KHz) the Maximum Transmit Power is reduced to 24dBm and the number of hops has to be less < 50.

[00130] As described in more detail below, according to various examples, the concept of Synchronization Unit (SU) is used which consists of certain amount of repetitions of

- Unlicensed Narrowband Primary Synchronization Sequences U-NPSS;
- Unlicensed Narrowband Secondary Synchronization Sequences U-NSSS and
- Unlicensed Physical Broadcast Channel, U-PBCH, information.

[00131] Within this SU and depending on the design options described below the Synchronization Burst contains also some OFDM symbols for reference symbols.

[00132] According to FCC some level of frequency hopping is needed in case of narrowband transmission. In the following it is considered that frequency hopping is required for synchronization and the maximum transmission time per each frequency is 400ms/20s period.

[00133] According to this case a frequency hopping pattern is considered. The frequency hopping could be very rapid (as shown in figure 9) or very slow depending on the regional regulations.

[00134] Figure 9 shows a signal diagram 900 illustrating a frequency hopping pattern for synchronization signal transmission.

[00135] Time flows from left to right in figure 9 and for each of a plurality of frequencies f_1 to f_N , transmissions using the frequency by a first UE are shown by blocks with a horizontal hatching and transmissions using the frequency by a second UE are shown by blocks with a vertical hatching.

[00136] According to this case a set of frequencies N is defined to be used for synchronization: for example if $f_0, \dots, f_{N-1}$ are the available frequencies. The hopping pattern could be

- At time n , select frequency f_k
- At time $n+1$ select frequency f_M

where $M = (k+N/2)$ if $k+N/2 < N$ and $M = (k+N/2) \bmod N + 1$.

[00137] A new frequency following the frequency hopping pattern is selected every e.g. 10ms in case a rapid frequency hopping pattern is required or e.g. some minutes in case a slow frequency hopping pattern is required.

[00138] Note that in figure 9 a number of 50 hoppings is indicated but this is only an example. The amount of frequencies over which to hop is a parameter N that depends on regional regulatory requirements and on the acquisition timing requirement.

In the following, an example for a synchronization procedure to fulfill the Synchronization use cases described above is described according to the two options mentioned above:

- Option 1. Single synchronization source
- Option 2. Single synchronization source and multiple secondary synchronization source.

[00139] Whenever no distinction between the options is provided the procedure is applicable to both the cases.

[00140] 1. Synchronization Use Case 1: A given UE enables DNB-U feature and wants to transmit data to a group and it does not receive any synchronization timing

[00141] The synchronization procedure for this use case is described in the form of two key stages and is illustrated in figure 10.

[00142] Figure 10 illustrates a synchronization procedure.

[00143] A communication arrangement having four UEs 1001, 1002, 1003, 1004 (denoted as UE_A to UE_D) is shown in figure 10 wherein a left-hand side representation of the communication arrangement illustrates the first stage of the synchronization procedure and the right-hand side representation of the communication arrangement illustrates the second stage of the synchronization procedure.

[00144] In the first stage, first, after enabling the DNB-U feature (manually or automatically) a UE scans the N anchor frequencies to try to synchronize:

- For example, the device UE_A 1001 scans each of the N frequencies for a time T_{synchf} for each frequency (total time to search $T_{\text{synchf}} * N + T_{\text{rnd}}$)
- T_{rnd} is a UE specific timer that each UE would select randomly within a certain range $\{0, T_{\text{rndmax}}\}$ which would limit collision.
- If synchronization to a source is not successful in the predefined time (according to a certain metric defined below) and if UE_A wants to transmit data it will start transmitting its synchronization sequences. UE_A becomes the synchronization source and goes to the second stage.

[00145] In the second stage, UE_A selects a predefined frequency to start transmitting the synchronization sequences or it will select randomly the frequency belonging to the set of allowed frequencies for synchronization autonomously based on e.g. the frequency for which the lowest received power level is detected.

- Synchronization sequences are sent for a certain period before data transmission start (for a period $T_{\text{pre-synch}}$) at least until UE_A needs to transmit data (for a period T_{data}) plus a preconfigured timer T_{add} that is used to limit cell reselections. The total time the device transmits the synchronization sequence is $T_s = T_{\text{pre-synch}} + T_{\text{data}} + T_{\text{add}}$
 - The timer T_{add} is defined and take a preconfigured set of values that the UE can select autonomously (T_{add} includes at least the value 0ms)
- The device (UE) has the possibility to further extend the timer according to a certain principle or stop transmitting synchronization sequence. The principle based on which the device keeps transmitting synchronization sequences (i.e. extends the timer) could be based on battery status, whether active communication is ongoing, based on the amount of users in the group, RSRP level of the LTE network or any combination of the above. If a device does not want to transmit data it does not send synchronization sequences. This may be important to ensure that battery of elected synchronization source is not drained.

[00146] In case of option 1, since there is no presence of a secondary synchronization source after the expiration of the timer T_S there would be an interruption due to the fact that there would be no synchronization sources any longer and devices would need to start again the procedure from stage 1. In order to avoid interruption time in case of option 1 an additional field may be included in the Master Information Block (carried by the U-PBCH) that includes information about the use of T_{add} and its selected value. In this case the devices synchronized to the synchronization source is able to become a synchronization source without large interruption. After the expiration of T_S , devices would scan the frequencies for a time given by the parameter T_{rnd} as defined above before entering into stage 2.

[00147] In case of option 2 secondary sources continue sending synchronization sequences and there is no need for a specific handling. However the presence of an additional field in MIB (Master Information Block) indicating the value of T_{add} allows secondary synchronization sources to decide whether to become synchronization sources (changing the U-NSSS ID).

[00148] The following metrics can be used to determine whether a device scanning the frequencies can decide to stop scanning and start stage 2.

- Reliability of the U-NPSS and/or U-NSSS peak detection
- Energy level detected over the U-NPSS and U-NSSS
- S-RSRP computed over the Reference Signals embedded in the Synchronization Unit (e.g. similarly as in D2D)

[00149] 2. Synchronization Use Case 2: A given UE enables DNB-U feature and wants to transmit data to a group and it does receive at least one synchronization signal after scanning the set of anchor frequency/frequencies.

[00150] Two options are considered for this use case:

[00151] Figure 11 illustrates a synchronization procedure according to a first option for Use Case 2.

[00152] A communication arrangement having eight UEs 1101-1108 (denoted as UE_A to UE_H) is shown in figure 11.

[00153] According to this option, a UE starts transmitting using the DL timing acquired via synchronization to the available Synch (synchronization) source (UE_A and UE_E in this example). A drawback is that UEs synchronized to different Sync sources (i.e. Sync devices) are not able to communicate with each other even in near proximity as indicated by the cross 1109 in figure 11: UE_F is not able to communicate to UE_D. Eventually communication will be possible when UE_D (or UE_F) becomes a Synch source.

[00154] Figure 12 illustrates a synchronization procedure according to a second option for Use Case 2.

[00155] A communication arrangement having four UEs 1201-1204 (denoted as UE_A to UE_D) is shown in figure 12.

[00156] In this example, UE_D is synchronized to UE_A. If UE_D wants to transmit data it will start propagating UE_A timing via the transmission of its synchronization sequences if certain conditions are respected, i.e. UE_D becomes a secondary Synch source. The conditions could be linked to the RSRP level of the received synchronization burst, i.e. at low RSRP time propagation is needed (cell edge conditions) at high RSRP one could assume that devices in the proximity could also receive the synchronization burst from UE_A.

[00157] UE_D reuses the same frequencies and the same synchronization burst content, but the Cell ID used for the U-NSSS is different and the content of the Master Information Block carried by the U-PBCH is different compared to UE_A (as it would carry information related to subframe and frame where the U-PBCH starts). It selects a subframe to transmit the synchronization sequences depending on offsets. A preconfigured offset for example depends on the periodicity at which the synchronization burst is set, e.g. $(\text{SFN} \cdot 10 + \text{subframe}) \bmod P$ where P is the periodicity of the SU (e.g. 500ms).

[00158] Synchronization sequences are sent according to the same principle as defined for Use Case 1. UE_C and UE_B will not recognize two different synchronization sources but only one after detection of U-NSSS and MIB.

[00159] 3. Synchronization Use Case 3: A given UE enables the DNB-U feature and it does receive multiple synchronization signal after scanning the set of anchor frequencies

[00160] Figure 13 illustrates a synchronization procedure according to a first option for Use Case 3.

[00161] A communication arrangement having eight UEs 1301-1308 (denoted as UE_A to UE_H) is shown in figure 13.

[00162] According to this option, UE_F , for example, detects the presence of multiple synchronization sources and it decides whether to synchronize to UE_D timing or if it keeps synchronization with UE_E . Decision metrics can be RSRP, frame number, priority, etc.

[00163] Figure 14 illustrates a synchronization procedure according to a second option for Use Case 3.

[00164] A communication arrangement having eight UEs 1401-1408 (denoted as UE_A to UE_H) is shown in figure 14.

[00165] According to this option, UE_F , for example, starts propagating the UE_E timing. UE_D detects the presence of multiple synchronization sources and decides whether to synchronize to UE_F timing or if it keeps synchronization with UE_A . Decision metrics can be RSRP, frame number, hop number limitation (via MIB or via cell ID), priority, etc. After deciding which synchronization source to follow it will start propagating the chosen timing. Eventually a single timing could be established.

[00166] It should be noted that the 3GPP ProSe D2D synchronization procedure is defined for licensed band only, i.e. even if a UE is out of coverage it means that it is not under the coverage of the cell but still operating in licensed band. As such this procedure cannot be directly applied to unlicensed spectrum. In D2D the synchronization sequences are located in a

specific symbol and there is no need for frequency hopping mechanisms. In the unlicensed spectrum there is the need to have a more or less dynamic frequency hopping pattern.

[00167] According to various examples of the synchronization described herein, a UE may listen to the spectrum to detect the presence of synchronization sources and then decide whether to become a synchronization source itself. Different metrics may be used to decide whether to become a synchronization source. This may include timers that are used to indicate how long a device is going to be a synchronization source (plus possible extensions). The above-mentioned modification of the MIB content allows informing the other users about the expiration of the timer. This allows reducing the power consumption of a UE which becomes a synchronization source.

[00168] A timing propagation may be used to create a large synchronization area as one option. It is not required to differentiate between out of coverage and in coverage UEs to handle priority. It should be noted that in 3GPP D2D the synchronization source selection is based on the S-RSRP based on the DM-RS. This is typically undesirable for the D2D synchronization in unlicensed band because it would potentially introduce a ping pong effect. The choice to always re-transmit synchronization sequences might introduce too much interference and potentially also a large amount of cell reselection.

[00169] The alternative approach based on no time propagation described above can be considered as low complexity approach. The use of timers to limit the time during which the device is considered as a synchronization source allows to create a dynamic network which eventually allows (even with some latency) to handle cases as in use case 3.

[00170] Synchronization signal design for NB-IOT usage in unlicensed spectrum

[00171] The Internet of Things (IoT) is beginning to grow significantly, as consumers, businesses, and governments recognize the benefit of connecting devices to the Internet. A significant segment of this industry is intended to operate over vast areas (e.g. civic infrastructures, agricultural applications) under the initiative low-power wide area networking (LP-WAN).

[00172] LP-WAN is supposed to provide a global solution for both licensed and unlicensed spectrum (e.g. European ISM band on 868MHz (as defined by ETSI and CEPT) as well as the 902MHz in the USA (as defined by the FCC)). Cellular technologies occupy a dominant position for the licensed IoT business, whereas in the unlicensed group there is a more homogenous contribution from wireless technologies such as Sigfox and Zigbee.

[00173] Globally standardized solutions can be deployed in licensed spectrums. In this context several solutions have been developed or are under development in 3GPP:

- Enhanced Coverage GSM based on GPRS standard (EC-GSM)
- The eMTC solution (commonly called Cat M1) which is based on an evolution of the legacy Cat 0
- The new NarrowBand-IOT (NB-IOT) which is a new non backward compatible radio access technology which is specifically optimized in order to satisfy the requirements required for typical IoT solutions.

[00174] Those solutions have been completed in the context of 3GPP Rel-13 and are now being evolved in 3GPP Rel-14. In addition proprietary solutions already exists in the market such as for example end to end solutions provided by Sigfox, Lora, OnRamp, WaveIoT etc. Those solutions can only be deployed in the unlicensed spectrum as they are not globally standardized solutions.

[00175] Licensed spectrum is in general used in order to deploy services which requires a certain QoS, especially in terms of latency. IoT can be considered to be a delay tolerant service. In fact the requirement is that the latency should be below 10s compared to approximately hundreds of milliseconds in case of normal LTE services. Operators might hence reserve the licensed spectrum to deploy normal mobile broadband type of service and might need to use unlicensed spectrum for delay tolerant services such as IoT.

[00176] Recently both 3GPP and MulteFire alliance have been discussing the possibility to evolve the NB-IOT or the eMTC solution to operate in the unlicensed spectrum. MuLTEFire has decided to conduct a feasibility study to understand whether this can be done and in which

frequency bands; it is not yet decided whether to focus on NB-IOT or the eMTC. 3GPP may possibly introduce a new work item focusing on NBIOT extension to unlicensed spectrum.

[00177] In addition, there is a strong interest to define a solution that operates in the unlicensed spectrum based on a narrowband system which allows direct communication between devices, i.e. for Unlicensed Direct Narrow Bandwidth (DNB-U), as described above, which can be considered as an extension of the legacy D2D framework to operate in a narrow bandwidth in the unlicensed spectrum.

[00178] In the following a design of synchronization sequences is described to operate in the case of unlicensed spectrum below 1GHz with the constraint of 200KHz bandwidth. In particular, a synchronization signal structure for NB-IOT is provided which is designed to support compatibility with in-band deployments where legacy LTE signals are present. This means that many resources are not completely exploited for standalone only type of deployment in order to improve the time and frequency acquisition timing or reduce the complexity. Moreover, considering the use of these synchronization sequences in a direct link type of connection robustness with respect to large frequency errors and timing errors has to be considered.

[00179] An extension of the synchronization signal design is described in the following in order to exploit all the degree of freedom available when a NB-IOT solution is used in the unlicensed spectrum such as 800 or 900MHz ISM band.

[00180] Specifically, the following is described:

- A general synchronization signal framework that can be parametrized in a different way depending on the regulatory requirements that can be specific to different countries.
- Extensions of the Primary Synchronization sequence design towards a design that provides performance improvements and hence a shorter acquisition timing. Different examples are given based on extension of the legacy NB-IOT to exploit additional degree of freedom design or based on the legacy D2D design by adapting it to a narrow bandwidth.

- Extension of the Secondary Synchronization sequence design in order to have performance benefits depending on implementation characteristics in terms of residual frequency offset and complexity savings. Different examples are given based on extension of the legacy NB-IOT to exploit additional degree of freedom design or based on the legacy D2D design by adapting it to a narrow bandwidth.
- Cell ID handling: A way to inform the users synchronizing to a device whether this user is the synchronization source or the n-th secondary synchronization source is given.

Two options are described in order to carry the Cell ID information.

[00181] It should be noted that the current design for NB-IOT is not optimized to exploit all the available degrees of freedom in the system and the current design for D2D is not optimized for a small bandwidth.

[00182] The approach described in the following provides a generic framework that can be used to parametrize the system in different regions, allows exploiting the additional degrees of freedom that are available when the NB-IOT works in a standalone manner in the unlicensed spectrum, provides new designs of primary and secondary synchronization sequences, allows performance improvements in terms of faster acquisition timing or for fixed acquisition time it allows for more reliability and provides certain options allow for complexity saving.

[00183] According to the synchronization signal framework a Synchronization Unit (SU) is introduced. This contains at least the following:

- U-NPSS: Unlicensed-Narrowband Primary Synchronization Signal
- U-NSSS: Unlicensed-Narrowband Secondary Synchronization Signal
- U-PBCH: Unlicensed –Physical Broadcast Channel information (which might include in the same subframe some symbols for reference signals).

[00184] A certain periodicity P for the Synchronization Unit (SU) of length W (e.g. in milliseconds) is introduced. Each SU is composed by a certain amount of instances (time units) of the primary synchronization sequence, secondary synchronization sequences and broadcast channel (which includes also some symbols of reference signals in order to have coherent

demodulation). The number of instances of the above mentioned channel is a design parameter and may be chosen depending on the regulatory constraints (in order for example to fulfill 10% duty cycle in Europe in a specific band or 400ms maximum dwell time in USA etc..).

[00185] Two examples of the framework are shown in figures 15 and 16 depending on the relative position of the channels in time domain.

[00186] Figure 15 shows a signal diagram 1500 illustrating a first example of a synchronization framework.

[00187] Time flows from left to right. A synchronization unit 1501 with a length of W milliseconds is periodically transmitted with a periodicity P . The synchronization unit 1501 includes multiple blocks 1502, wherein each block includes N_{U-NSSS} transmissions of U-NSSS, N_{U-NPSS} transmissions of U-NPSS and N_{U-PBCH} transmissions of U-PBCH.

[00188] Each channel, i.e. the transmission of each of U-NSSS, U-NPSS and U-PBCH, occupies all the frequency resources.

[00189] Figure 16 shows a signal diagram 1600 illustrating a second example of a synchronization framework.

[00190] The second example illustrated in figure 16 is similar to the first example illustrated in figure 15, except that in the blocks 1602 of the synchronization unit 1601 U-NPSS is transmitted before U-NSSS.

[00191] Table 1 gives examples of the choice of N_{U-NSSS} , N_{U-NPSS} and N_{U-PBCH} .

	$N_{U-NPBCH}$	N_{U-NSSS}	N_{U-NPSS}	$W[SU]$	$P[ms]$	Computed $W[ms]$
"NB-IOT"	1	0.5	1	1	10	2 or 3
"Short"	1	1	1	1	10	3
"Short #2"	1	1	1	2	10	6
"Long"	8	4	8	1	80	20

"Very Long"	16	4	14	1	80	34
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Table 1

[00192] The example of table 1 could be applicable in USA when a maximum on time for a particular frequency chunk is possible.

[00193] In Europe a different parametrization would need to be defined in case a distributed (in time) access to the spectrum has to be guaranteed. For example

NU-NPBCH:1, NU-NSSS:1, NU-NPSS:1, W: 1 SU, P: 80ms

with $3/80=3.75\%$ of the resources used for synchronization and 6.25% used for data transmission.

[00194] A certain amount of time units may be reserved in order to do carrier sensing at the beginning of the SU window as illustrated in figure 15 and 16.

[00195] It should be noted that the order used for U-NPSSS, U-NSSS and U-NPBCH in figures 15 and 16 are examples and other orders are also possible.

[00196] In the following, examples for the designs of U-NPSS and U-NSS are given.

[00197] Figure 17 shows an NPSS sequence 1700 in NB-IOT. The NPSS sequence is defined as a length 11 sequence repeated over 11 OFDM symbols (indicated from left to right in a communication resource block 1701, wherein each OFDM symbol corresponds to a column of the resource block 1701) with a particular cover code that is used in order to have better frequency error estimation. Each square of the communication resource block 1701 (and similarly of the other communication resource blocks shown in the following figures) corresponds to a resource element such that each column of resource elements corresponds to an OFDM symbol.

[00198] Figure 18 shows a U-NPSS structure 1800 according to a first example (which can be seen as an extension with respect to figure 17).

[00199] The U-NPSS structure 1800 includes 14 OFDM symbols numbered from 0 to 13 illustrated in the form of a communication resource block 1801. The first three OFDM symbols (the first three columns of the communication resource block 1801) are filled with NPSS sequences. An extension of the cover code is provided. Any type of cover code can be used as it can be shown that performance is not sensitive to the specific cover code. In this example a specific cover code is used as shown in figure 18 but this can be generalized to any cover code. A receiver algorithm based on sliding autocorrelation can be used with coherent or non-coherent combining. Coherent combining achieves better performance. Coherent weighted combining can be used by deriving coefficients with the following formula:

$$w_u = \frac{L}{2\pi} \frac{(L-u)(L-u+1) - H(L-H)}{H(4H^2 - 6LH + 3L^2 - 1)}$$

where L is the number of used OFDM symbols (14 in this example) and H is the number of lags used for the sliding autocorrelation receiver which is known as a potential solution together with cross-correlation based receivers. Alternative weights =1 can be also considered.

[00200] Figure 19 shows an NSSS sequence 1900 in NB-IOT (according to 3GPP Rel-13). Similarly to figure 19, the NSSS sequence 1900 is illustrated as a communication resource block 1901.

[00201] According to a second example the U-NPSS sequence exploits the extra symbols available in the subframe normally used by NSSS in order to increase the amount of repetitions. This is shown in figure 20 (normal cyclic prefix (CP)).

[00202] Figure 20 shows a U-NPSS structure 2000 according to a second example.

[00203] The indicated subframe, shown as communication resource block 2001, is the one normally used by NSSS. Figure 20 shows which subframes are used by U-NSSS and which one by U-NPSS.

[00204] According to a combination of the first example (figure 18) and the second example (figure 20) there would be minimum 17 U-NPSS repetitions per SU. The cover code can be generalized to any combinations of -1 and 1.

[00205] Figure 21 shows diagrams 2101, 2102, each showing time to acquire 90% probability of detection depending on SNR illustrating the performance that can be achieved by the U-NPSS of the first example.

[00206] Each diagram 2101, 2102 shows four curves, wherein the lowest curve corresponds to usage of the NPSS (legacy design) with 4 lags, the second to lowest curve to the usage of NPSS (legacy design) with 6 lags, the third to lowest curve to the usage of U-NPSS according to the first example with 4 lags and the top curve to top curve to the usage of U-NPSS according to the first example with 6 lags, wherein the left diagram 2101 shows the performance for coherent combining and the right diagram 2102 shows the performance for incoherent combining.

[00207] As can be seen, there is approximately a 30% improvement of the performance when using 14 symbols rather than 11 symbols. Further improvements are obtained when combining the first example and the second example of figures 18 and 20.

[00208] Figure 22 shows the synchronization sequence of in a legacy D2D system.

[00209] Time increases from left to right along a time axis 2201 and frequency increases from bottom to top along a frequency axis 2202.

[00210] As a third example for a U-NPSS structure the following can be considered: Use of a length-48, or length-60 (wherein length is given in REs (resource elements)) Zadoff-Chu sequence (length 49, 61 in case of extended CP, and 61 or 85 for normal CP rather than length 63 in D2D system) repeated at least twice in a subframe. This scheme allows for larger reliability than shorter sequences (length-11 sequence). However, sliding autocorrelation receivers cannot be used (only cross-correlation –similar to legacy LTE can be used).

[00211] Figure 23 shows a mapping of a U-NPSS sequence into a signal PRB (physical resource block) design according to the third example into time and frequency for length 61 (left diagram 2301) and length 49 (right diagram 2302). The mapping is to be considered first in frequency and then in time. Other mappings could be also considered. Again, each square represents a resource element and each column of squares an OFDM symbol.

[00212] In figure 23 the possibility to map DM-RS (demodulation reference signal) into the last two symbols is also shown in the right diagram 2302. This could be particularly beneficial when N-PBCH is located after the U-NPSS. Each repetition could be scrambled in a different way to limit the crosscorrelation between the sequences.

[00213] For the U-NSSS design four examples are given in addition to the case when the U-NSSS sequence is kept the same as in legacy NB-IOT system.

[00214] As first example of the U-NSSS design, the same design for U-NSSS as for legacy NSSS may be kept and the first three symbols may be used for symbols for U-NPSS sequences or alternatively use U-NPSS (see figure 20).

[00215] Figure 24 illustrates a second example for U-NSSS design 2400. In this example, a long sequence may be defined for U-NSSS (normal cyclic prefix CP).

[00216] The U-NSSS sequence is designed according to a length-167 ZC sequence

$$d(n) = b_q(m) e^{-j2\theta_f n} e^{-j \frac{\pi u n'(n'+1)}{167}}$$

with cyclic shift

$$\theta_f = \frac{\left(\frac{168}{s}\right)}{168} \left(\frac{n_f}{2}\right) \bmod s$$

where

s is the number of cyclic shifts

$b_q(m)$ is the Hadamard sequence 'q' as in NSSS (q-th row of the Hadamard Matrix e.g.

as defined in 3GPP)

$n = 0, 1, \dots, 167, n' = n \bmod 167$

$m = n \bmod 128$

$u = \text{CellID} \bmod 126 + 3$

$q = \text{Floor}(\text{Cell ID}/126)$ (q-th indicates the row of the Hadamard Matrix e.g. as defined in 3GPP)

[00217] In legacy NB-IOT 4 cyclic shifts are used in order to provide the 80ms boundaries for PBCH decoding. However, depending on the parametrization of the framework there might not be the need for cyclic shift can this parameter can be set to 0.

[00218] Figure 25 illustrates a third example for U-NSSS design (normal CP) 2500, again in the form of a communication resource block 2501.

[00219] According to the third example a short sequence is transmitted during the first three symbols.

[00220] Different information can be transmitted via this short sequence. According to a first case the length-35 ZC sequence is used to convey information about the 'q' parameter, where q is encoded in 32 size Hadamard scrambling sequence:

$$d(n) = bb_q(m) e^{-j \frac{\pi u n'(n'+1)}{35}}$$

where u is a root different from the roots that could be used by the length 131 sequence and bbq(m) corresponds to the one Hadamard sequence of size 32. In this example, four different Hadamard sequences are used. Any four length 32 Hadamard sequences could be considered. A different value could be used depending on the amount of cell ID that the device has to be able to detect. According to a different version of the third example, the length-35 ZC sequence carries information about 'q' parameter and this is encoded via the use of different roots 'h':

$$d(n) = e^{-j \frac{\pi h n'(n'+1)}{35}}$$

[00221] The possible roots that could be used without colliding with the length 131 sequence are 0, 1, 2, 129 and 130. Any combination of four roots among those values may be considered. It can be shown via simulations that depending on different residual frequency offset after U-NPSS detection, target SNR and target complexity different methods for U-NSSS might be more beneficial.

[00222] As fourth example for U-NSSS, the U-NSSS is extended from the D2D design (similar to legacy LTE design) as an interleaved concatenation of two length-N/2 binary sequences

without DFT (Discrete Fourier Transform) precoding (same sequences as for LTE) scrambled via a binary sequence that depends on the Side Link ID. Total length is e.g. $N=48$ or $N=60$ for extended CP or 60 and 84 for normal coverage.

[00223] Figure 26 shows a mapping of a U-NPSS sequence according to the fourth example into time and frequency for length 60 (left diagram 2601) and length 48 (right diagram 2602). The mapping is to be considered first in frequency and then in time. As in figure 22, each square represents a resource element and each column of squares an OFDM symbol.

[00224] Each repetition may be scrambled in a different way to limit the cross-correlation between the sequences. Spare symbols can be used for reference signals which are particularly useful if U-NSSS is located before the U-PBCH.

[00225] For all the above designs a subcarrier spacing of 15KHz may be considered as in legacy LTE to avoid high sensitivity to frequency error.

[00226] The same sequence design as in D2D is capable of discriminating between 336 Cell IDs divided into two groups depending on whether the device is located in coverage ($N_{ID}^{SL} = 0-167$) or out of coverage ($N_{ID}^{SL} = 168-335$). In NB-IOT 504 cell IDs can be discriminated.

[00227] The cell ID is determined depending on the number of synchronization propagation hops. As described above synchronization propagation hops may be used: a device (UE) could be the synchronization source or it can be a secondary synchronization source (i.e. it is propagating the timing of another user).

[00228] In the following, a way is described to inform the users synchronizing to a device whether this user is the (primary) synchronization source or the n-th secondary synchronization source in a sequence of synchronization sources, wherein the first synchronization source is the primary synchronization source and each secondary synchronization source receives the synchronization signal from the previous synchronization source in the sequence of synchronization sources and forwards it (which is referred to as a hop).

[00229] In case the device is a (primary) synchronization source it selects a cell ID in the range

$(M*(n-1)/K -- (M*n/K - 1))$ with $n=1$, this is called range $n=1$. In case a device is synchronized to a synchronization source with cell ID in range n (starting from $n=1$) it transmits U-NSSS by using cell ID with range $n+1$. The selection of the cell ID continue up to a limit K such that $n=K$. M corresponds to the maximum cell ID (e.g. 336 or 504), K is the amount of hops that are allowed and n is the range index.

[00230] As an alternative the indication of n is embedded into the U-NPSS design (by using different roots e.g. $n=1 \rightarrow u_1$, $n=2 \rightarrow u_2$, $n=3 \rightarrow u_3$ etc...) which indicates whether the device is the (primary) synchronization source or the n -th secondary synchronization source). In that case the U-NSSS sequence design carries only information about a single range.

[00231] It should be noted that all designs described above are UE specific and can be implemented without changing the standard. However, they could be standardized in the future or included into proprietary designs for the support of the unlicensed direct communication between devices.

[00232] Hybrid systems for Narrowband Direct Link Systems in Unlicensed Spectrum

[00233] For a system to operate in an unlicensed spectrum, it must comply with FCC regulations. FCC introduces specific regulations that have to be followed depending on which type of device the system complies with. Following options are possible:

- Frequency hopping type of systems
 - where the systems with less than 250 KHz 20dB bandwidth will have to hop over 50 channels and can transmit with up to 36dBm eirp (equivalent isotropic radiated power) including the antenna gain (up to 30dB maximum output power). The dwell time in this case is 400ms/20s and all the frequencies have to be used in average the same amount of time.
 - where the systems with more than 250 KHz 20dB bandwidth but less than 500KHz will have to hop over more than 25 channels and can transmit with up

to 30dBm eirp including the antenna gain (up to 24dB maximum output power).

The dwell time in this case is 400ms/10s and all the frequencies have to be used in average the same amount of time.

- Digital Modulations (DTS) with PSD (Power Spectral Density) limitation of 8dBm/3KHz and maximum output power of 30dBm and a minimum bandwidth of 500kHz. No dwell time is specified.
- Hybrid type of system where the device has to comply with the power density standard of 8 dBm in any 3 kHz band when the frequency hopping function is turned off. The transmission also must comply with a 0.4 second/channel maximum dwell time when the hopping function is turned on. There is no requirement for this type of hybrid system to comply with the 500 kHz minimum bandwidth normally associated with a DTS transmission; and, there is no minimum number of hopping channels associated with this type of hybrid system.

[00234] The approaches described above regarding specific variants of synchronization and discovery procedures respectively and the specific details of the synchronization sequences can be seen to focus on the use of a radio access technology which is based on frequency hopping and as such it satisfies the FCC requirement for those technologies.

[00235] However, the requirements in terms of frequency hopping are unclear and subject to approval from FCC on whether a system is or is not compliant. One of the main issue is the acquisition time (the time to acquire correct timing and frequency in order to start the transmission) and the discovery period (the exchange of information between devices in order to discover who is in a certain range). Furthermore, the key constraint that makes synchronization long is the dwell time requirement. This requires the synchronization procedure to hop over different frequencies in order to be able to transmit for a longer time. The handling of the frequency hopping would require either a long period to sense the network to be able to synchronize or higher complexity in the device in order to support the possibility to receive the signal over a larger bandwidth (e.g. 5 times the narrowband over which the system is based)

and then down-convert in a different manner each 180KHz chunk in order to process the different portion of the synchronization signal transmission.

[00236] In the following, an approach for using device to device type of unlicensed communication system as a hybrid system by exploiting the benefits of the digital modulation for the synchronization phase and the benefits of the frequency hopping for the communication is described. The approach extends the design of synchronization procedures described above to operate in unlicensed spectrum below 1GHz within a hybrid digital modulation/frequency hopping system based on a bandwidth breathing approach.

[00237] This could be considered as an additional synchronization use case compared to synchronization use cases 1, 2 and 3 above.

[00238] A basic idea of the approach described in the following is the introduction of specific phases (N phases where N could for example be 2 or 3) during which a devices in unlicensed band perform synchronization, discovery and communications according to different procedures and different mapping into the physical layer. Each phase is characterized by different type of transmission.

[00239] In particular, the synchronization phase is based on the use of a wide channel bandwidth (more than one physical resource block (PRB)) satisfying the regulation for digital modulation (as per FCC). The communication is based on the use of a narrowband scheme that follows the frequency hopping regulation (as per FCC). The discovery phase can be either associated to the communication phase and multiplexed with the communication phase or can be considered as an independent phase and based on a wide channel bandwidth (more than one PRB) satisfying the regulation for digital modulation. In addition synchronization sequences are provided in order to adapt to a wider bandwidth.

[00240] It should be noted that the current design for NB-IOT is not optimized to exploit all the available degree of freedom in the system and the current design for D2D is not optimized to a small bandwidth and in particular neither the NB-IOT nor the D2D technology are adapted to the FCC regulatory requirements. While the above approaches can be seen to focus on the

use of a narrowband system (1 PRB) and aiming at satisfying the frequency hopping regulation, the approach described in the following addresses a system design that satisfies regulations of a hybrid system and that exploits the benefit of both digital modulation and frequency hopping (as per FCC).

[00241] Figure 27 shows a diagram 2700 illustrating a two stage approach for synchronization, discovery and communication.

[00242] Time flows from left to right and frequency increases from bottom to top in figure 27.

[00243] In the example of figure 27, each device (UE) has $N = 2$ states which indicates the type of activity. The first state corresponds to a synchronization phase 2701 while a second state corresponds to the discovery and communication phase 2702. The synchronization procedures and synch source may for example work as described above.

[00244] The device enters the synchronization phase 2701

- when switching on the D-UNB feature (feature that enables device to device communication in unlicensed spectrum),
- in a periodic manner for the time during which D-UNB feature is enabled, or according to a (dynamic or semi-statically configured or predefined) DRX (Discontinuous Reception) cycle.

[00245] In this case the device enters into synchronization phase (Synch or SYNCH_PHASE). This phase has a maximum duration T_{SYNCH} .

[00246] During the synchronization phase the device is either listening for the frequency/frequencies where synchronization sequences are sent by the synchronization device or it transmits itself synchronization sequence. It operates as a digital modulation system and it transmits synchronization sequences and broadcast channel mapped into a bandwidth of width B . The bandwidth B is for example larger than 500KHz. For example, in a typical implementation, $B = 504\text{kHz}$. This corresponds to 3 PRBs.

[00247] When operating as synchronization source, the device may transmit synchronization sequences U-NPSS and U-NSSS as described above: for example, U-NPSS as a length 35 ZC sequence that spans 35 subcarriers potentially excluding the DC subcarrier. It repeats the sequence over the at least 14 symbols available in 1 subframe. To generalize the U-NSSS 3 extra symbols in the U-NSSS subframe could also be used for the U-NPSS.

[00248] To operate as a hybrid system, U-NSSS design can be extended according to different methodologies:

1. A 393 ZC sequence mapped first in frequency and then in time, spanning 3 PRBs in frequency and 11 symbols in time domain
2. A 501 ZC long sequence mapped first in frequency and then in time, spanning 3 PRBs in frequency and 14 symbols in time domain.

[00249] PBCH is mapped into 3 PRBs also, split into blocks and each repeated RLPBCH times.

[00250] During the synchronization phase the synchronization device transmits in a continuous manner in a specified frequency the following set of signals:

- U-NPSS with periodicity P_P
- U-NSSS with periodicity P_S
- U-NPBCH with periodicity P_B .

[00251] P_P , P_S and P_B may be different depending on the amount of repetitions needed in order to achieve a target SNR of e.g. -19dB.

[00252] In one embodiment, a single frequency is used for synchronization within the given band, the maximum transmit power is $1W = 30\text{dBm}$. It follows that the target SNR to achieve 160dB MCL is -19dB with 3PRB bandwidth based system.

[00253] It is expected that roughly 500 accumulations would be needed for U-NPSS, approximately 250 accumulations for U-NSSS and approximately 400 ($384 = 16$ blocks each of

24 RLS) transmission for the broadcast channel, leading to a minimum timing of e.g. about 1.15s.

[00254] The synchronization device exits the synchronization phase at the end of the transmission of the predefined amount of U-NPSS, U-NSSS and U-NPBCH repetitions.

[00255] A device (UE) listening for the spectrum to detect a synchronization source (i.e. a synchronization device) reads the predefined synchronization frequency (pre-configured in the device) for a min period $T_{\min} = X$ (e.g. $X=10s$ or $20s$) as shown in figure 27 by considering its receiver to e.g. 3PRB bandwidth.

[00256] If after X seconds the device does not detect any synchronization source already present it continues the synchronization phase and becomes a synchronization source by operating as sync device as described above.

[00257] If after a period below or equal to X seconds the device has detected a synchronization source it exits the synchronization phase and enters into the discovery and communication phase 2702 when the timer related to the synchronization phase has expired.

[00258] In the discovery and communication phase 2702, discovery and communication may be operating in the same way and hence the device could be able to multiplex communication signals with discovery signals. In the discovery and communication phase 2702 the device operates according to a frequency hopping pattern and it operates in a narrowband transmission method with a bandwidth that spans from single tone (e.g. for discovery signal or for user data) to single PRB transmission (multi-tone transmission for communication).

[00259] During the discovery and communication phase 2702 the device sends pilot signals (based on DM-RS) together with the transmission burst in order to allow compensation of the frequency and time misalignment.

[00260] Figure 28 shows a diagram illustrating a three stage approach for synchronization, discovery and communication.

[00261] Time flows from left to right and frequency increases from bottom to top in figure 28.

[00262] In the example of figure 28, each device (UE) has $N = 3$ states which indicates the type of activity. The first state corresponds to a synchronization phase 2801, the second state corresponds to a discovery phase 2802 and the third state corresponds to a communication phase 2803.

[00263] The synchronization phase 2801 may be similar to the synchronization phase 2701 of figure 27.

[00264] When a device exits the synchronization phase 2801 the device enters into a discovery phase (DISCOVERY_PHASE) 2802 with a maximum duration T_{DISC} . The discovery phase 2802 is based on the use of a digital modulation and hence a discovery signal is transmitted in a similar manner as the synchronization signal. The discovery signal is periodically transmitted with a duty cycle of Y seconds within the synchronization duty cycle, creating a regular pattern as illustrated in figure 28.

[00265] During the communication phase 2803 the device follows the same procedure as described with reference to figure 27.

[00266] It should be noted that all designs described are UE specific and it can be implemented without changing the standard. However, they could be standardized in the future and included into the proprietary design for the support of the unlicensed direct communication between devices.

[00267] In summary, according to various examples, a communication terminal is provided as illustrated in figure 29.

[00268] Figure 29 shows a communication terminal 2900.

[00269] The communication terminal 2900 includes a transceiver 2901 configured to support radio communication with a cellular radio communication network via a first frequency band (e.g. via a first carrier frequency) using a first bandwidth and a controller 2902 configured to control the transceiver 2901 to (e.g. directly) communicate with another communication terminal via a second frequency band (e.g. via a second carrier frequency) using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free.

[00270] According to various examples, in other words, a communication terminal uses direct communication (in other words direct device-to-device communication, i.e. bypassing a cellular radio network radio access network, e.g. bypassing base stations; in particular, the direct device-to-device communication may be a communication without central resource allocation) in a different frequency band e.g. in the case that communication via a cellular mobile communication network, i.e. via the radio access network of a cellular mobile communication network, is not possible, e.g. due to high load of the radio access network or due to the communication terminal not being in a coverage region of the radio access network.

[00271] The direct communication may be entirely proprietary or may be implemented as a variation of any of the below mentioned radio communication technologies and/or standards including but not limited to: a Global System for Mobile Communications (GSM) radio communication technology, a General Packet Radio Service (GPRS) radio communication technology, an Enhanced Data Rates for GSM Evolution (EDGE) radio communication technology, and/or a Third Generation Partnership Project (3GPP) radio communication technology, for example Universal Mobile Telecommunications System (UMTS), Freedom of Multimedia Access (FOMA), 3GPP Long Term Evolution (LTE), 3GPP Long Term Evolution Advanced (LTE Advanced), Code division multiple access 2000 (CDMA2000), Cellular Digital Packet Data (CDPD), Mobitex, Third Generation (3G), Circuit Switched Data (CSD), High-Speed Circuit-Switched Data (HSCSD), Universal Mobile Telecommunications System (Third Generation) (UMTS (3G)), Wideband Code Division Multiple Access (Universal Mobile Telecommunications System) (W-CDMA (UMTS)), High Speed Packet Access (HSPA), High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA), High Speed Packet Access Plus (HSPA+), Universal Mobile Telecommunications System-Time-Division Duplex (UMTS-TDD), Time Division-Code Division Multiple Access (TD-CDMA), Time Division-Synchronous Code Division Multiple Access (TD-CDMA), 3rd Generation Partnership Project Release 8 (Pre-4th Generation) (3GPP Rel. 8 (Pre-4G)), 3GPP Rel. 9 (3rd Generation Partnership Project Release 9), 3GPP Rel. 10 (3rd Generation Partnership Project Release 10) ,

3GPP Rel. 11 (3rd Generation Partnership Project Release 11), 3GPP Rel. 12 (3rd Generation Partnership Project Release 12), 3GPP Rel. 13 (3rd Generation Partnership Project Release 13), 3GPP Rel. 14 (3rd Generation Partnership Project Release 14), 3GPP Rel. 15 (3rd Generation Partnership Project Release 15), 3GPP Rel. 16 (3rd Generation Partnership Project Release 16), 3GPP Rel. 17 (3rd Generation Partnership Project Release 17), 3GPP Rel. 18 (3rd Generation Partnership Project Release 18), 3GPP 5G, 3GPP LTE Extra, LTE-Advanced Pro, LTE Licensed-Assisted Access (LAA), MuLTEfire, UMTS Terrestrial Radio Access (UTRA), Evolved UMTS Terrestrial Radio Access (E-UTRA), Long Term Evolution Advanced (4th Generation) (LTE Advanced (4G)), cdmaOne (2G), Code division multiple access 2000 (Third generation) (CDMA2000 (3G)), Evolution-Data Optimized or Evolution-Data Only (EV-DO), Advanced Mobile Phone System (1st Generation) (AMPS (1G)), Total Access Communication System/Extended Total Access Communication System (TACS/ETACS), Digital AMPS (2nd Generation) (D-AMPS (2G)), Push-to-talk (PTT), Mobile Telephone System (MTS), Improved Mobile Telephone System (IMTS), Advanced Mobile Telephone System (AMTS), OLT (Norwegian for Offentlig Landmobil Telefoni, Public Land Mobile Telephony), MTD (Swedish abbreviation for Mobiltelefonisystem D, or Mobile telephony system D), Public Automated Land Mobile (Autotel/PALM), ARP (Finnish for Autoradiopuhelin, "car radio phone"), NMT (Nordic Mobile Telephony), High capacity version of NTT (Nippon Telegraph and Telephone) (Hicap), Cellular Digital Packet Data (CDPD), Mobitex, DataTAC, Integrated Digital Enhanced Network (iDEN), Personal Digital Cellular (PDC), Circuit Switched Data (CSD), Personal Handy-phone System (PHS), Wideband Integrated Digital Enhanced Network (WiDEN), iBurst, Unlicensed Mobile Access (UMA), also referred to as also referred to as 3GPP Generic Access Network, or GAN standard), Zigbee, Bluetooth®, Wireless Gigabit Alliance (WiGig) standard, mmWave standards in general (wireless systems operating at 10-300 GHz and above such as WiGig, IEEE 802.11ad, IEEE 802.11ay, etc.), technologies operating above 300 GHz and THz bands, (3GPP/LTE based or IEEE 802.11p and other) Vehicle-to-Vehicle (V2V) and Vehicle-to-X (V2X)

communication technologies, DSRC (Dedicated Short Range Communications) communication systems such as Intelligent-Transport-Systems and others, etc.

[00272] The direct communication mode may be implemented as i) a fully proprietary mode or ii) as a modification of an existing (standardized) RAT, for example by introducing new signaling mechanisms on the MAC layer. In case ii), the (de)activation of the direct communication may be done by (de)activating the modification (e.g., MAC signaling) when the concerned direct communication transmission starts (ends).

[00273] The direct communication may be narrowband communication i.e. may be performed in a narrowband (e.g. at 180KHz or 1.4MHz). It may for example be based on a contention based radio access protocol, e.g. Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA).

[00274] The communication terminal may further include a transmitter configured to transmit a discovery signal to make the presence of the communication terminal detectable by the other communication terminal. The communication terminal may also include a receiver configured to receive a discovery signal to detect the presence of the other communication terminal.

[00275] The components of the communication terminal (e.g. the transceiver and the controller) may for example be implemented by one or more circuits. A "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus a "circuit" may be a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor. A "circuit" may also be a processor executing software, e.g. any kind of computer program. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit".

[00276] The communication terminal may for example carry out a method as illustrated in figure 30.

[00277] Figure 30 shows a flow diagram 3000 illustrating a method for initiating a communication, for example carried out by a communication terminal.

[00278] In 3001, the communication terminal (e.g. directly) communicates, by means of a transceiver supporting radio communication with a cellular radio communication network via a first frequency band using a first bandwidth, with another communication terminal via a second frequency band using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free.

[00279] The following examples pertain to further exemplary implementations.

[00280] Example 1 is a communication terminal as illustrated in figure 29.

[00281] In Example 2, the subject-matter of Example 1 may optionally include the second bandwidth being equal or smaller than the first bandwidth.

[00282] In Example 3, the subject-matter of Example 1 or 2 may optionally include the first frequency band being one of the licensed bands used for GSM, GPRS, UTRA, EUTRA and the communication with the other communication terminal operating in a non-licensed band.

[00283] In Example 4, the subject-matter of any one of Examples 1 to 3 may optionally include the controller being configured to control the transceiver to communicate with the other communication terminal by means of a direct communication via the second frequency band using the second bandwidth.

[00284] In Example 5, the subject-matter of any one of Examples 1 to 4 may optionally include the transceiver being configured to operate the direct communication in a narrowband.

[00285] In Example 6, the subject-matter of any one of Examples 1 to 5 may optionally include the controller being configured to control the transceiver to directly communicate with the other communication terminal if communication with the cellular radio communication network is not available.

[00286] In Example 7, the subject-matter of any one of Examples 1 to 6 may optionally include the controller being configured to control the transceiver to directly communicate with the other communication terminal based on at least one of an availability of radio resources for

communicating with the cellular mobile communication network, a load of the cellular mobile communication network and whether the communication terminal is in a coverage area of the cellular mobile communication network.

[00287] In Example 8, the subject-matter of any one of Examples 1 to 7 may optionally include the controller being configured to control the transceiver to directly communicate with the other communication terminal if a load of the cellular mobile communication network is above a predetermined threshold.

[00288] In Example 9, the subject-matter of any one of Examples 1 to 8 may optionally include the controller of the communication terminal being configured to select the other communication terminal from a plurality of other communication terminals.

[00289] In Example 10, the subject-matter of Example 9 may optionally include the controller being configured to select the other communication terminal from a plurality of other communication terminals being in direct-to-direct communication range of the communication terminal.

[00290] In Example 11, the subject-matter of Example 9 or 10 may optionally include the controller being configured to group the plurality of other communication terminals and to select the other communication terminal based on priorities associated with the groups.

[00291] In Example 12, the subject-matter of Example 11 may optionally include the controller being configured to select the other communication terminal based on that the other subject-matter of the plurality of other communication terminals has the highest priority among the plurality of other communication terminals.

[00292] In Example 13, the subject-matter of any one of Examples 1 to 12 may optionally include the controller being configured to initiate the direct communication based on whether a user input indicates a request to initiate direct communication.

[00293] In Example 14, the subject-matter of any one of Examples 1 to 13, further comprising a transmitter configured to transmit information about further communication

terminals which are in the communication terminal's range for direct communication to the other communication terminal.

[00294] In Example 15, the subject-matter of any one of Examples 1 to 14 may optionally include the transceiver being configured to transmit a synchronization signal to a least the other communication terminal for the purpose of synchronization in at least a single frequency for a given period of time and changing frequency with a specific duty cycle.

[00295] In Example 16, the subject-matter of Example 15 may optionally include synchronizing with the other communication terminal comprising synchronizing at least one of a transmission frequency and a transmission timing with the other communication terminal.

[00296] In Example 17, the subject-matter of Example 14 or 15 may optionally include the transceiver being configured to transmit the synchronization signal after detecting no other synchronization sources present during a plurality of predetermined times portion of which are indicated in master information.

[00297] In Example 18, the subject-matter of Example 14 or 15 may optionally include the transmitter being configured to transmit the synchronization signal based on forwarding a synchronization signal received from a third communication terminal whenever it needs to communicate under specific conditions related to the received power, number of hops already used, battery status etc.

[00298] In Example 19, the subject-matter of Example 14 or 15 may optionally include the transmitter being explicitly not allowed to transmit the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.

[00299] In Example 20, the subject-matter of any one of Examples 15 to 19 may optionally include the transmitting the synchronization signal comprising a periodic transmission of a synchronization unit.

[00300] In Example 21, the subject-matter of Example 20 may optionally include the transmission of a synchronization unit comprising the transmission of one or more synchronization blocks.

[00301] In Example 22, the subject-matter of Example 21 may optionally include each synchronization block comprising one or more times a primary synchronization sequence, one or more times a secondary synchronization sequence and one or more times broadcast channel master information.

[00302] In Example 23, the subject-matter of any one of Examples 15 to 22 may optionally include the synchronization signal indicating whether the communication terminal is a synchronization source or transmits the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.

[00303] In Example 24, the subject-matter of any one of Examples 1 to 23 may optionally include the controller being configured to control the transceiver to initiate communication with the other communication terminal by means of a two-stage discovery procedure.

[00304] In Example 25, the subject-matter of Example 24 may optionally include the two-stage discovery procedure comprising a first stage including an exchange of an anonymized version of an identification of the communication terminal with the other communication terminal.

[00305] In Example 26, the subject-matter of Example 25 may optionally include the anonymized version of the identification of the communication terminal being a shortened form of an identification of the communication terminal which misses a part of the identification of the communication terminal.

[00306] In Example 27, the subject-matter of Example 25 or 26 may optionally include the two-stage discovery procedure comprising a second stage after the first stage comprising an authentication and a group credential exchange with the other communication terminal.

[00307] In Example 28, the subject-matter of any one of Examples 1 to 27 may optionally include the communication terminal being configured to transmit a synchronization signal during a first time period based on a first bandwidth ((in a continuous manner) based on the use of at least 3 PRBs (504KHz)) and to perform discovery of communication devices or communication with the other communication device during a second time period based on a

second bandwidth narrower than the first bandwidth (with frequency hopping scheme on a single frequency) based on a narrow bandwidth (e.g. smaller than 504KHz).

[00308] In Example 29, the subject-matter of any one of Examples 1 to 28 may optionally include the communication terminal being configured to transmit a synchronization signal during a first time period ((in a continuous manner on a single frequency) based on the use of at least 3 PRBs (504KHz)) based on a first bandwidth, to perform discovery of communication devices during a second time period ((in a continuous manner on a single frequency) based on the use of at least 3 PRBs (504KHz)) based on a second bandwidth and to perform communication with the other communication device during a third time period based on a third bandwidth narrower than the first bandwidth and the second bandwidth (with frequency hopping scheme) based on a narrow bandwidth (e.g. smaller than 504KHz).

[00309] Example 30, the subject-matter of Example 29 may optionally include the first time period and the second time period being periodically scheduled with a given duty cycle.

[00310] In Example 31 is a method for initiating a communication as illustrated in figure 30.

[00311] In Example 32, the subject-matter of Example 31 may optionally include the second bandwidth being equal or smaller than the first bandwidth.

[00312] In Example 33, the subject-matter of Example 31 or 32 may optionally include the first frequency band being one of the licensed bands used for GSM, GPRS, UTRA, EUTRA and the communication with the other communication terminal operating in a non-licensed band.

[00313] In Example 34, the subject-matter of any one of Examples 31 to 33 may optionally include controlling the transceiver to communicate with the other communication terminal by means of a direct communication via the second frequency band using the second bandwidth.

[00314] In Example 35, the subject-matter of any one of Examples 31 to 34 may optionally include the transceiver operating the direct communication in a narrowband.

[00315] In Example 36, the subject-matter of any one of Examples 31 to 35 may optionally include controlling the transceiver to directly communicate with the other communication terminal if communication with the cellular radio communication network is not available.

[00316] In Example 37, the subject-matter of any one of Examples 31 to 36 may optionally include controlling the transceiver to directly communicate with the other communication terminal based on at least one of an availability of radio resources for communicating with the cellular mobile communication network, a load of the cellular mobile communication network and whether the communication terminal is in a coverage area of the cellular mobile communication network.

[00317] In Example 38, the subject-matter of any one of Examples 31 to 37 may optionally include controlling the transceiver to directly communicate with the other communication terminal if a load of the cellular mobile communication network is above a predetermined threshold.

[00318] In Example 39, the subject-matter of any one of Examples 31 to 38 may optionally include selecting the other communication terminal from a plurality of other communication terminals.

[00319] In Example 40, the subject-matter of Example 39 may optionally include selecting the other communication terminal from a plurality of other communication terminals being in direct-to-direct communication range of the communication terminal.

[00320] In Example 41, the subject-matter of Example 39 or 40 may optionally include grouping the plurality of other communication terminals and selecting the other communication terminal based on priorities associated with the groups.

[00321] In Example 42, the subject-matter of Example 41 may optionally include selecting the other communication terminal based on that the other subject-matter of the plurality of other communication terminals has the highest priority among the plurality of other communication terminals.

[00322] In Example 43, the subject-matter of any one of Examples 31 to 42 may optionally include initiating the direct communication based on whether a user input indicates a request to initiate direct communication.

[00323] In Example 44, the subject-matter of any one of Examples 31 to 43 may optionally include transmitting information about further communication terminals which are in the communication terminal's range for direct communication to the other communication terminal.

[00324] In Example 45, the subject-matter of any one of Examples 31 to 44 may optionally include transmitting a synchronization signal to at least the other communication terminal for the purpose of synchronization in at least a single frequency for a given period of time and changing frequency with a specific duty cycle.

[00325] In Example 46, the subject-matter of Example 45 may optionally include synchronizing with the other communication terminal comprising synchronizing at least one of a transmission frequency and a transmission timing with the other communication terminal.

[00326] In Example 47, the subject-matter of Example 44 or 45 may optionally include transmitting the synchronization signal after detecting no other synchronization sources present during a plurality of predetermined times portion of which are indicated in master information.

[00327] In Example 48, the subject-matter of Example 44 or 45 may optionally include transmitting the synchronization signal based on forwarding a synchronization signal received from a third communication terminal whenever it needs to communicate under specific conditions related to the received power, number of hops already used, battery status etc.

[00328] In Example 49, the subject-matter of Example 44 or 45 may optionally include explicitly not being allowed to transmit the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.

[00329] In Example 50, the subject-matter of any one of Examples 45 to 49 may optionally include the transmitting the synchronization signal comprising a periodic transmission of a synchronization unit.

[00330] In Example 51, the subject-matter of Example 50 may optionally include the transmission of a synchronization unit comprising the transmission of one or more synchronization blocks.

[00331] In Example 52, the subject-matter of Example 51 may optionally include each synchronization block comprising one or more times a primary synchronization sequence, one or more times a secondary synchronization sequence and one or more times broadcast channel master information.

[00332] In Example 53, the subject-matter of any one of Examples 45 to 52 may optionally include the synchronization signal indicating whether the communication terminal is a synchronization source or transmits the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.

[00333] In Example 54, the subject-matter of any one of Examples 31 to 53 may optionally include controlling the transceiver to initiate communication with the other communication terminal by means of a two-stage discovery procedure.

[00334] In Example 55, the subject-matter of Example 54 may optionally include the two-stage discovery procedure comprising a first stage including an exchange of an anonymized version of an identification of the communication terminal with the other communication terminal.

[00335] In Example 56, the subject-matter of Example 55 may optionally include the anonymized version of the identification of the communication terminal being a shortened form of an identification of the communication terminal which misses a part of the identification of the communication terminal.

[00336] In Example 57, the subject-matter of Example 55 or 56 may optionally include the two-stage discovery procedure comprising a second stage after the first stage comprising an authentication and a group credential exchange with the other communication terminal.

[00337] In Example 58, the subject-matter of any one of Examples 31 to 57 may optionally include transmitting a synchronization signal during a first time period based on a first bandwidth ((in a continuous manner) based on the use of at least 3 PRBs (504KHz)) and performing discovery of communication devices or communication with the other communication device during a second time period based on a second bandwidth narrower

than the first bandwidth (with frequency hopping scheme on a single frequency) based on a narrow bandwidth (e.g. smaller than 504KHz).

[00338] In Example 59, the subject-matter of any one of Examples 31 to 58 may optionally include transmitting a synchronization signal during a first time period ((in a continuous manner on a single frequency) based on the use of at least 3 PRBs (504KHz)) based on a first bandwidth, to perform discovery of communication devices during a second time period ((in a continuous manner on a single frequency) based on the use of at least 3 PRBs (504KHz)) based on a second bandwidth and performing communication with the other communication device during a third time period based on a third bandwidth narrower than the first bandwidth and the second bandwidth (with frequency hopping scheme) based on a narrow bandwidth (e.g. smaller than 504KHz).

[00339] In Example 60, the subject-matter of Example 59 may optionally include the first time period and the second time period being periodically scheduled with a given duty cycle.

[00340] According to a further example, a mobile communication device is provided comprising a transceiver configured to, in response to communication via a cellular communication network via a first frequency band being unavailable, switch to direct communication via a second frequency band.

[00341] According to a further example, a mobile communication device is provided which i) first has a classical connection (between mobile communication device and cellular network infrastructure) based on a standardized RAT, then ii) it switches to a proprietary device to device mode if communication resources are not available or are limited (wherein the device to device mode fully proprietary or modification of a standardized RAT), then iii) the mobile communication device exchanges data using the device to device connection, then iv) the mobile communication device switches back to the classical connection (to the cellular network infrastructure) once the communication resources become available again. Alternatively, the device to device (e.g. proprietary) connection can be established in parallel to the classical connection.

[00342] According to a further example, a mobile communication device in a standalone manner uses an unlicensed band to communicate with other devices based on a narrowband communication and exchanges data with the other device. For example, this mobile communication device is a classical device capable of supporting a connection to a cellular radio network infrastructure based on a standard RAT and supports switching from the standardized RAT to a proprietary RAT depending on resource availability, traffic load, quality of the connections (RSRP for example) and alternatively there is the possibility to support this via a dual connection capability.

[00343] According to a further example, a communication terminal (and a corresponding method for initiating a communication) is provided comprising a detector configured to detect whether communication in a first frequency band via a cellular mobile communication network is available and a controller configured to initiate, based on whether communication via the cellular mobile communication network is available, direct communication with another communication terminal in a second frequency band different from the first frequency band.

[00344] The controller may for example be configured to check whether direct communication with the other communication terminal is allowed and is configured to initiate the direct communication based on whether direct communication with the other communication terminal is allowed.

[00345] For example, the controller is configured to check whether direct communication with the other communication terminal is allowed based on an authorization of the other communication terminal.

[00346] The detector may be configured to perform an authorization procedure with other communication terminal and initiate direct communication with the other communication terminal if the authorization procedure successfully authorizes the other communication terminal.

[00347] The controller may be configured to check whether direct communication with the other communication terminal is allowed based on a manufacturer identification of other communication terminal.

[00348] According to further examples, a mobile communication device capable of communicating at least with other devices in a narrowband manner operating in the unlicensed spectrum is provided, wherein e.g. the device is also capable of communicate to the network based on a standardized rat. For example, the device is capable of switching to the direct narrowband communication when e.g. resources are not available or radio conditions become poor and of switching back to the standardized RAT method when e.g. radio conditions are above a certain threshold. The device may be capable of establishing always a dual communications and choose in a dynamic manner the best technology to communicate.

[00349] It should be noted that one or more of the features of any of the examples above may be combined with any one of the other examples.

[00350] While specific aspects have been described, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the aspects of this disclosure as defined by the appended claims. The scope is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

1. A communication terminal comprising:
a transceiver configured to support radio communication with a cellular radio communication network via a first frequency band using a first bandwidth;
a controller configured to control the transceiver to communicate with another communication terminal via a second frequency band using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free.
2. The communication terminal of claim 1, wherein the second bandwidth is equal or smaller than the first bandwidth.
3. The communication terminal of claim 1, wherein the first frequency band is one of the licensed bands used for GSM, GPRS, UTRA, EUTRA and the communication with the other communication terminal operates in a non-licensed band.
4. The communication terminal of claim 1, wherein the controller is configured to control the transceiver to communicate with the other communication terminal by means of a direct communication via the second frequency band using the second bandwidth.
5. The communication terminal of claim 1, wherein the transceiver is configured to operate the direct communication in a narrowband.
6. The communication terminal of claim 1, wherein the controller is configured to control the transceiver to directly communicate with the other communication terminal if communication with the cellular radio communication network is not available.

7. The communication terminal of claim 1, wherein the controller is configured to control the transceiver to directly communicate with the other communication terminal based on at least one of an availability of radio resources for communicating with the cellular mobile communication network, a load of the cellular mobile communication network and whether the communication terminal is in a coverage area of the cellular mobile communication network.
8. The communication terminal of claim 1, wherein the controller is configured to control the transceiver to directly communicate with the other communication terminal if a load of the cellular mobile communication network is above a predetermined threshold.
9. The communication terminal of claim 1, wherein the controller of the communication terminal is configured to select the other communication terminal from a plurality of other communication terminals.
10. The communication terminal of claim 9, wherein the controller is configured to select the other communication terminal from a plurality of other communication terminals being in direct-to-direct communication range of the communication terminal.
11. The communication terminal of claim 9, wherein the controller is configured to group the plurality of other communication terminals and to select the other communication terminal based on priorities associated with the groups.
12. The communication terminal of claim 11, wherein the controller is configured to select the other communication terminal based on that the other communication terminal of the plurality of other communication terminals has the highest priority among the plurality of other communication terminals.

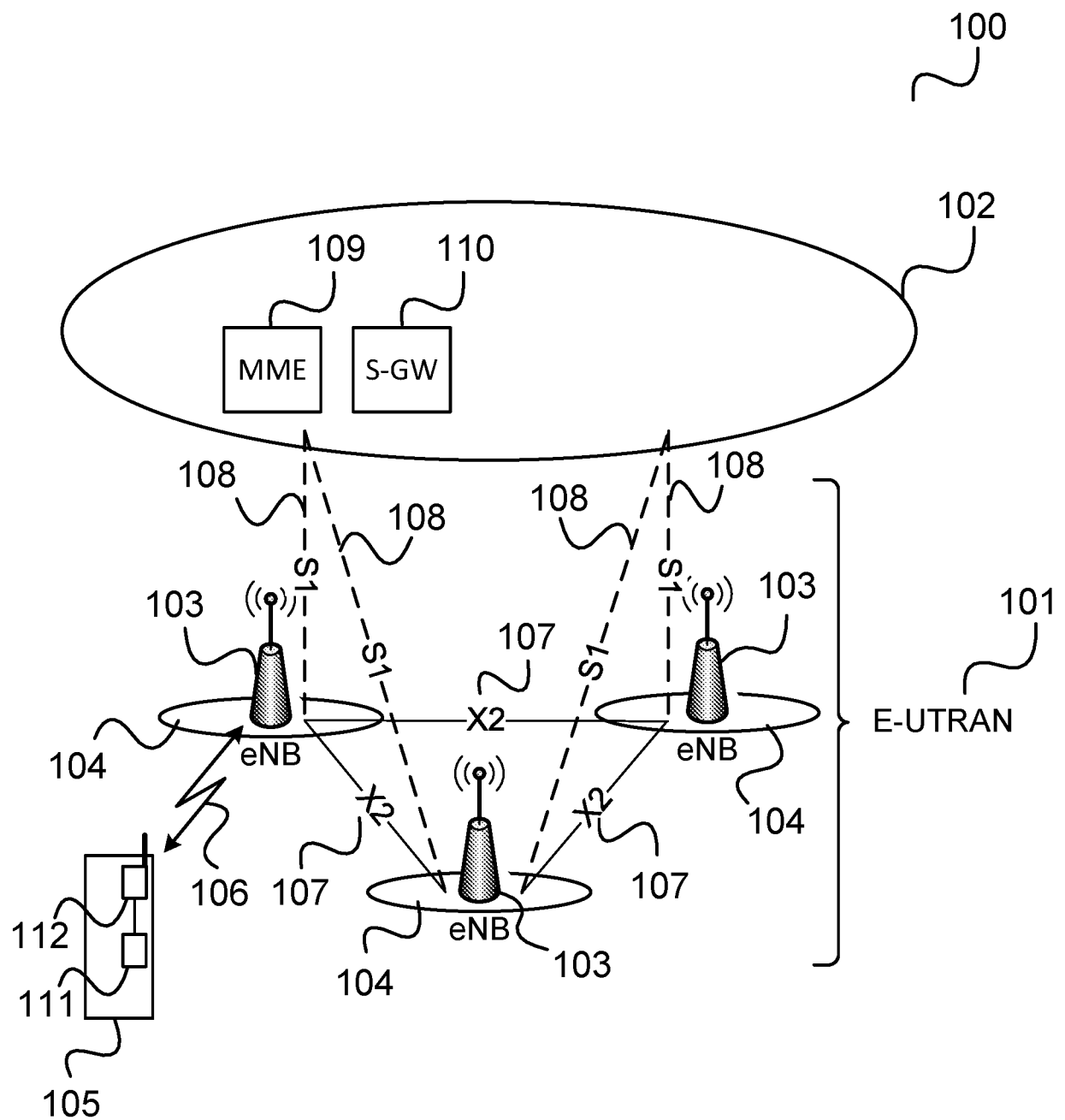
13. The communication terminal of claim 1, wherein the controller is configured to initiate the direct communication based on whether a user input indicates a request to initiate direct communication.
14. The communication terminal of claim 1, further comprising a transmitter configured to transmit information about further communication terminals which are in the communication terminal's range for direct communication to the other communication terminal.
15. The communication terminal of claim 1, wherein the transceiver is configured to transmit a synchronization signal to at least the other communication terminal for the purpose of synchronization in at least a single frequency for a given period of time and changing frequency with a specific duty cycle.
16. The communication terminal of claim 15, wherein synchronizing with the other communication terminal comprises synchronizing at least one of a transmission frequency and a transmission timing with the other communication terminal.
17. The communication terminal of claim 14, wherein the transceiver is configured to transmit the synchronization signal after detecting no other synchronization sources present during a plurality of predetermined times portion of which are indicated in master information.
18. The communication terminal of claim 14, wherein the transmitter is configured to transmit the synchronization signal based on forwarding a synchronization signal received from a third communication terminal whenever it needs to communicate under

specific conditions related to the received power, number of hops already used, battery status etc.

19. The communication terminal of claim 14, wherein the transmitter is explicitly not allowed to transmit the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.
20. The communication terminal of claim 15, wherein the transmitting the synchronization signal comprises a periodic transmission of a synchronization unit.
21. The communication terminal of claim 20, wherein the transmission of a synchronization unit comprises the transmission of one or more synchronization blocks.
22. The communication terminal of claim 21, wherein each synchronization block comprises one or more times a primary synchronization sequence, one or more times a secondary synchronization sequence and one or more times broadcast channel master information.
23. The communication terminal of claim 15, wherein the synchronization signal indicates whether the communication terminal is a synchronization source or transmits the synchronization signal based on forwarding a synchronization signal received from a third communication terminal.
24. The communication terminal of claim 1, wherein the controller is configured to control the transceiver to initiate communication with the other communication terminal by means of a two-stage discovery procedure.
25. A method for initiating a communication comprising:

communicating, by means of a transceiver of a communication terminal supporting radio communication with a cellular radio communication network via a first frequency band using a first bandwidth, with another communication terminal via a second frequency band using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free.

FIG 1



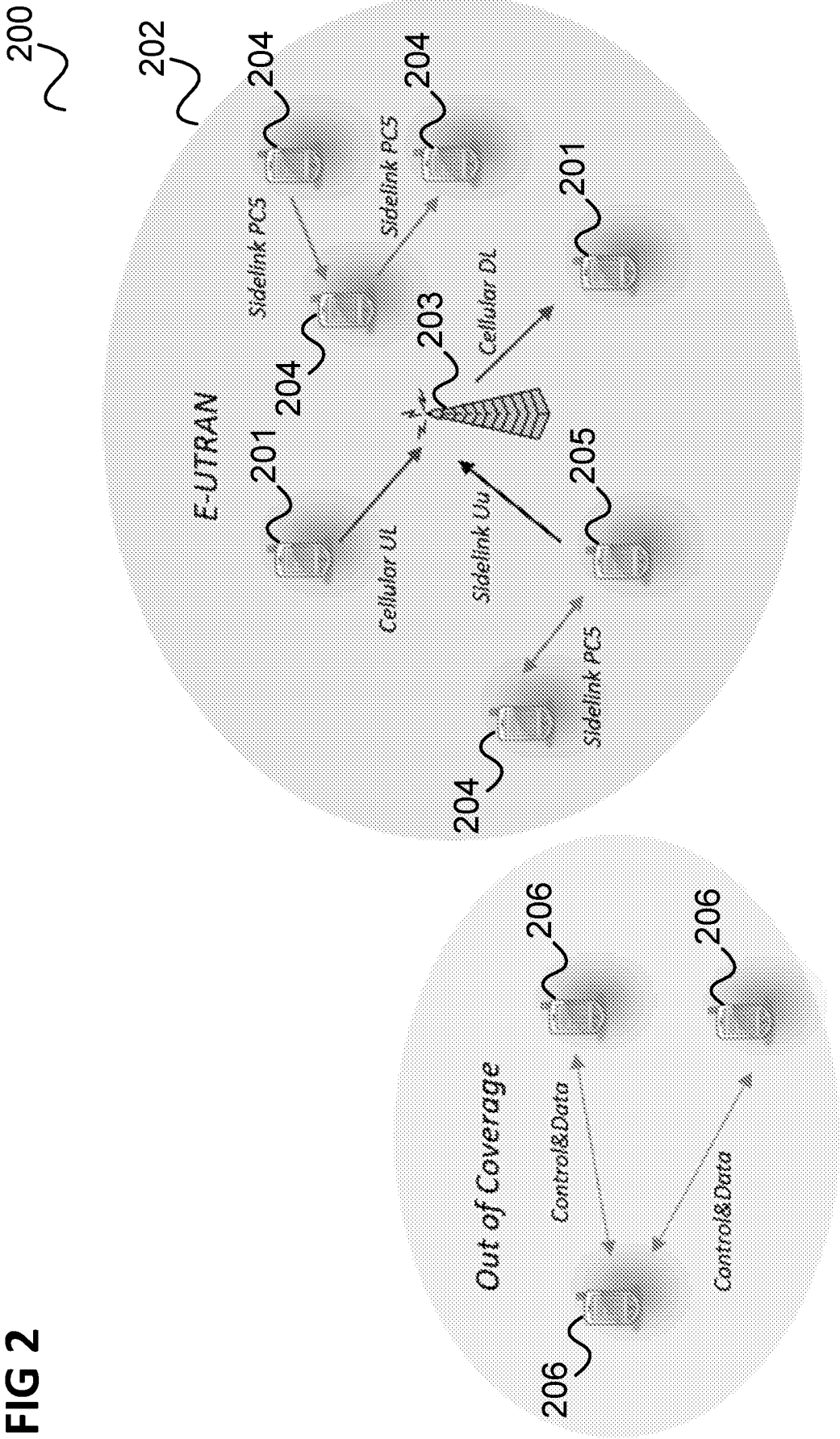


FIG 3

300

Band (MHz)	Bandwidth	Region	ERP	Duty cycle/LBT requirements	ON time, dwell time	Others
863-870	7MHz, max channel BW 300kHz	Europe	25mW e.r.p	≤ 0.1 % duty cycle or poller spectrum access*		RECOMMENDATION ONLY • Band available in 80% of Europe • Sub-bands [868.8 MHz to 869.4MHz], [869.450 MHz to 869.700MHz] for alarms are excluded
863-865	3MHz, No max requirements		25mW e.r.p	≤ 0.1 % duty cycle or poller spectrum access*		Band number 46a from 2013/752/EU
865-868	3MHz, No max requirements		25mW e.r.p	≤ 0.1 % duty cycle or poller spectrum access*, The PSD ≤ +6 dBm/100kHz		Band number 47 from 2013/752/EU, DSSS or other than FHSS
868 - 868.6	600kHz, No max requirements		25mW e.r.p	≤ 1 % duty cycle or poller spectrum access*		Band number 48 from 2013/752/EU
868.7 - 869.2	500kHz, No max requirements		25mW e.r.p	≤ 0.1 % duty cycle or poller spectrum access*		Band number 50 from 2013/752/EU
869.4 - 869.65	250kHz, No max requirements		500mW e.r.p	≤ 10 % duty cycle or poller spectrum access*		Band number 54b from 2013/752/EU
869.7 - 870	300kHz, No max requirements		25mW e.r.p	≤ 1 % duty cycle or poller spectrum access*		Band number 56b from 2013/752/EU
870-875.8	≤ 600 kHz within the 5.0MHz	US/most of Americas	500 mW e.r.p / 100 mW e.r.p	• ≤ 0.1 % in (873-875.8MHz) • ≤ 0.01%	in (873-875.8MHz) D is 5ms/1s	RECOMMENDATION ONLY • 500 mW restricted to vehicle-to-vehicle applications. • 100 mW is restricted to in-vehicle applications. • Adaptive Power Control (APC) is required • Band available in 20% of Europe
902-918	10MHz to use it. 250kHz ≤ 20kHz channel bandwidth* 500kHz		2-50 hopping channels, +30dBm MOP (including 6dB antenna gain)	LBT permitted, no coordination possible	400ms/20s	• Hopping channel carrier frequencies separated by N-max(25 kHz, 20 dB bandwidth) • In any 100 kHz bandwidth outside the frequency band -- allocation at least 30dB below the max desired power in this band
	10MHz to use it. 250kHz < 20kHz channel bandwidth* ≤ 500kHz		< 50 channels, +30 dBm MOP (including 6dB antenna gain)	LBT permitted, no coordination possible	400ms/10s	

FIG 4

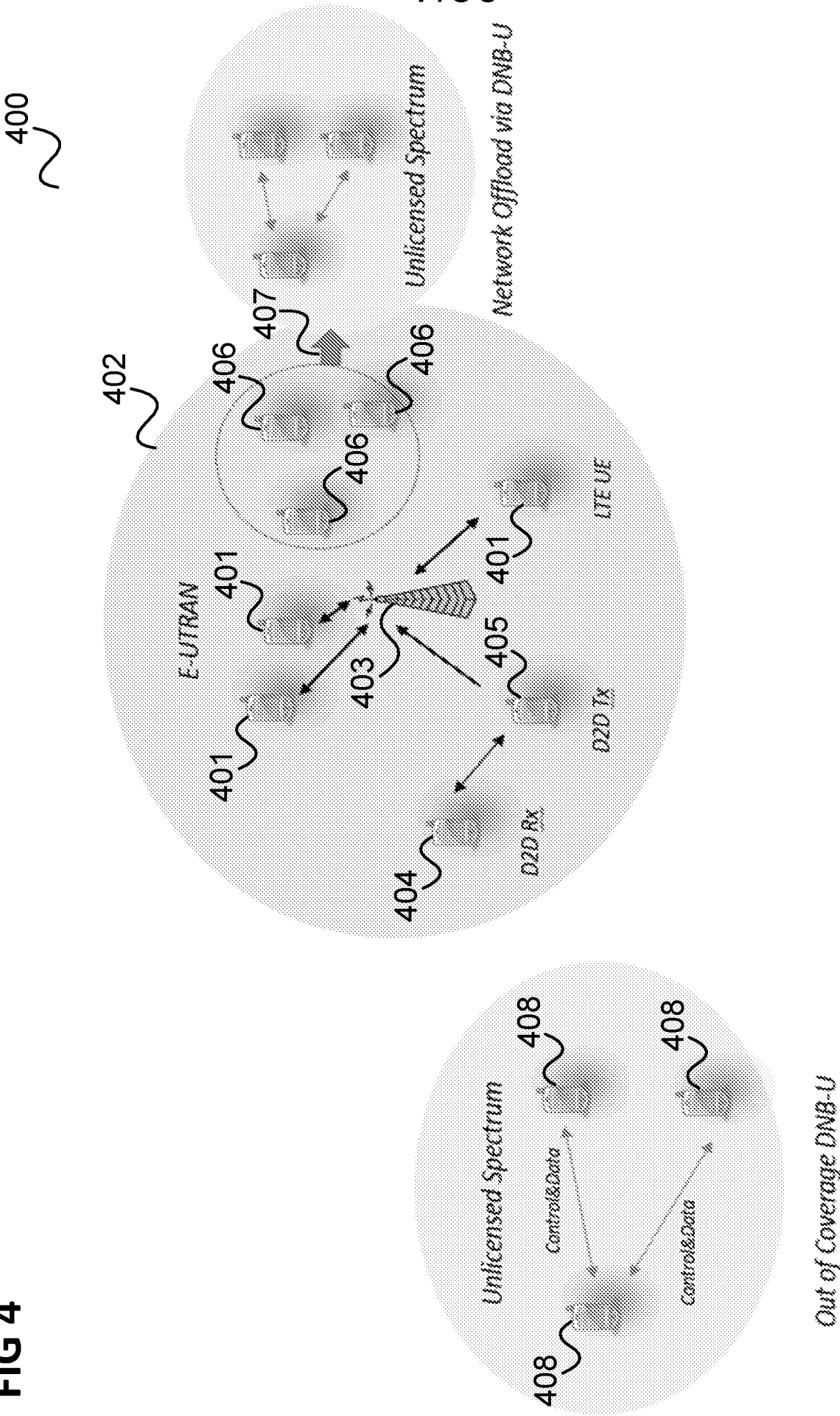


FIG 5

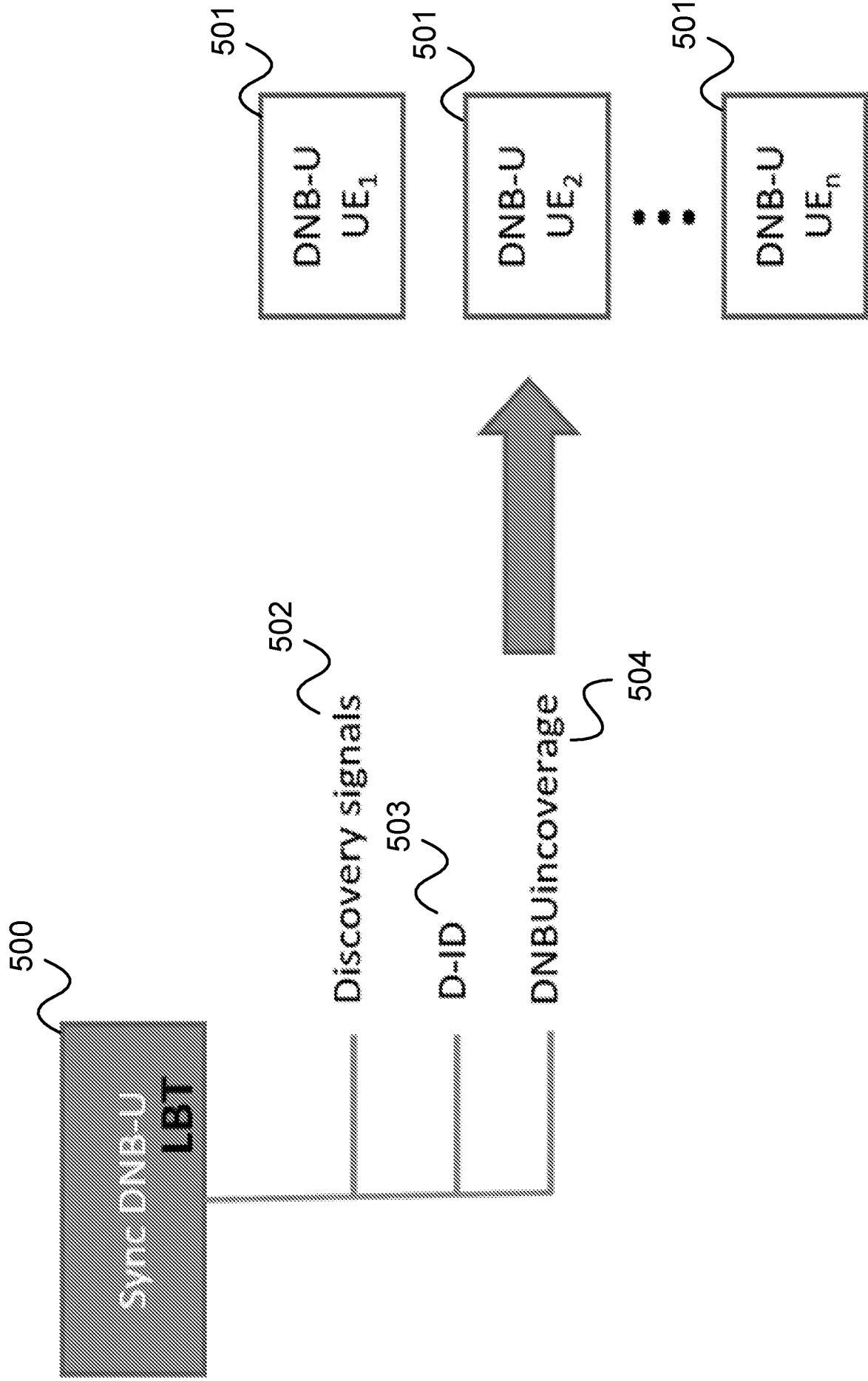


FIG 6

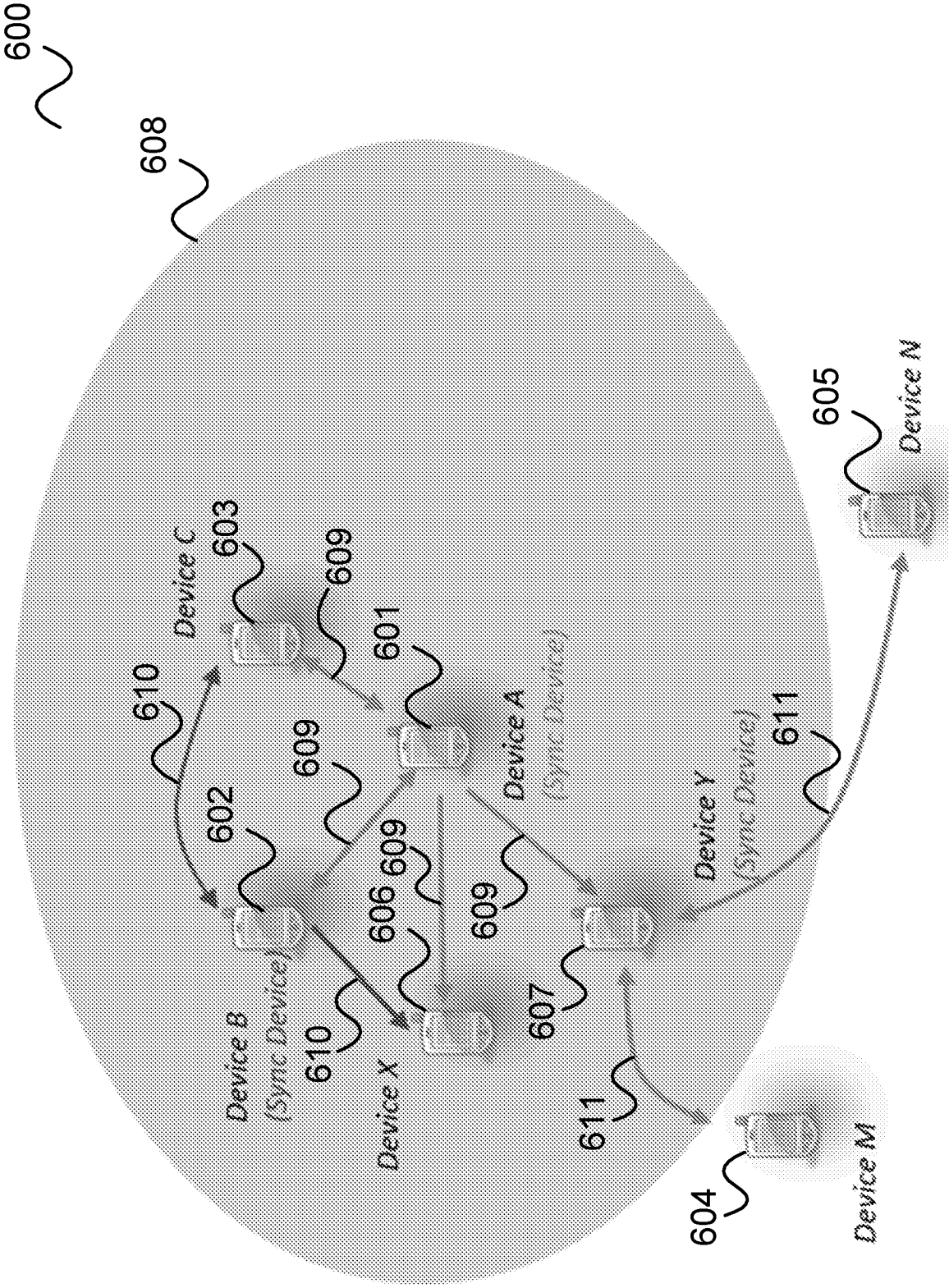


FIG 7

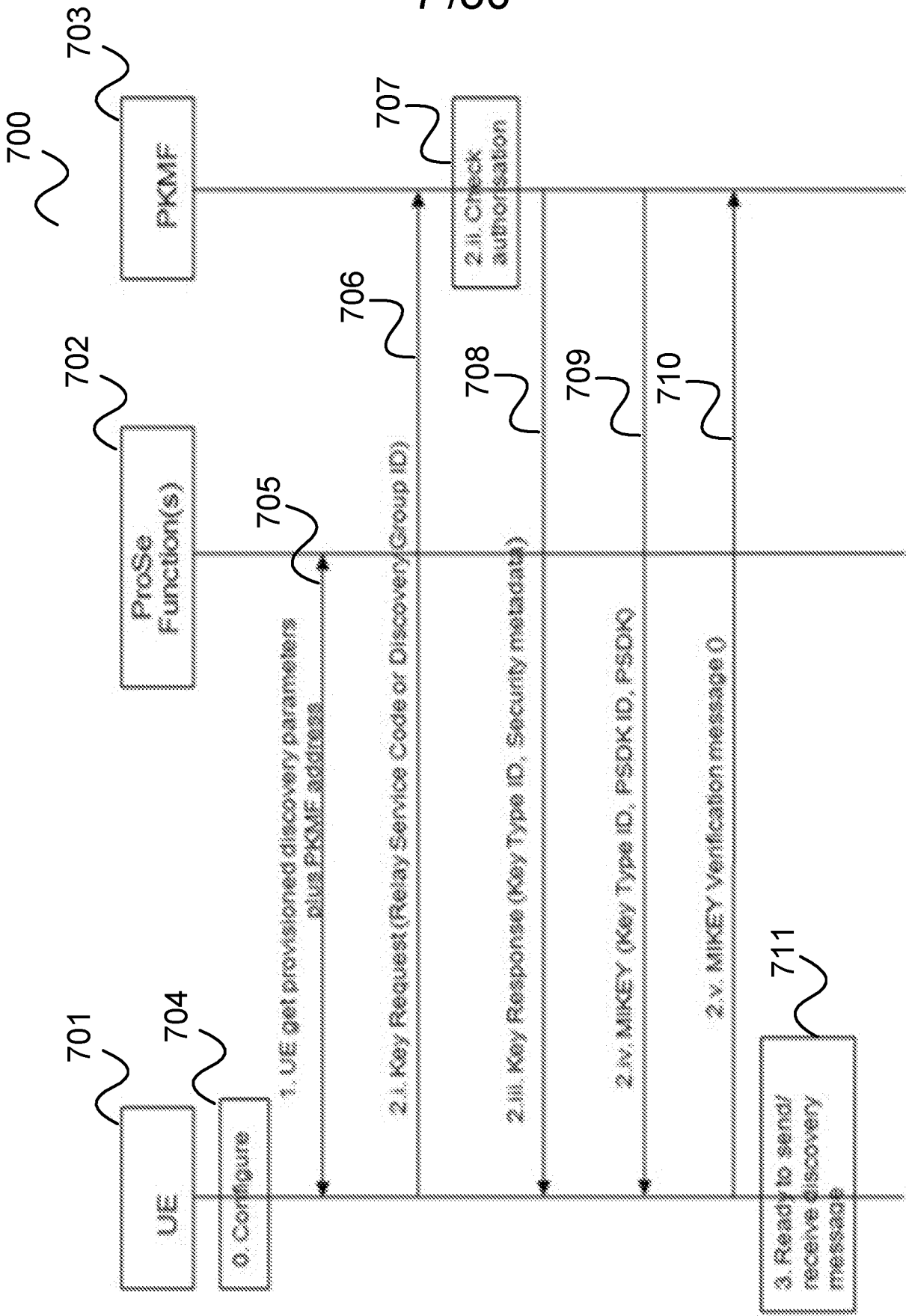


FIG 8

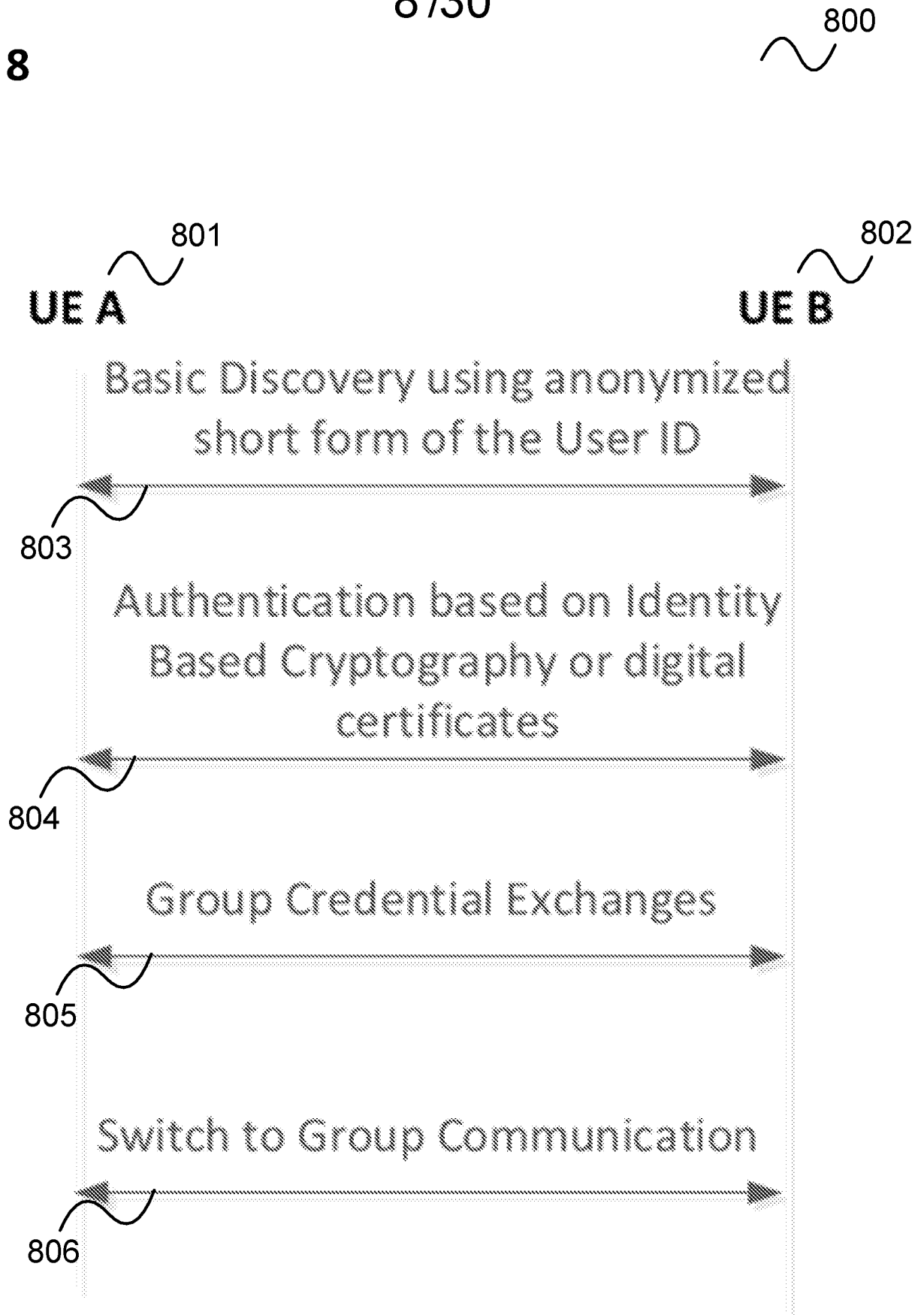


FIG 9

900

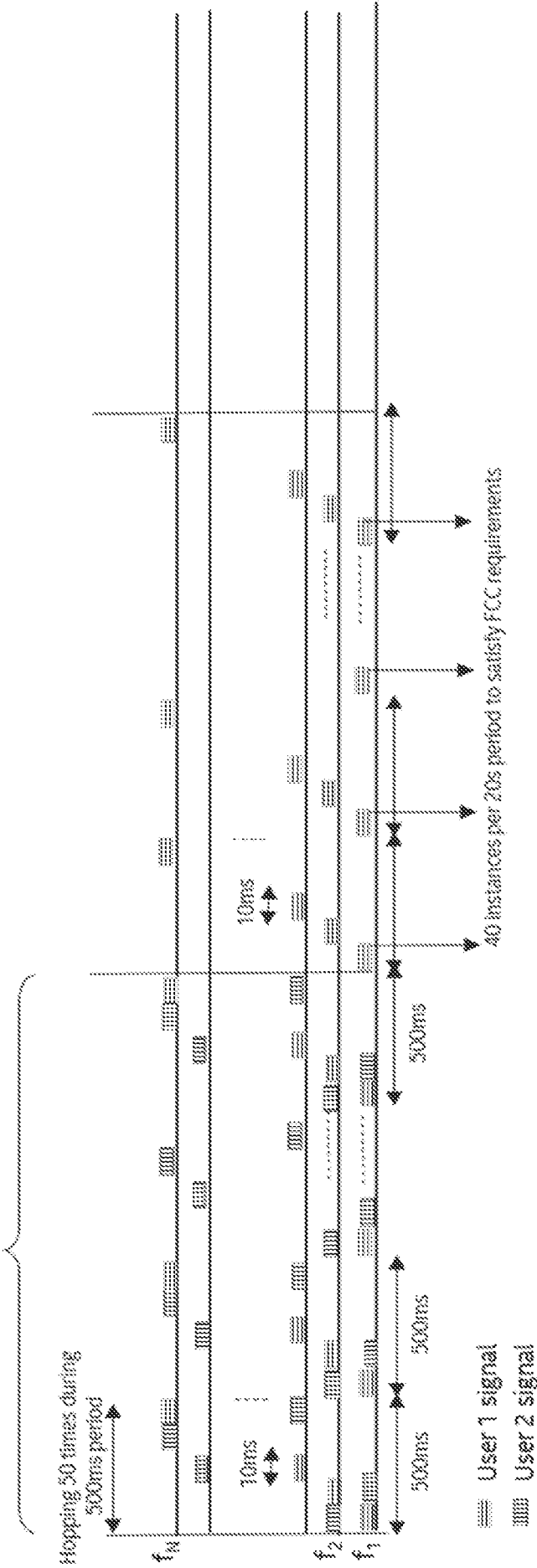


FIG 10

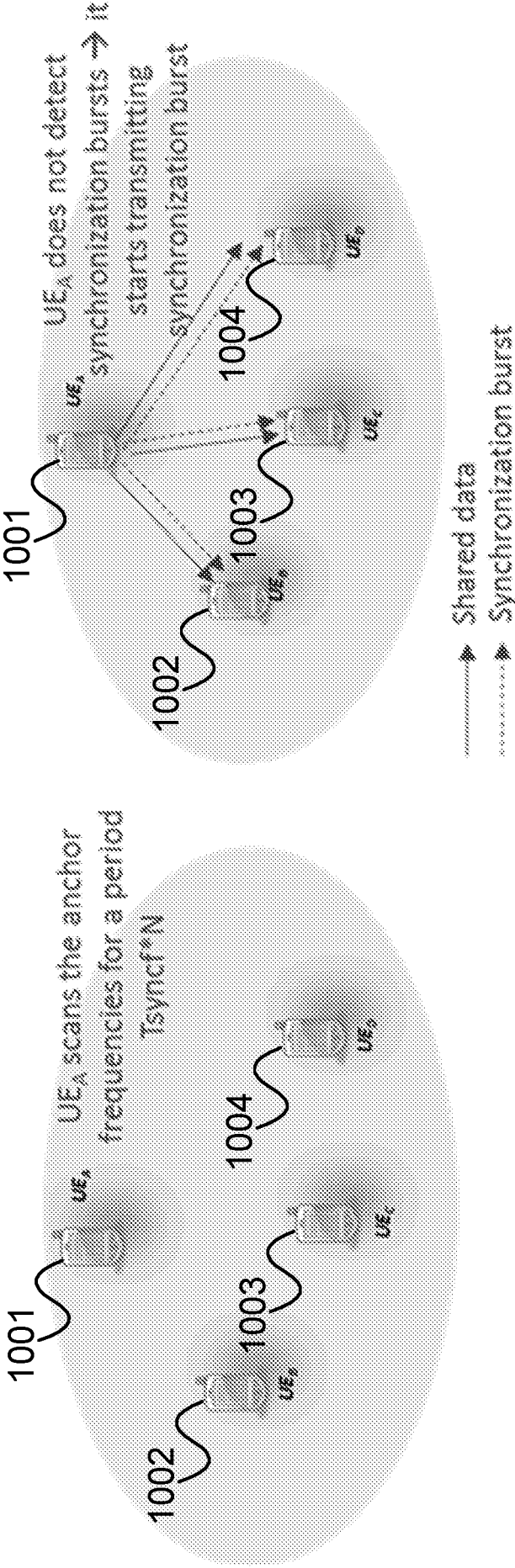


FIG 11

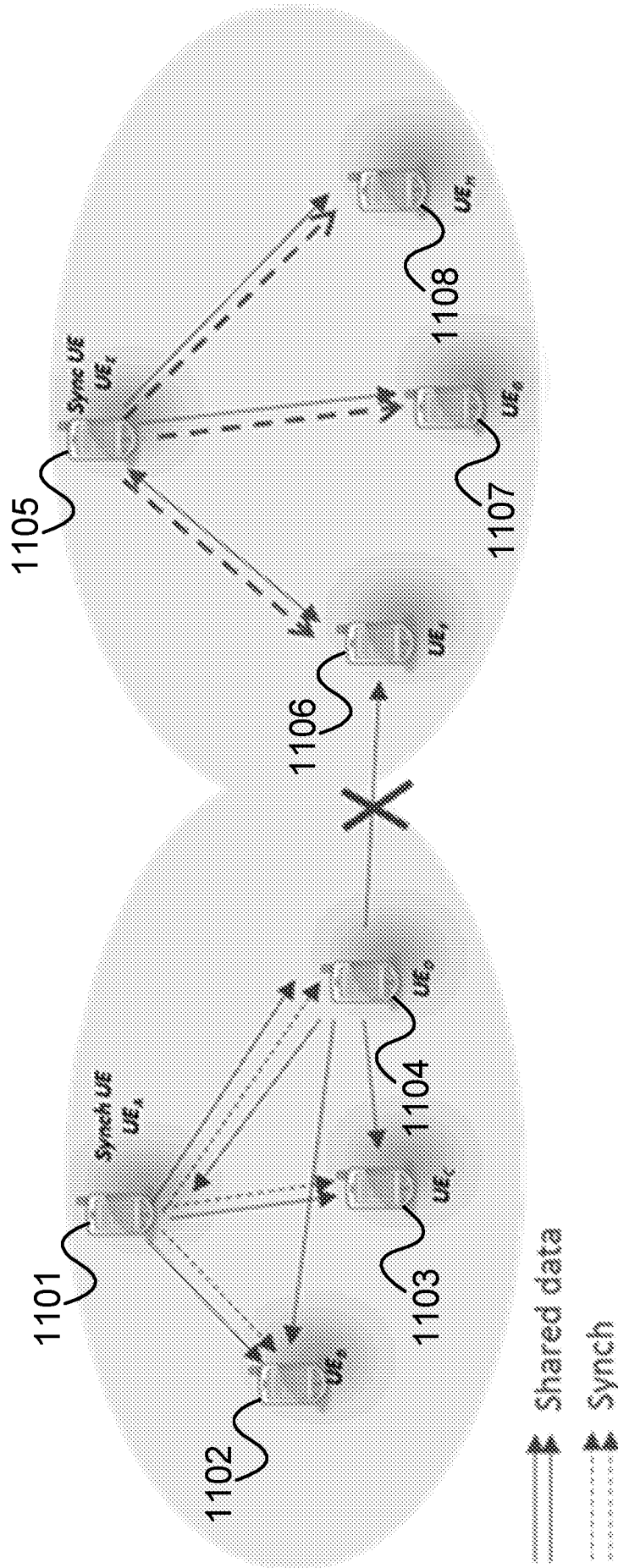


FIG 12

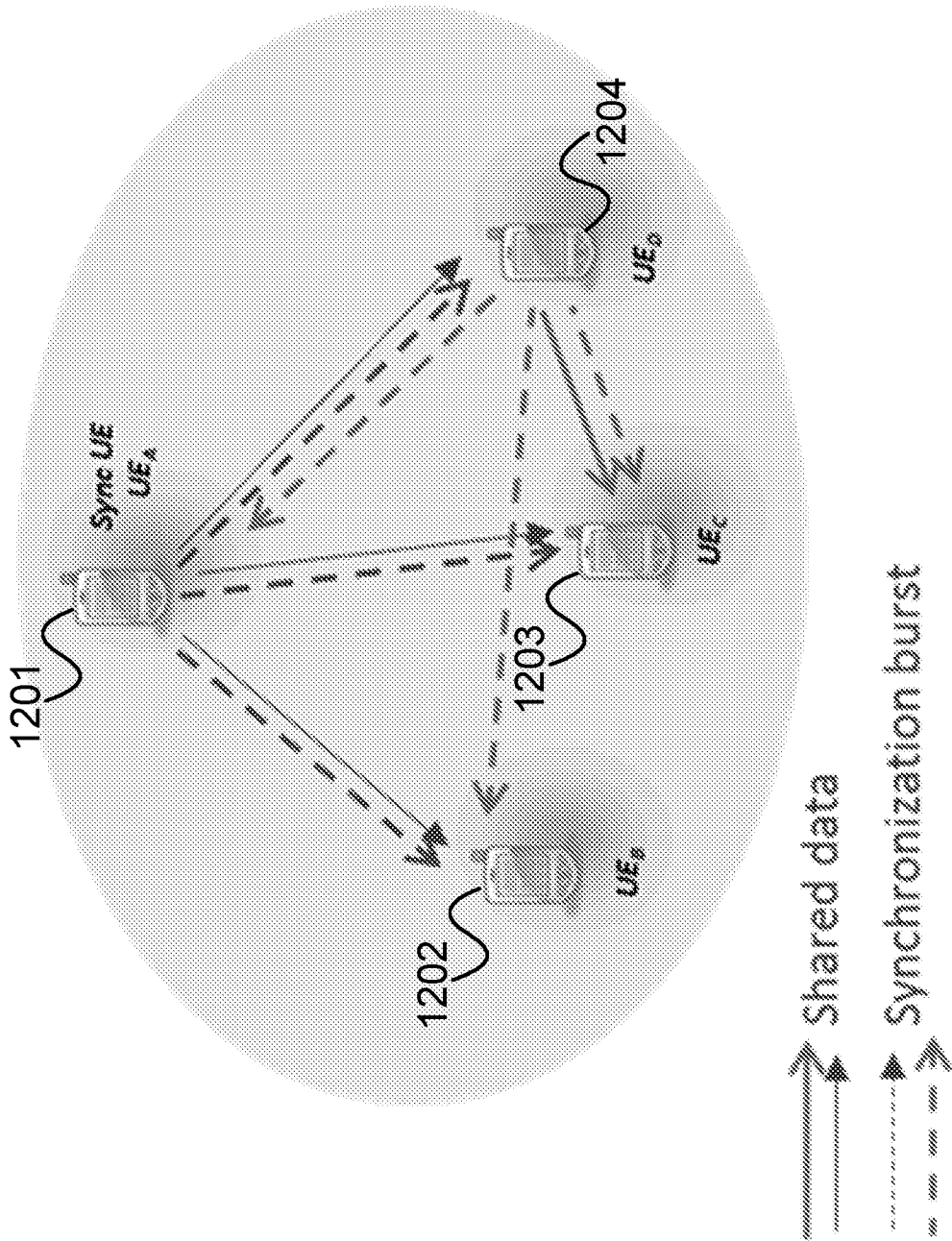


FIG 13

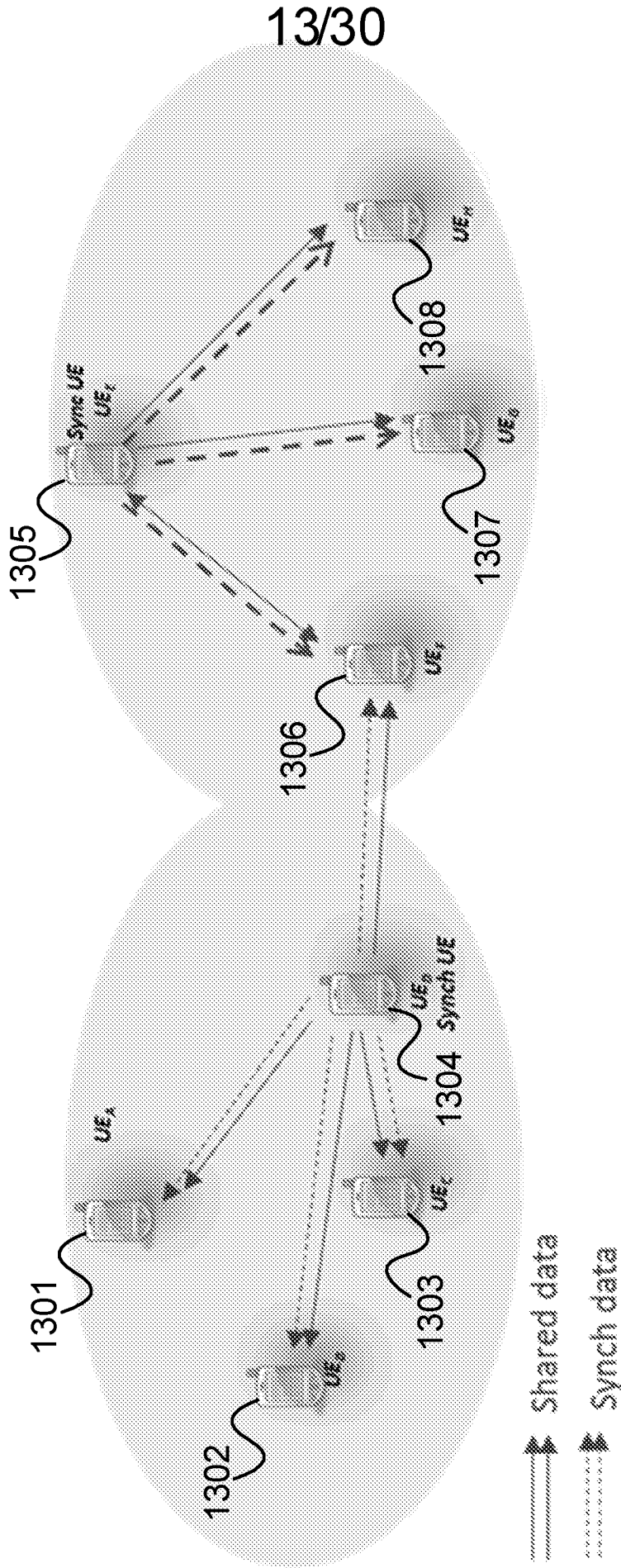


FIG 14

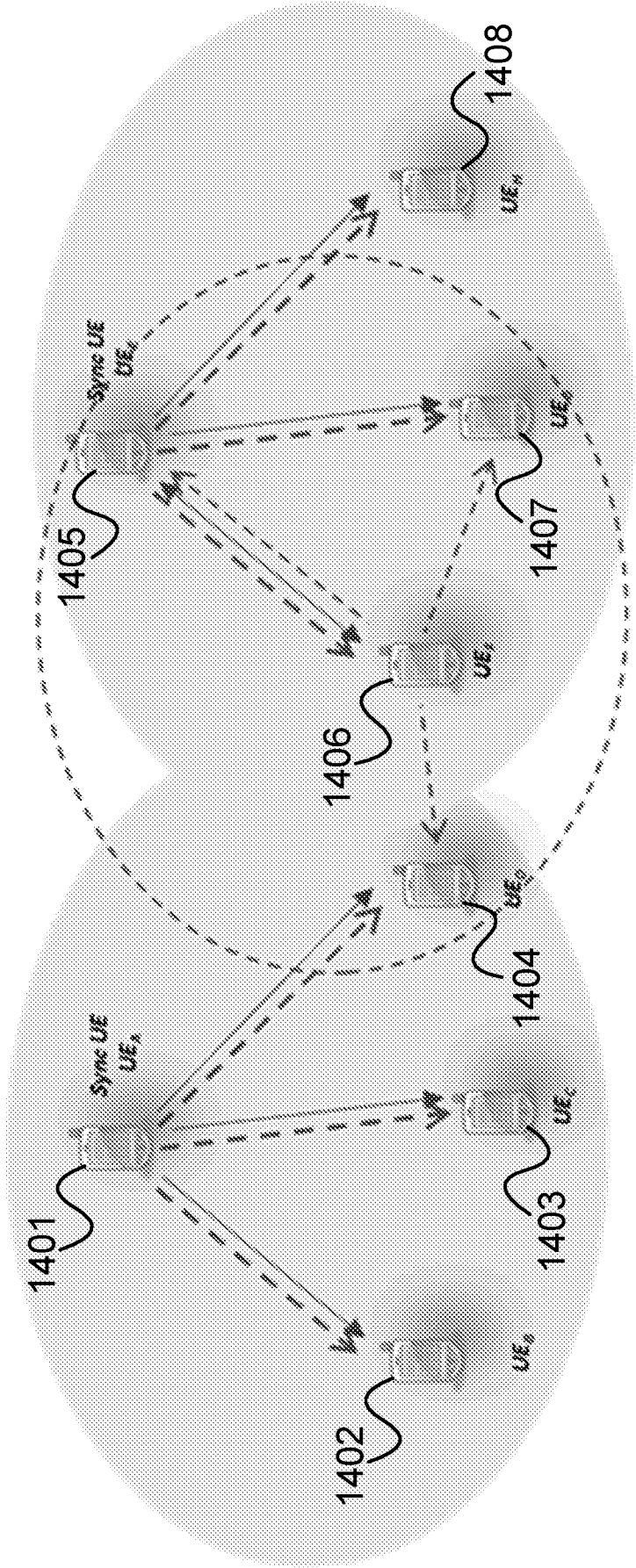


FIG 15

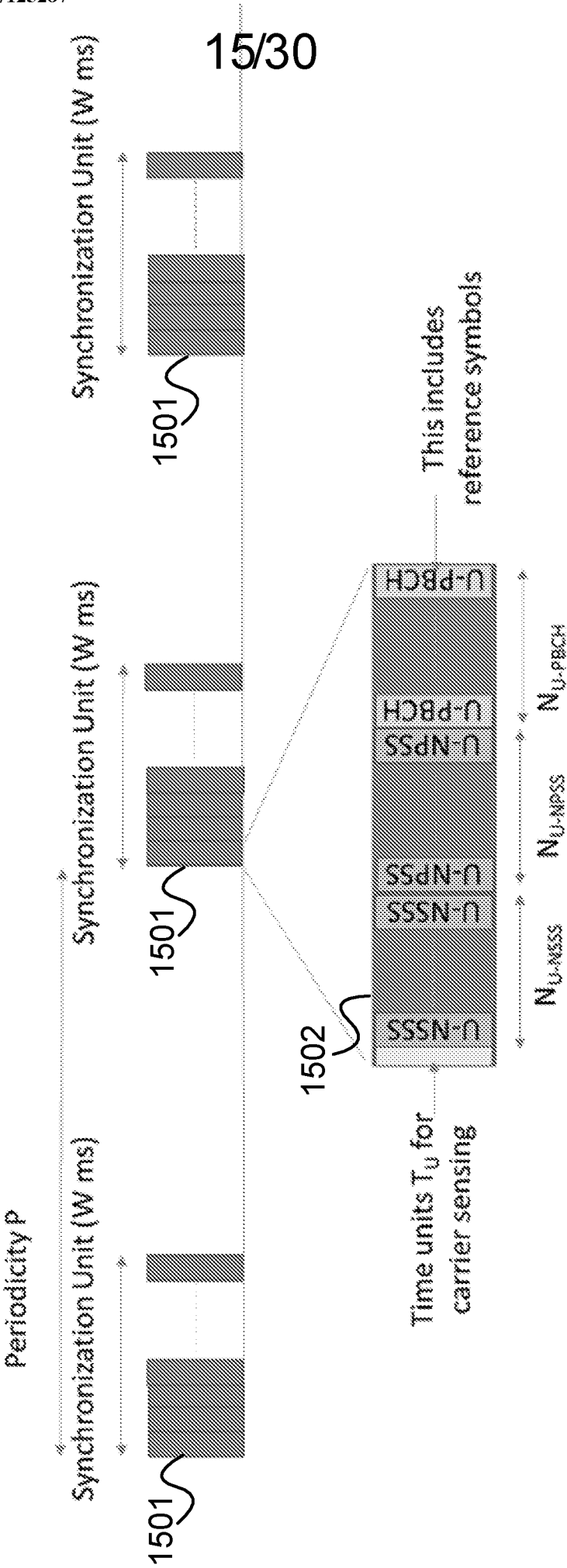
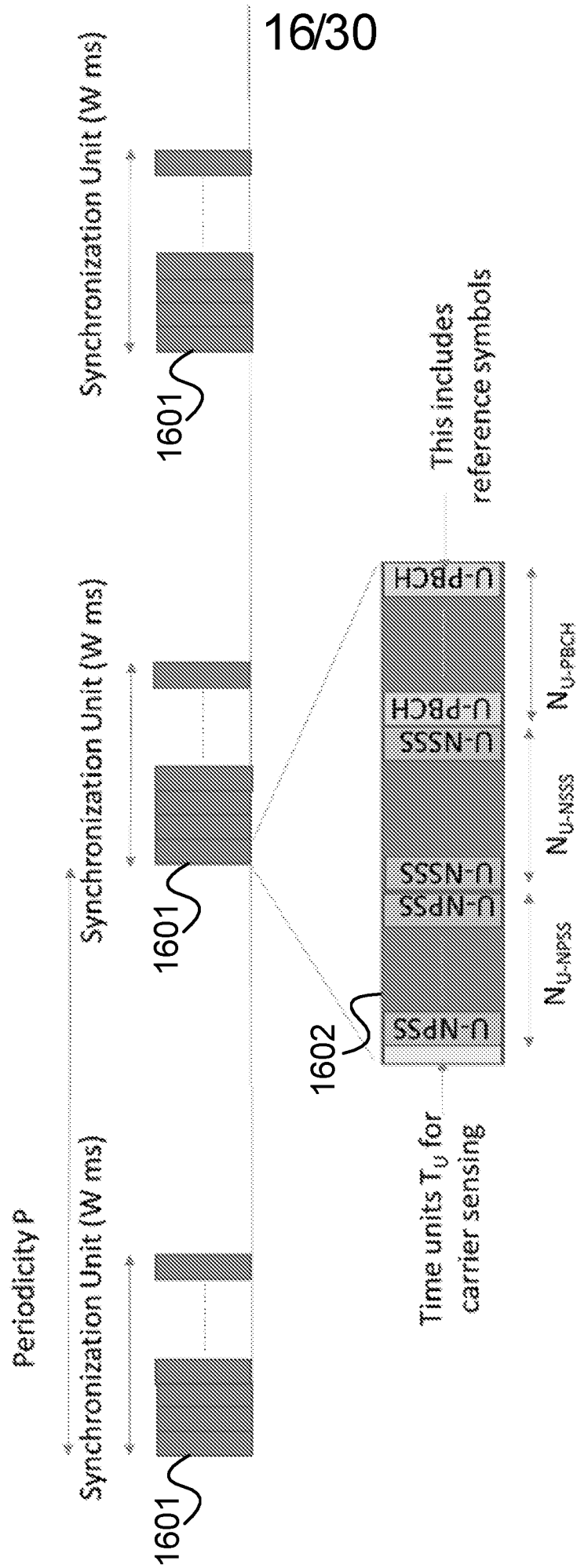


FIG 16



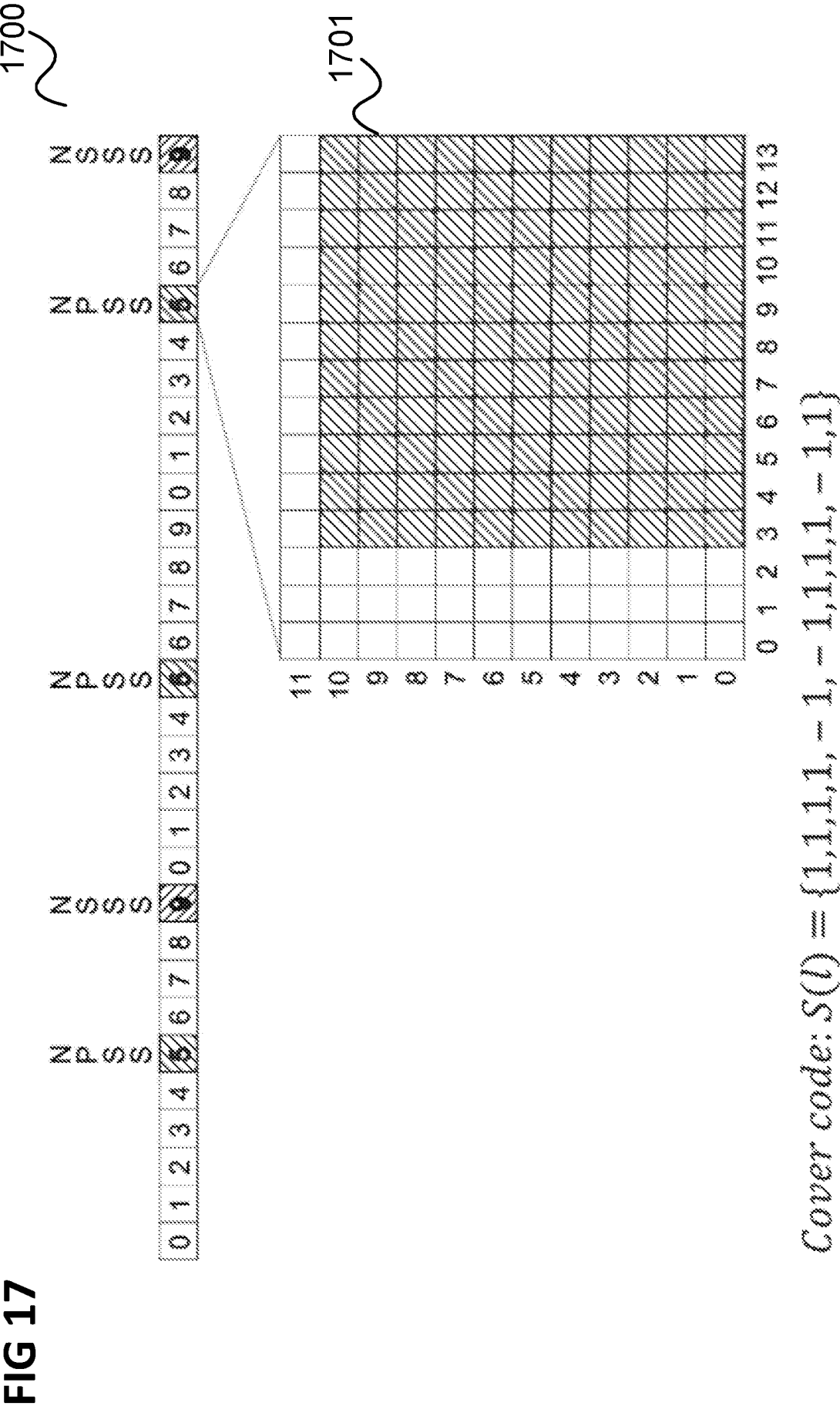
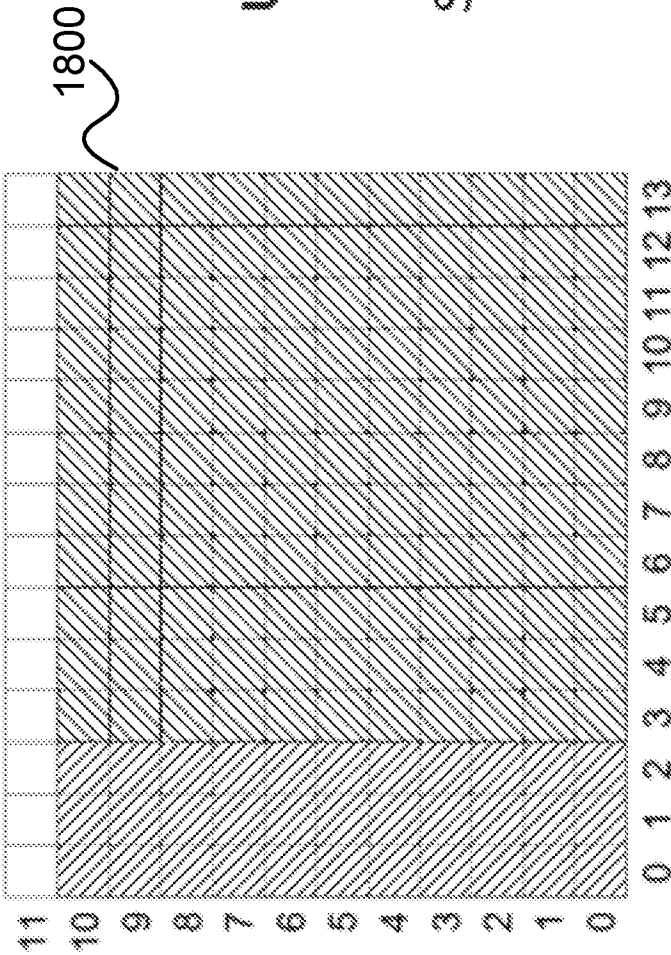


FIG 18

1800



U-NPSS follows NPSS design:

- NPSS extended to 14 repetitions
- Extended Cover Code:

$$S = [-1, 1, -1, 1, -1, 1, 1, 1, -1, 1, 1, 1, 1, -1]$$

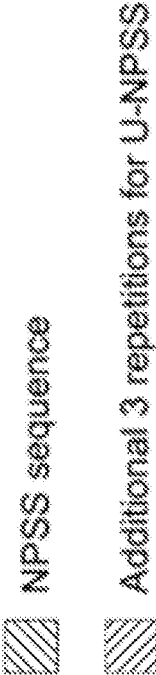


FIG 19

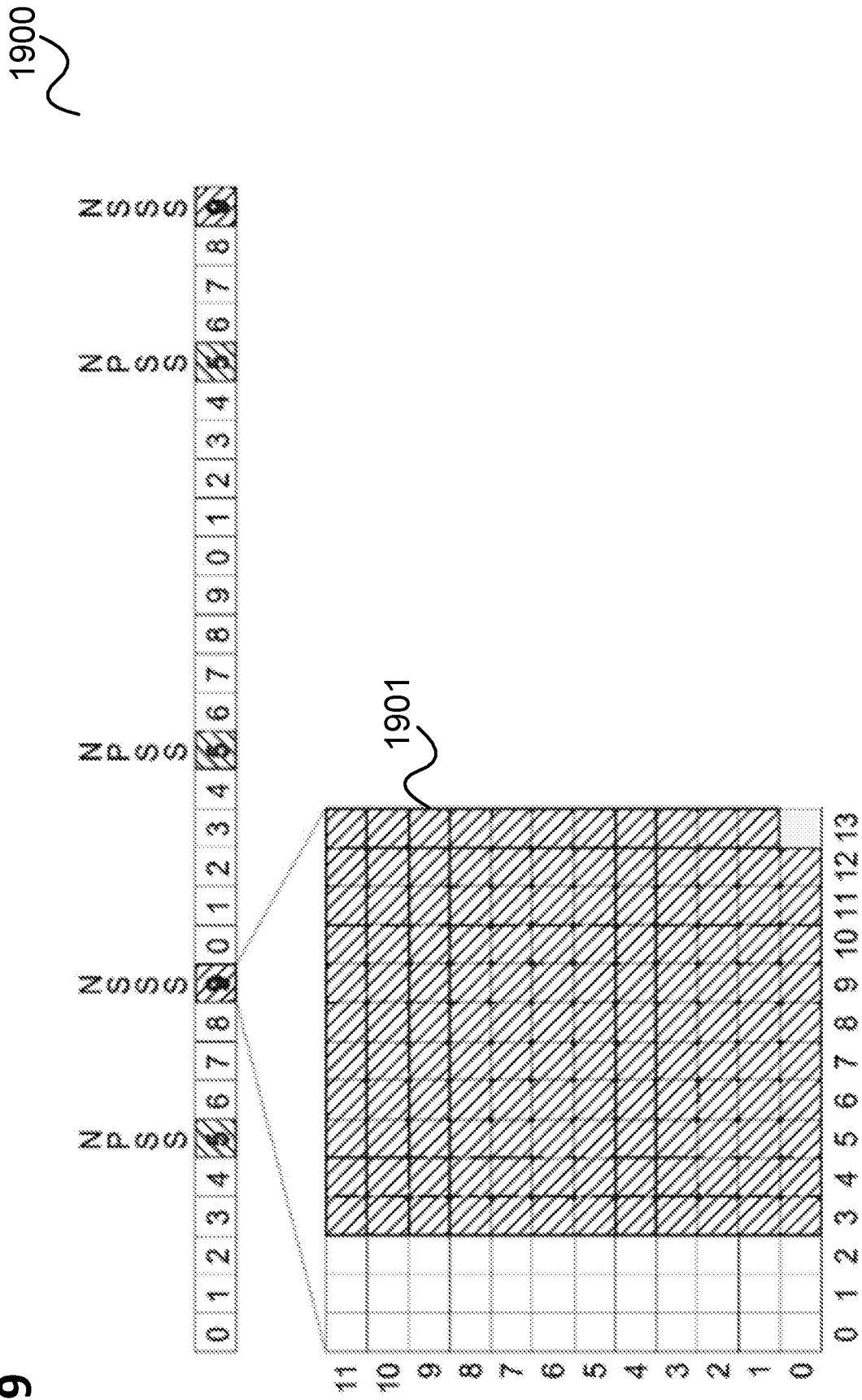
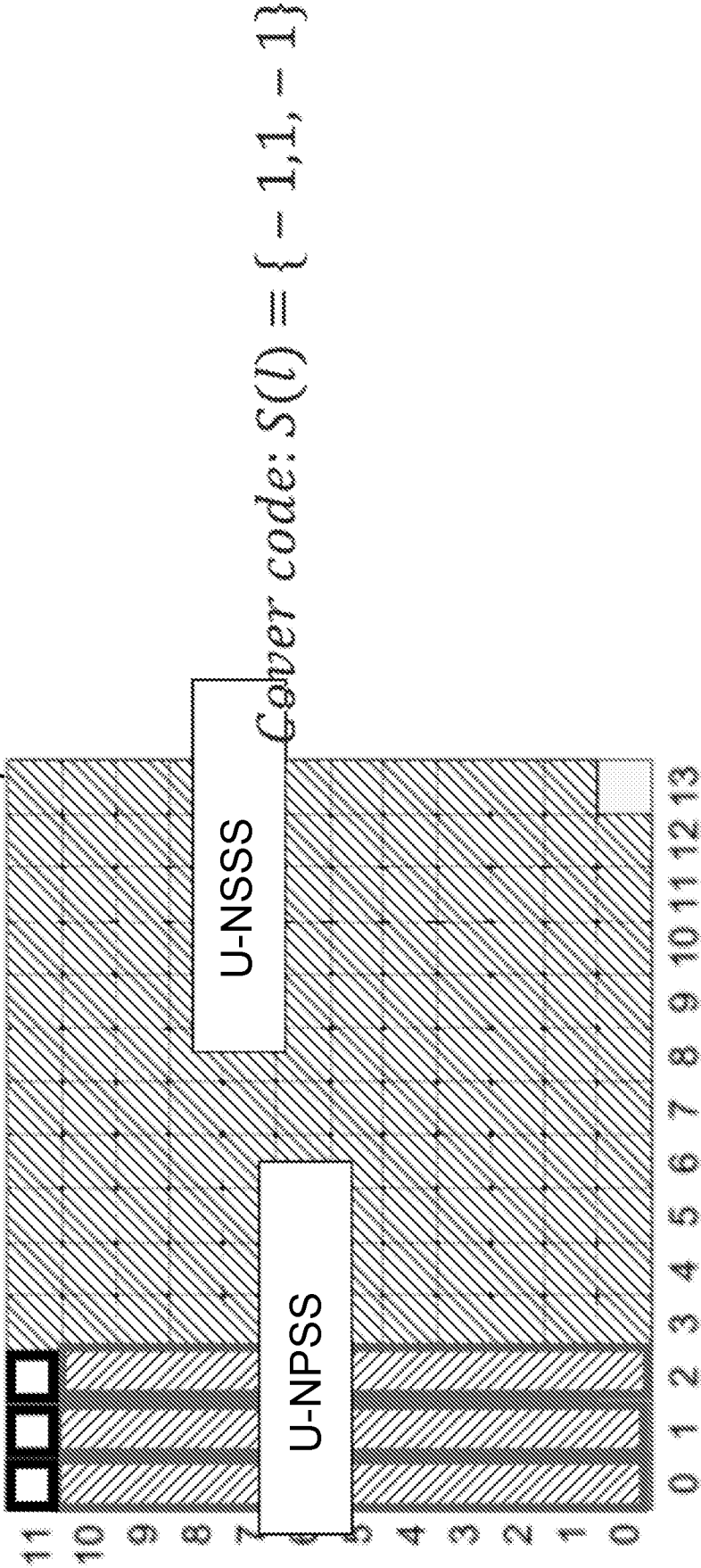


FIG 20

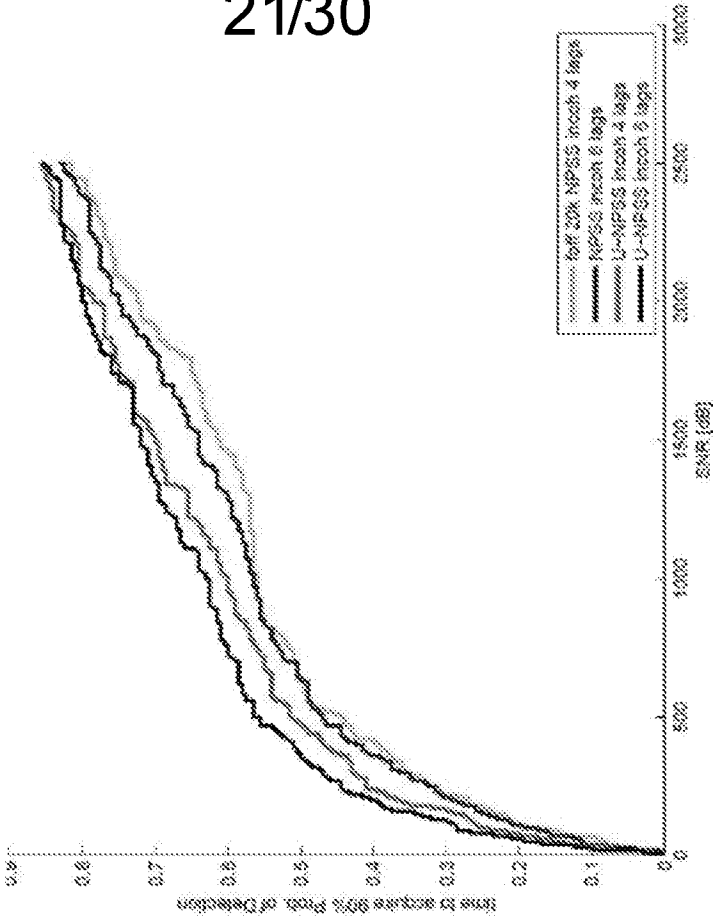
2000

2001



21/30

2102



2101

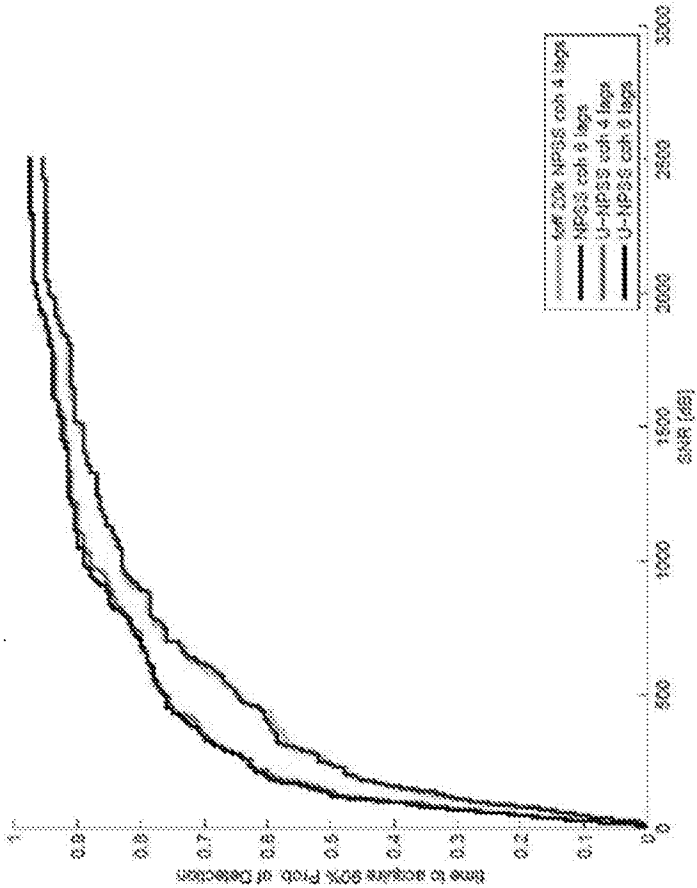


FIG 21

FIG 22

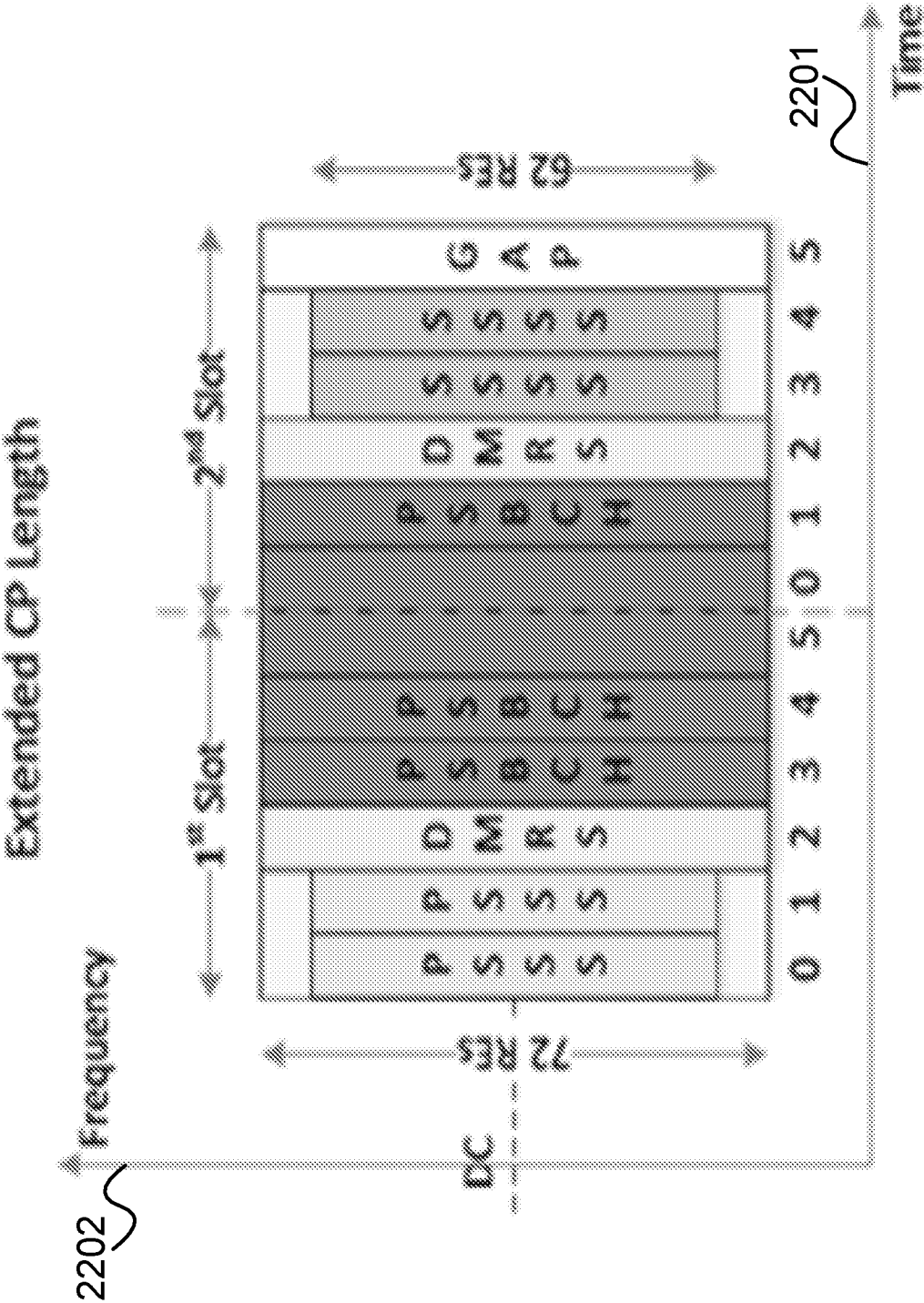
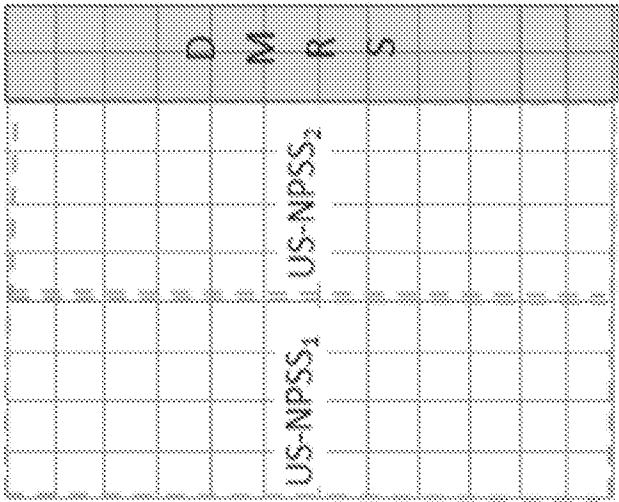


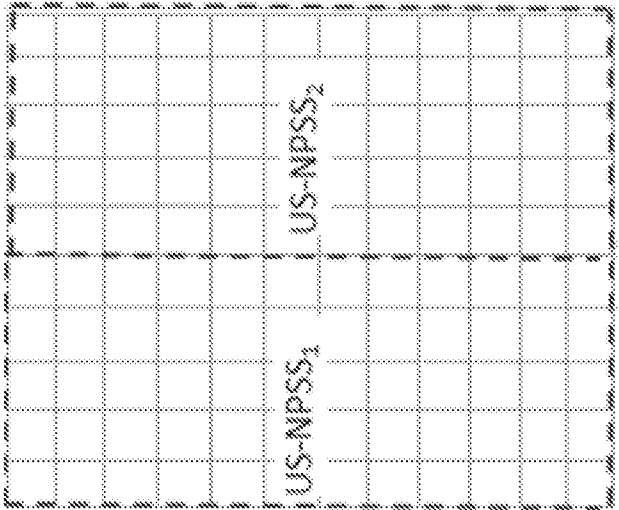
FIG 23

2302



d.c.

2301



d.c.

Example given for eCP and

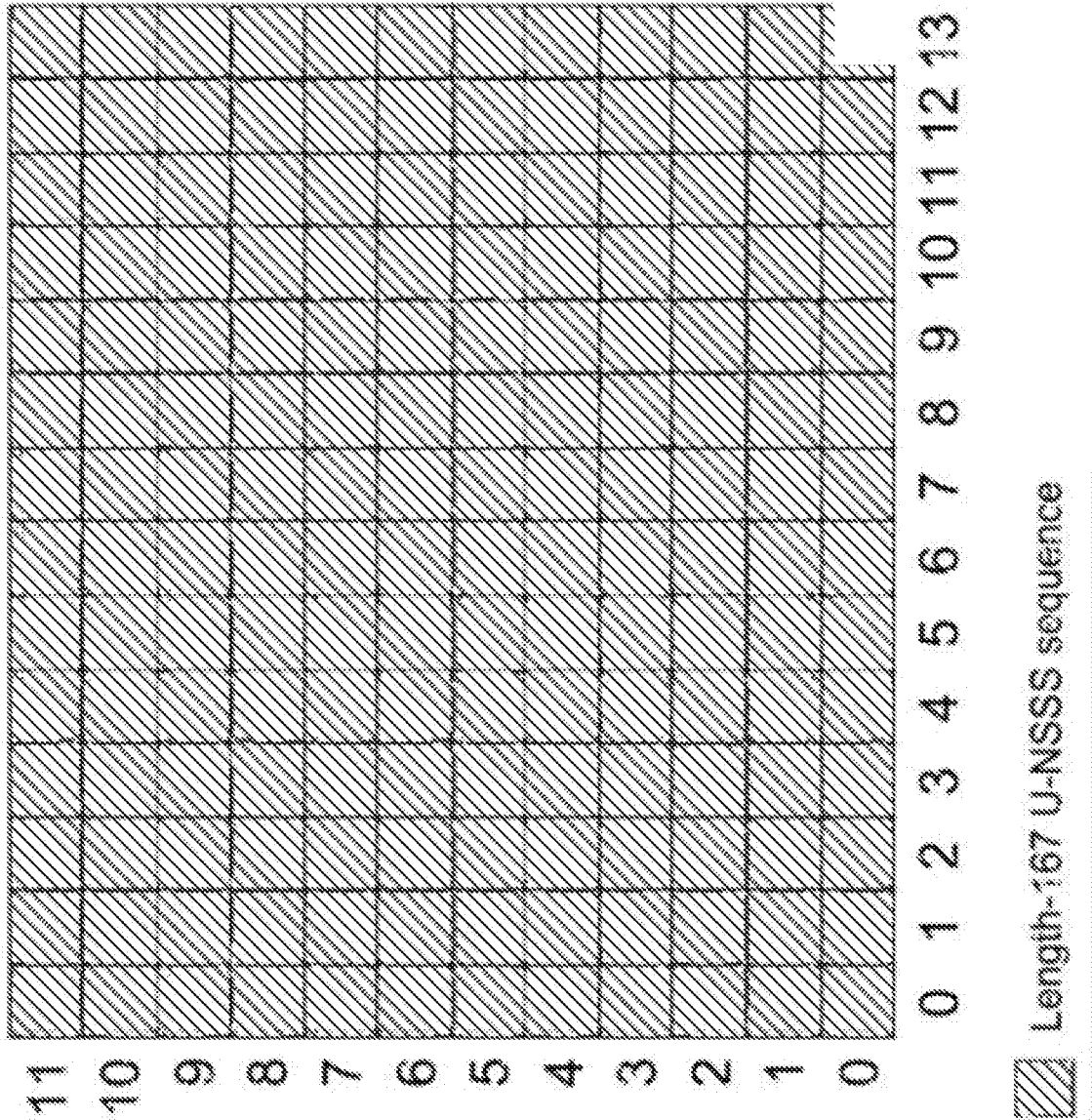
Length 49

Example given for eCP and

Length 61

2400

FIG 24



2500

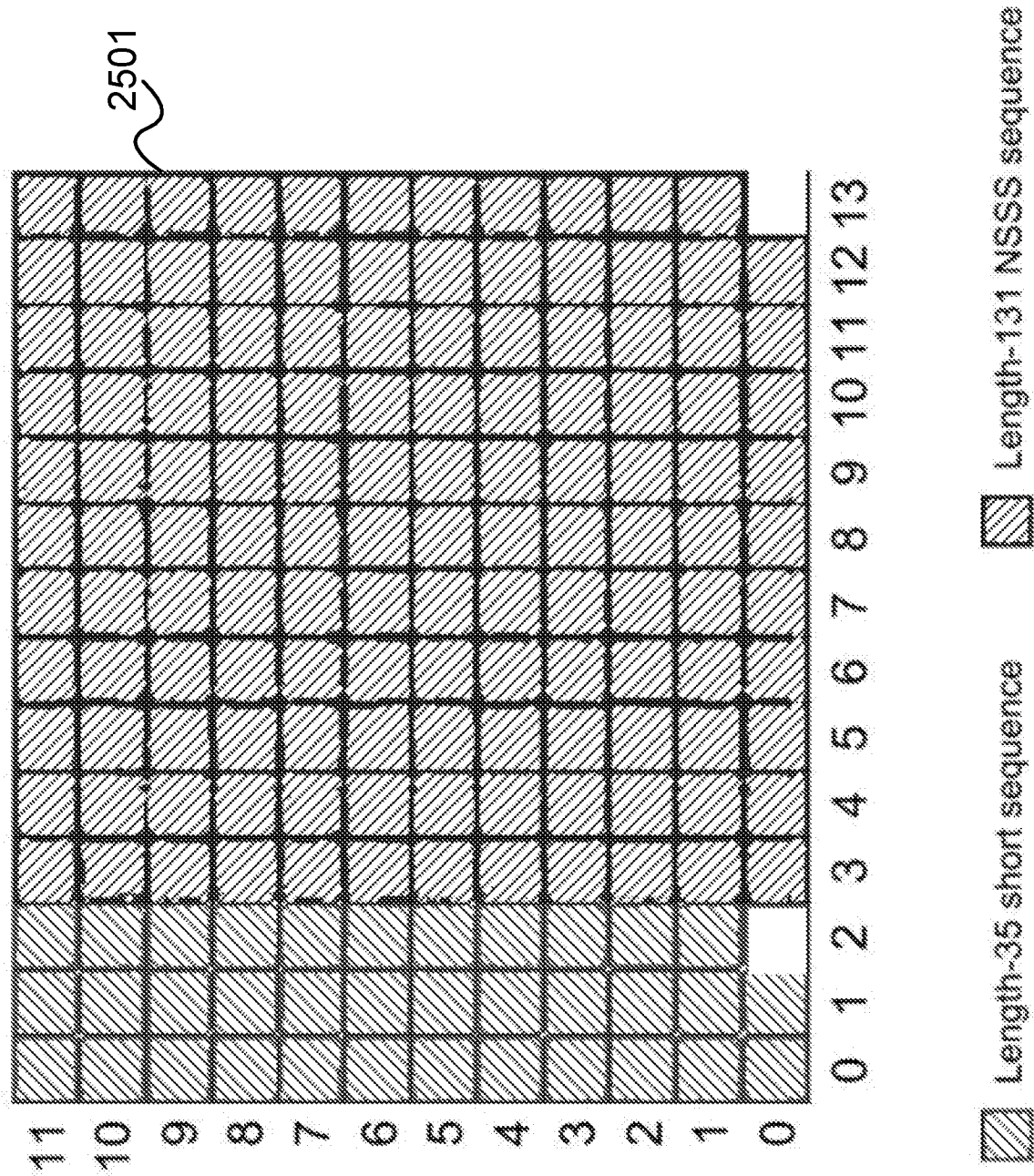
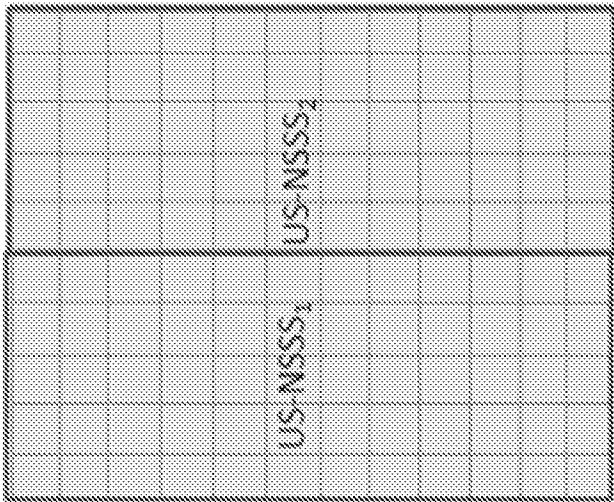


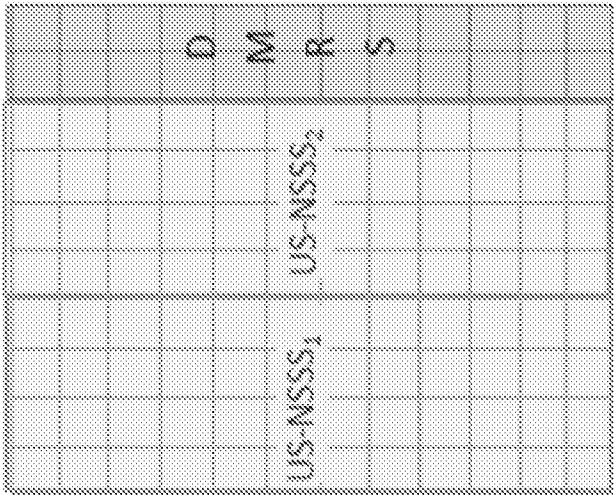
FIG 26

2601



d.c. →

2602



d.c. →

Example given for eCP and
..... Length 60

Example given for eCP and
..... Length 48

FIG 27

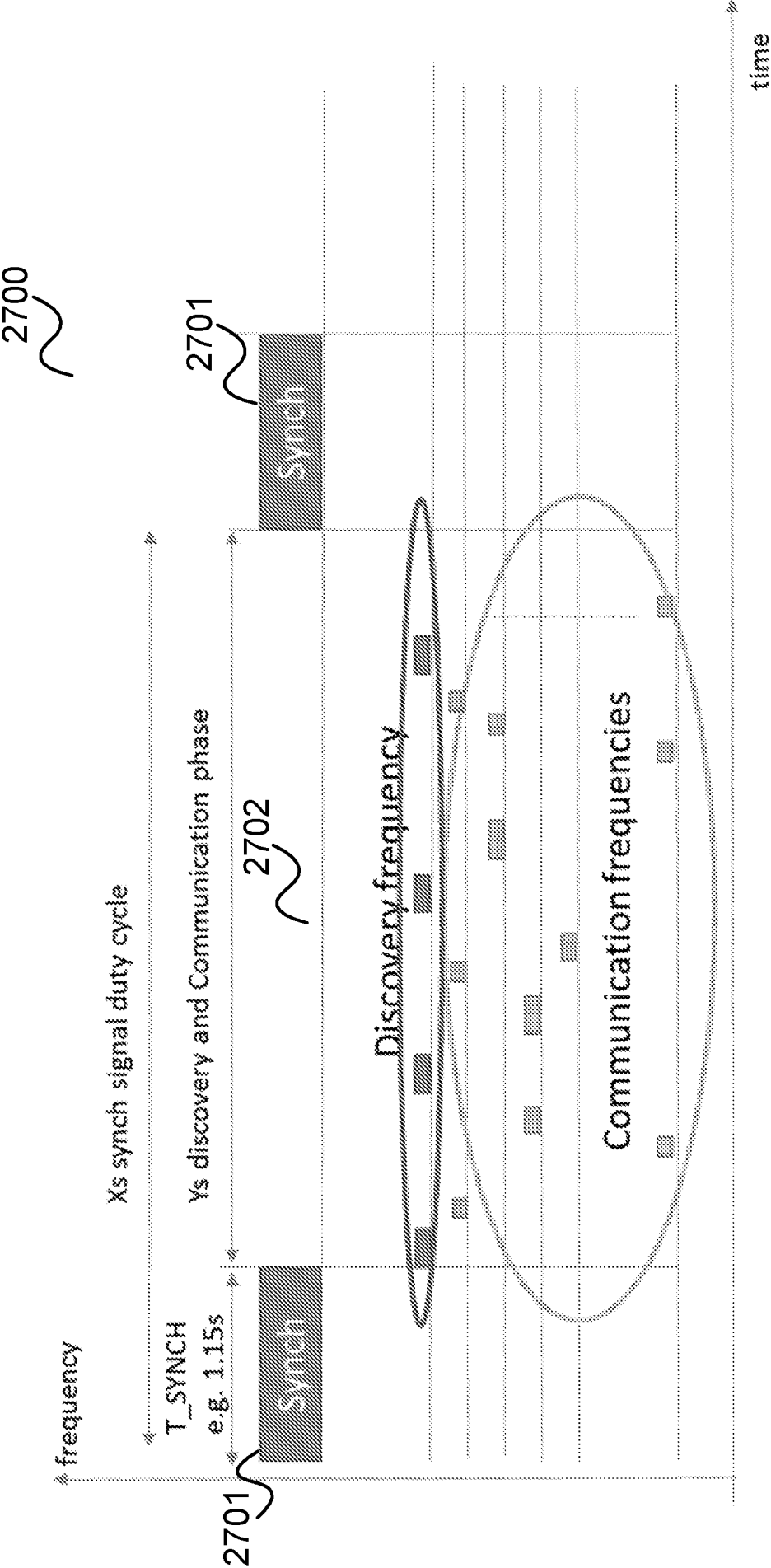
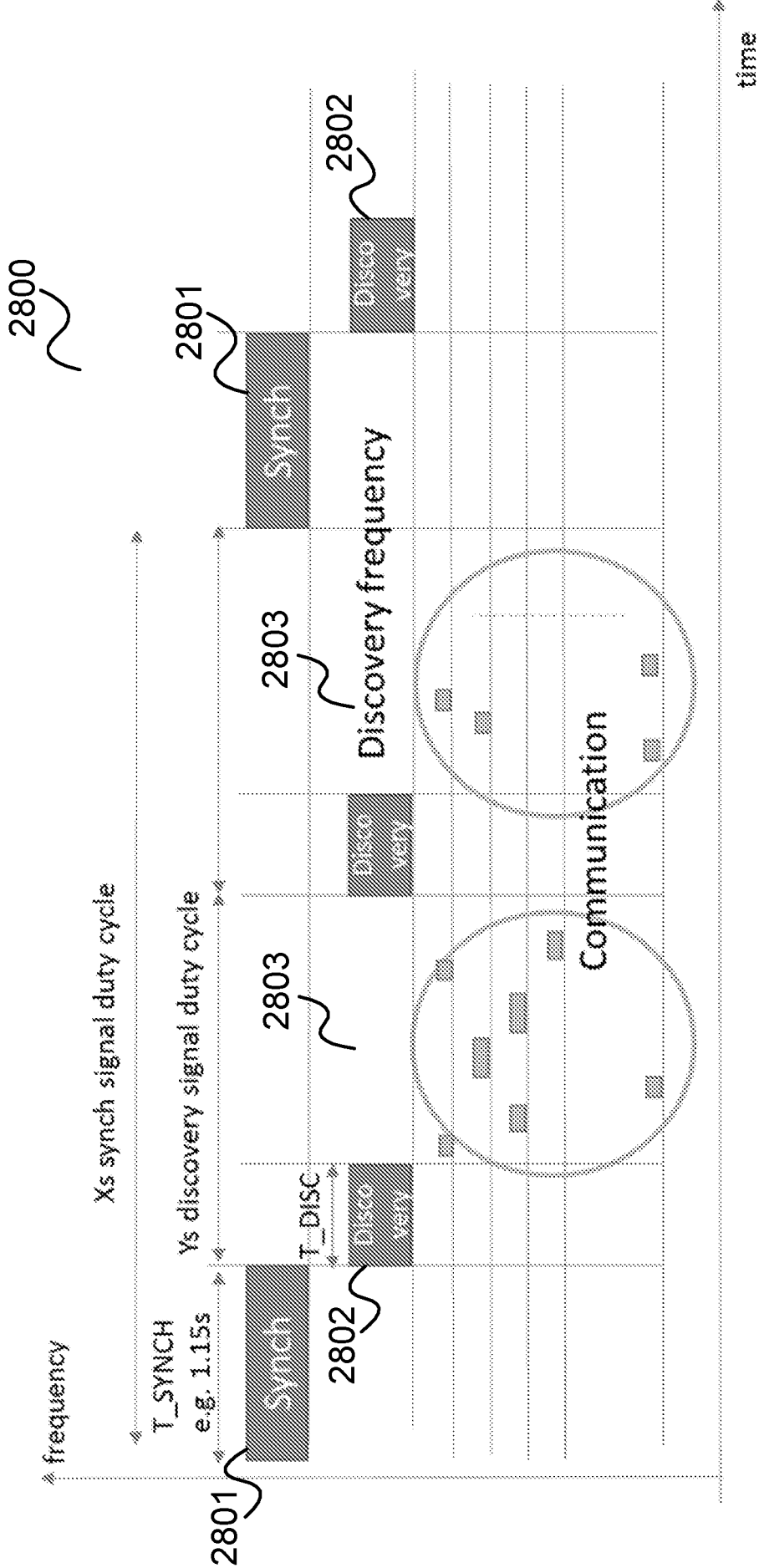


FIG 28



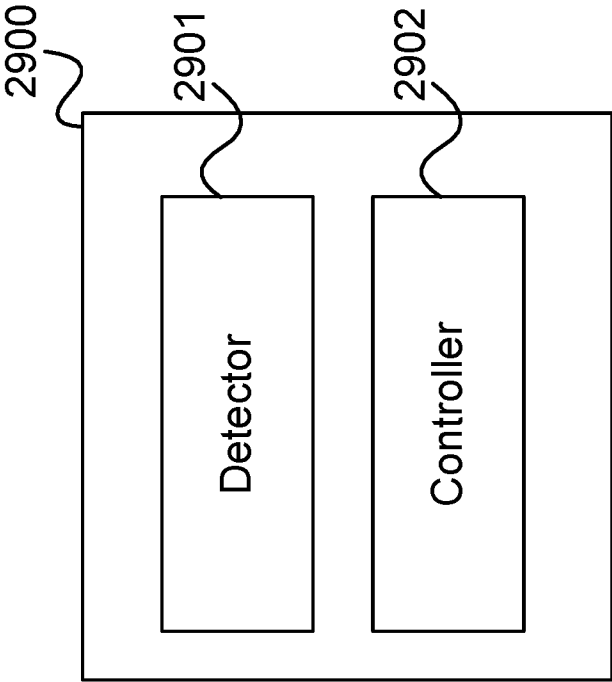


FIG 29

30/30

FIG 303000
3001


Directly communicate, by means of a transceiver supporting radio communication with a cellular radio communication network in a first frequency band using a first bandwidth, with another communication terminal via a second frequency band using a second bandwidth, wherein the second frequency band is located in a spectrum which is license free

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/039851**A. CLASSIFICATION OF SUBJECT MATTER****H04W 88/06(2009.01)i, H04W 56/00(2009.01)i, H04W 92/18(2009.01)i**

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 88/06; H04L 5/00; H04W 36/16; H04W 76/02; H04J 11/00; H04W 56/00; H04W 72/10; H04W 36/00; H04W 40/04; H04W 92/18

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: first/second frequency band, license free, licensed band, non-licensed band, direct communication, narrowband, priority, two-stage discovery

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0249937 A1 (BENGT LINDOFF et al.) 03 September 2015 See paragraphs [0008]–[0009], [0027], [0049], [0059]–[0060], [0075]; claims 1, 9; and figures 1A, 1B.	1–4, 6–8, 13–16, 18, 25
Y		5, 9–12, 20–24
A		17, 19
Y	US 2015-0085789 A1 (QUALCOMM INCORPORATED) 26 March 2015 See paragraphs [0047], [0049], [0053]; and figure 7.	5, 9–12
Y	WO 2016-203290 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 22 December 2016 See pages 1, 9; claims 1, 15, 17; and figure 6.	20–22
Y	US 2016-0174179 A1 (LG ELECTRONICS INC.) 16 June 2016 See claim 1.	23
Y	WO 2015-021345 A2 (ALCATEL-LUCENT USA INC. et al.) 12 February 2015 See paragraph [0031]; and figure 1.	24

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

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"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

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Date of the actual completion of the international search

24 October 2017 (24.10.2017)

Date of mailing of the international search report

24 October 2017 (24.10.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

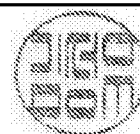


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Authorized officer

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Telephone No. +82-42-481-3348



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/039851

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US 2016-0174179 A1	16/06/2016	None	
WO 2015-021345 A2	12/02/2015	US 2015-0043545 A1 US 9456330 B2 WO 2015-021345 A3	12/02/2015 27/09/2016 14/05/2015