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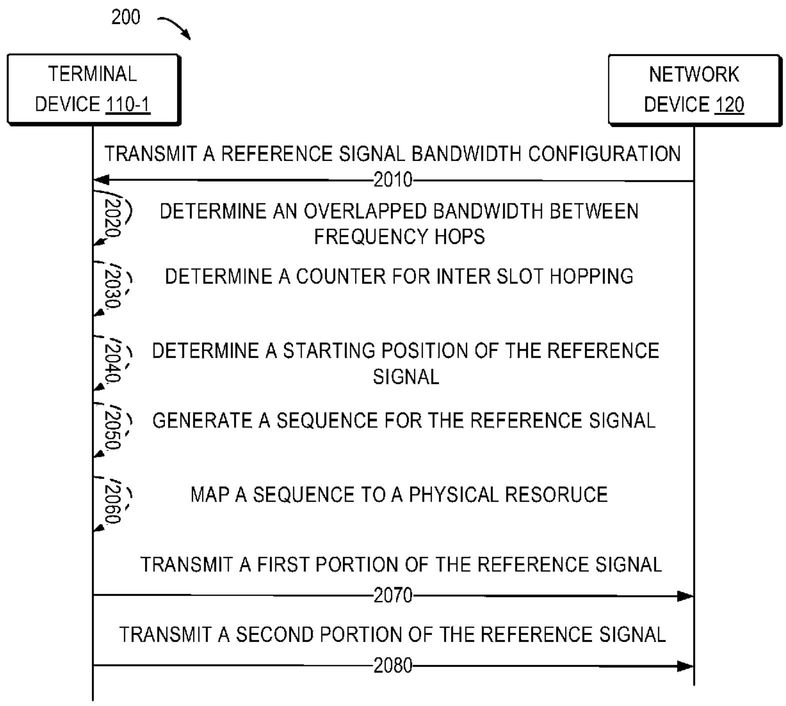

Fig. 2

(57) **Abstract:** Embodiments of the present disclosure relate to methods, devices, and computer readable medium for communication. A network device transmits a reference signal bandwidth configuration to a terminal device. The reference signal bandwidth configuration indicates a frequency hopping scheme for a transmission of reference signal. The terminal device determines an overlapped bandwidth between frequency hops based on the reference signal bandwidth configuration. The terminal device transmits a first portion of the reference signal at a first frequency hop. The terminal device transmits a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth. In this way, the reference signal hopping subbands can be flexible and not in a fixed position, and the frequency diversity gain may be obtained.

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METHODS, DEVICES, AND COMPUTER READABLE MEDIUM FOR COMMUNICATION

TECHNICAL FIELD

[0001] Embodiments of the present disclosure generally relate to the field of telecommunication, and in particular, to methods, devices, and computer readable medium for communication.

BACKGROUND

[0002] Several technologies have been proposed to improve communication performances. For example, reduced capability (RedCap) user equipment (UE) has been proposed. The RedCap UE may be with reduced bandwidth support and reduced complexity including reduced number of receive chains. Such UEs may support new radio (NR) positioning functionality.

SUMMARY

[0003] In general, example embodiments of the present disclosure provide a solution for communication.

[0004] In a first aspect, there is provided a method for communication. The method comprises receiving, at a terminal device and from a network device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; determining, based on the reference signal bandwidth configuration, an overlapped bandwidth between frequency hops in the frequency hopping scheme; transmitting, to the network device, a first portion of the reference signal at a first frequency hop; and transmitting, to the network device, a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth.

[0005] In a second aspect, there is provided a method for communication. The method comprises transmitting, at a network device and to a terminal device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; receiving, from the terminal device, a first portion of the reference signal at a first frequency hop; and receiving, from the terminal device, a second portion of the reference signal at a second frequency hop based on an overlapped bandwidth between frequency hops in the frequency hopping scheme.

[0006] In a third aspect, there is provided a method for communication. The method comprises receiving, at a terminal device and from a network device, a reference signal configuration indicating a frequency hopping scheme for a transmission of a reference signal in which at least one hop is outside an active BWP of the terminal device; determining whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop.

[0007] In a fourth aspect, there is provided a terminal device. The terminal device comprises a processing unit; and a memory coupled to the processing unit and storing instructions thereon, the instructions, when executed by the processing unit, causing the terminal device to perform acts comprising: receiving, from a network device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; determining, based on the reference signal bandwidth configuration, an overlapped bandwidth between frequency hops in the frequency hopping scheme; transmitting, to the network device, a first portion of the reference signal at a first frequency hop; and transmitting, to the network device, a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth.

[0008] In a fifth aspect, there is provided a network device. The network device comprises a processing unit; and a memory coupled to the processing unit and storing instructions thereon, the instructions, when executed by the processing unit, causing the network device to perform acts comprising: transmitting, to a terminal device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; receiving, from the terminal device, a first portion of the reference signal at a first frequency hop; and receiving, from the terminal device, a second portion of the reference signal at a second frequency hop based on an overlapped bandwidth between frequency hops in the frequency hopping scheme.

[0009] In a sixth aspect, there is provided a terminal device. The terminal device comprises a processing unit; and a memory coupled to the processing unit and storing instructions thereon, the instructions, when executed by the processing unit, causing the terminal device to perform acts comprising: receiving, from a network device, a reference signal configuration indicating a frequency hopping scheme for a transmission of a reference signal in which at least one hop is outside an active BWP of the terminal device; determining whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop.

[0010] In a seventh aspect, there is provided a computer readable medium having instructions stored thereon, the instructions, when executed on at least one processor, causing the at least one processor to carry out the method according to the first, second or third aspect.

[0011] Other features of the present disclosure will become easily comprehensible through the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Through the more detailed description of some example embodiments of the present disclosure in the accompanying drawings, the above and other objects, features and advantages of the present disclosure will become more apparent, wherein:

[0013] Fig. 1 is a schematic diagram of a communication environment in which embodiments of the present disclosure can be implemented;

[0014] Fig. 2 illustrates a signaling flow for communications according to some embodiments of the present disclosure;

[0015] Fig. 3 shows a schematic diagram of a frequency hopping scheme according to some embodiments of the present disclosure;

[0016] Fig. 4 shows a schematic diagram of mapping resources according to some embodiments of the present disclosure;

[0017] Fig. 5 illustrates a signaling flow for communications according to some embodiments of the present disclosure;

[0018] Fig. 6 shows a schematic diagram of a transmission collision according to some embodiments of the present disclosure;

[0019] Figs. 7A-7D show schematic diagrams of collisions handling according to some embodiments of the present disclosure;

[0020] Fig. 8 shows a schematic diagram of collisions handling according to some embodiments of the present disclosure;

[0021] Fig. 9 shows a schematic diagram of a processing window according to some embodiments of the present disclosure;

[0022] Fig. 10 is a flowchart of an example method in accordance with an embodiment of the present disclosure;

[0023] Fig. 11 is a flowchart of an example method in accordance with an embodiment of the present disclosure;

[0024] Fig. 12 is a flowchart of an example method in accordance with an embodiment of the present disclosure; and

[0025] Fig. 13 is a simplified block diagram of a device that is suitable for implementing embodiments of the present disclosure.

[0026] Throughout the drawings, the same or similar reference numerals represent the same or similar element.

DETAILED DESCRIPTION

[0027] Principle of the present disclosure will now be described with reference to some example embodiments. It is to be understood that these embodiments are described only for the purpose of illustration and help those skilled in the art to understand and implement the present disclosure, without suggesting any limitations as to the scope of the disclosure. The disclosure described herein can be implemented in various manners other than the ones described below.

[0028] In the following description and claims, unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skills in the art to which this disclosure belongs.

[0029] As used herein, the term 'terminal device' refers to any device having wireless or wired communication capabilities. Examples of the terminal device include, but not limited to, user equipment (UE), personal computers, desktops, mobile phones, cellular phones, smart phones, personal digital assistants (PDAs), portable computers, tablets, wearable devices, internet of things (IoT) devices, Ultra-reliable and Low Latency Communications (URLLC) devices, Internet of Everything (IoE) devices, machine type communication (MTC) devices, device on vehicle for V2X communication where X means pedestrian, vehicle, or infrastructure/network, devices for Integrated Access and Backhaul (IAB), Space borne vehicles or Air borne vehicles in Non-terrestrial networks (NTN) including Satellites and High Altitude Platforms (HAPs) encompassing Unmanned Aircraft Systems (UAS), eXtended Reality (XR) devices including different types of realities such as Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR), the unmanned aerial vehicle (UAV) commonly known as a drone which is an aircraft without any human pilot, devices on high speed train (HST), or image capture devices such as digital cameras, sensors, gaming devices, music storage and playback appliances, or Internet appliances enabling wireless or wired Internet access and browsing and the like. The 'terminal device' can further has 'multicast/broadcast' feature, to support public safety and mission critical, V2X applications, transparent IPv4/IPv6 multicast delivery, IPTV, smart TV, radio services, software delivery over wireless, group communications and IoT applications. It may also incorporate one or multiple Subscriber Identity Module (SIM) as known as Multi-SIM. The term "terminal device" can be used interchangeably with a UE, a mobile station, a subscriber station, a mobile terminal, a user terminal or a wireless device. In the following description, the terms "terminal device", "communication device", "terminal", "user equipment" and "UE" may be used interchangeably.

[0030] The terminal device or the network device may have Artificial Intelligence (AI) or Machine Learning (ML) capability. It generally includes a model which has been trained from numerous collected data for a specific function, and can be used to predict some information.

[0031] The terminal or the network device may work on several frequency ranges, e.g. FR1 (410 MHz – 7125 MHz), FR2 (24.25GHz to 71GHz), frequency band larger than 100GHz as well as Terahertz (THz). It can further work on licensed/unlicensed/shared spectrum. The terminal device may have more than one connection with the network devices under Multi-Radio Dual Connectivity (MR-DC) application scenario. The terminal device or the network device can work on full duplex, flexible duplex and cross division duplex modes.

[0032] The term "network device" refers to a device which is capable of providing or hosting a cell or coverage where terminal devices can communicate. Examples of a network device include, but not limited to, a Node B (NodeB or NB), an evolved NodeB (eNodeB or eNB), a next generation NodeB (gNB), a transmission reception point (TRP), a remote radio unit (RRU), a radio head (RH), a remote radio head (RRH), an IAB node, a low power node such as a femto node, a pico node, a reconfigurable intelligent surface (RIS), and the like.

[0033] In one embodiment, the terminal device may be connected with a first network device and a second network device. One of the first network device and the second network device may be a master node and the other one may be a secondary node. The first network device and the second network device may use different radio access technologies (RATs). In one embodiment, the first network device may be a first RAT device and the second network device may be a second RAT device. In one embodiment, the first RAT device is eNB and the second RAT device is gNB. Information related with different RATs may be transmitted to the terminal device from at least one of the first network device and the second network device. In one embodiment, first information may be transmitted to the terminal device from the first network device and second information may be transmitted to the terminal device from the second network device directly or via the first network device. In one embodiment, information related with configuration for the terminal device configured by the second network device may be transmitted from the second network device via the first network device. Information related with reconfiguration for the terminal device configured by the second network device may be transmitted to the terminal device from the second network device directly or via the first network device.

[0034] Communications discussed herein may use conform to any suitable standards including, but not limited to, New Radio Access (NR), Long Term Evolution (LTE), LTE-Evolution, LTE-Advanced (LTE-A), Wideband Code Division Multiple Access (WCDMA), Code Division Multiple Access (CDMA), cdma2000, and Global System for Mobile Communications (GSM) and the like. Furthermore, the communications may be performed according to any generation communication protocols either currently known or to be developed in the future. Examples of the communication protocols include, but not limited to, the first generation (1G), the second generation (2G), 2.5G, 2.85G, the third generation (3G), the fourth generation (4G), 4.5G, the fifth generation (5G), and the sixth (6G) communication protocols. The techniques described herein may be used for the wireless networks and radio technologies mentioned above as well as other wireless networks and radio technologies. The embodiments of the present disclosure may be performed according to any generation communication protocols either currently known or to be developed in the future. Examples of the communication protocols include, but not limited to, the first generation (1G), the second generation (2G), 2.5G, 2.75G, the third generation (3G), the fourth generation (4G), 4.5G, the fifth generation (5G) communication protocols, 5.5G, 5G-Advanced networks, or the sixth generation (6G) networks.

[0035] The term "circuitry" used herein may refer to hardware circuits and/or combinations of hardware circuits and software. For example, the circuitry may be a combination of analog and/or digital hardware circuits with software/firmware. As a further example, the circuitry may be any portions of hardware processors with software including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus, such as a terminal device or a network device, to perform various functions. In a still further example, the circuitry may be hardware circuits and or processors, such as a microprocessor or a portion of a microprocessor, that requires software/firmware for operation, but the software may not be present when it is not needed for operation. As used herein, the term circuitry also covers an implementation of merely a hardware circuit or processor(s) or a portion of a hardware circuit or processor(s) and its (or their) accompanying software and/or firmware.

[0036] As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. The term "includes" and its variants are to be read as open terms that mean "includes, but is not limited to." The term "based on" is to be read as "based at least in part on." The term "one embodiment" and "an embodiment" are to be read as "at least one embodiment." The term "another embodiment" is to be read as "at least one other embodiment." The terms "first," "second," and the like may refer to different or same objects. Other definitions, explicit and implicit, may be included below.

[0037] In some examples, values, procedures, or apparatus are referred to as "best," "lowest," "highest," "minimum," "maximum," or the like. It will be appreciated that such descriptions are intended to indicate that a selection among many used functional alternatives can be made, and such selections need not be better, smaller, higher, or otherwise preferable to other selections.

[0038] As mentioned above, RedCap UEs may support NR positioning functionality. However, there is a gap in that the core and performance requirements have not been specified for the positioning related measurements performed by RedCap UEs, and no evaluation was performed to see how the reduced capabilities of RedCap UEs might impact eventual position accuracy. The term "RedCap UE" used herein can refer to a UE which has UE complexity reduction features. The complexity reduction features may comprise one or more of: (1) reduced maximum UE bandwidth, for example, a maximum bandwidth of an frequency range (FR) 1 RedCap UE during and after initial access is 20 MHz and a maximum bandwidth of FR 2 RedCap UE during and after initial access is 100 MHz; (2) a reduced minimum number of receiving (Rx) branches; (3) a maximum number of downlink (DL) multi-input-multi-output (MIMO) layers; (4) a relaxed maximum modulation order; (5) a duplex operation.

[0039] For RedCap UE positioning, sounding reference signal (SRS) may be sent in a limited bandwidth, and it may have an impact on the positioning accuracy. Frequency hopping may be a candidate enhancement to enlarge an effective bandwidth for positioning. If partial bandwidth (BW) overlapping in frequency domain between hops in transmission is considered, it is worth studying the inter slot hopping procedure and resource mapping for the overlapping subbands. Moreover, the collision handling needs to be studied if the RF retuning time for SRS hopping or the subband itself is overlapped with other signals.

[0040] In order to solve at least part of the above problems or other potential problems, solutions on frequency hopping for reference signals are proposed. A network device transmits a reference signal bandwidth configuration to a terminal device. The reference signal bandwidth configuration indicates a frequency hopping scheme for a transmission of reference signal. The terminal device determines an overlapped bandwidth between frequency hops based on the reference signal bandwidth configuration. The terminal device transmits a first portion of the reference signal at a first frequency hop. The terminal device transmits a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth. In this way, the reference signal hopping subbands can be flexible and not in a fixed position, and the frequency diversity gain may be obtained.

[0041] Fig. 1 illustrates a schematic diagram of a communication system in which embodiments of the present disclosure can be implemented. The communication system 100, which is a part of a communication network, comprises a terminal device 110-1, a terminal device 110-2, . . . , a terminal device 110-N, which can be collectively referred to as "terminal device(s) 110." The number N can be any suitable integer number.

[0042] The communication system 100 further comprises a network device 120. In the communication system 100, the network device 120 and the terminal devices 110 can communicate data and control information to each other. The terminal devices 110 can also communicate with each other. The numbers of terminal devices shown in Fig. 1 are given for the purpose of illustration without suggesting any limitations. The interface between the terminal device110 and the network device 120 may be called Uu interface.

[0043] Communications in the communication system 100 may be implemented according to any proper communication protocol(s), comprising, but not limited to, cellular communication protocols of the first generation (1G), the second generation (2G), the third generation (3G), the fourth generation (4G) and the fifth generation (5G) and on the like, wireless local network communication protocols such as Institute for Electrical and Electronics Engineers (IEEE) 802.11 and the like, and/or any other protocols currently known or to be developed in the future. Moreover, the communication may utilize any proper wireless communication technology, comprising but not limited to: Code Divided Multiple Address (CDMA), Frequency Divided Multiple Address (FDMA), Time Divided Multiple Address (TDMA), Frequency Divided Duplexer (FDD), Time Divided Duplexer (TDD), Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency Divided Multiple Access (OFDMA) and/or any other technologies currently known or to be developed in the future.

[0044] Embodiments of the present disclosure can be applied to any suitable scenarios. For example, embodiments of the present disclosure can be implemented at reduced capability NR devices. Alternatively, embodiments of the present disclosure can be implemented in one of the followings: NR multiple-input and multiple-output (MIMO), NR sidelink enhancements, NR systems with frequency above 52.6GHz, an extending NR operation up to 71GHz, narrow band-Internet of Thing (NB-IOT)/ enhanced Machine Type Communication (eMTC) over non-terrestrial networks (NTN), NTN, UE power saving enhancements, NR coverage enhancement, NB-IoT and LTE-MTC, Integrated Access and Backhaul (IAB), NR Multicast and Broadcast Services, or enhancements on Multi-Radio Dual-Connectivity.

[0045] The term “slot” used herein refers to a dynamic scheduling unit. One slot comprises a predetermined number of symbols. The slot used herein may refer to a normal slot which comprises a predetermined number of symbols and also refer to a sub-slot which comprises fewer symbols than the predetermined number of symbols.

[0046] Embodiments of the present disclosure will be described in detail below. Reference is first made to Fig. 2, which shows a signaling chart illustrating process 200 among the terminal device and the network device according to some example embodiments of the present disclosure. Only for the purpose of discussion, the process 200 will be described with reference to Fig. 1. For example, the process 200 may involve the terminal device 110-1 and the network device 120.

[0047] The network device 120 transmits 2010 a reference signal bandwidth configuration to the terminal device 110-1. The reference signal bandwidth configuration indicates a frequency hopping scheme for a transmission of a reference signal. In some embodiments, the reference signal configuration may comprise an indication for enabling a frequency hopping for positioning. Alternatively, or in addition, the reference signal bandwidth configuration may comprise an index of the frequency hopping scheme. The term "frequency hopping" used herein means to transmit the reference signal bits in different frequency subbands.

[0048] In some embodiments, the frequency hopping scheme may indicate a total bandwidth for the transmission of the reference signal. For example, as shown in Fig. 3, the frequency hopping scheme may indicate the total bandwidth 310 for the transmission of the reference signal. Alternatively, or in addition, the frequency hopping scheme may indicate a number of frequency hops for the transmission of the reference signal. For example, as shown in Fig. 3, the frequency hopping scheme may indicate 4 frequency hops. It is noted that the number of frequency hops shown in Fig. 3 is only an example not limitation. The frequency hopping scheme may also indicate a bandwidth of a subband associated with one frequency hop.

[0049] The terminal device 110-1 determines 2020 an overlapped bandwidth between frequency hops in the frequency hopping scheme based on the reference signal bandwidth configuration. For example, as shown in Fig. 3, the frequency hopping scheme may indicate the frequency hops 320-1, 320-2, 320-3 and 320-4. The terminal device 110-1 may determine the overlapped bandwidth 330-1 between frequency hops 320-1 and 320-2, the overlapped bandwidth 330-2 between frequency hops 320-2 and 320-3, and the overlapped bandwidth 330-3 between frequency hops 320-3 and 320-4. In some embodiments, the overlapped bandwidth may be determined based on the total bandwidth, the number of frequency hops and the bandwidth of the subband associated with one frequency hop. The frequency hop used herein may refer to a normal frequency subband which is out of an active bandwidth part (BWP) of a terminal device. The frequency hop used herein may also refer to a frequency subband which is within the active BWP, which does not involve radio frequency tunning.

[0050] In some embodiments, the frequency hopping for RedCap positioning may consider 2-level resource block (RB) sets allocation. In this case, the first level may be the total bandwidth after hopping and combine receiving, the second level may be the bandwidth of each subband and the hopping number indication. In some embodiments, a new and special SRS bandwidth configuration for sounding hopping may be added, and a SRS frequency hopping enable flag may be added in *SRS-PosResource* information element (IE). In this case, when the frequency hopping is enabled, c-SRS in *SRS-PosResource* IE may be the index of the reference signal bandwidth configuration, and b-SRS may be default set to 1 if not configured. In this case, since the sub-band may be overlapped, and the number of overlap RBs may be implicitly indicated by the configuration table. For example, the overlapping RBs (i.e., the overlapped bandwidth) may be floor $((m_{SRS,1} * N_1 - m_{SRS,0})/(N_1 - 1))$. Table 1 below shows an example of reference signal bandwidth configuration. It is noted that values and parameters in Table 1 are only examples not limitations.

Table 1

C_{SRS}	$B_{SRS}=0$		$B_{SRS}=1$	
	$m_{SRS,0}$	N_0	$m_{SRS,1}$	N_1
0	96	1	36	3
1	100	1	28	4
2	160	1	56	3
3	168	1	48	4
4	240	1	68	4
5	252	1	72	4

[0051] As shown in Table 1, the parameter "C_{SRS}" may represent the index of the reference bandwidth configuration. If there is not an extra indication for enabling a frequency hopping for positioning, the parameter "B_{SRS}" may represent whether the frequency hopping is enabled for positioning, if there is an extra indication for enabling a frequency hopping for positioning, the parameter "B_{SRS}" may be default set to 1 if not configured. The parameter "$m_{SRS,0}$" may represent the number of RBs (i.e., the total bandwidth) for the frequency hopping, the parameter "$m_{SRS,1}$" may represent the number of RBs (i.e., the subbandwidth) for one frequency hopping, and the parameter "N_1" may represent the number of frequency hops in the frequency hopping scheme. Only as an example, from Table 1, for the reference signal bandwidth configuration with the index 0, the total bandwidth for the frequency hopping may be 96 RBs, the subband bandwidth for each frequency hopping may be 36 and the number of frequency hops may be 3.

[0052] In some embodiments, a first overlapped bandwidth between the first and second frequency hops may be same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop. For example, as shown in Fig. 3, the overlapped bandwidths 330-1, 330-2 and 330-3 may be the same. By way of example, according to Table 1, if the c-SRS is 3, the total bandwidth for SRS after combine receiving may be 168 RBs, and there may be 4 times frequency hopping, and the bandwidth of each sub-band may be 48 RBs. In this case, the partial overlapping RBs in frequency domain between each hop may be determined as: floor((48*4-168)/(4-1)) = 8 RBs. The overlapped RBs may also be a granularity of 4 PRBs. For example, as shown in Fig. 3, each of the overlapped bandwidths 330-1, 330-2 and 330-3 may be 8 RBs.

[0053] In some other embodiments, the first overlapped bandwidth between the first and second frequency hops may be different from the overlapped bandwidth between the third frequency hop and the fourth frequency hop. For example, as shown in Fig. 3, the overlapped bandwidth 330-1 between frequency hops 320-1 and 320-2 may be different from the overlapped bandwidth 330-2 between frequency hops 320-2 and 320-3. In some example embodiments, the overlapped bandwidths may be different from each other. Alternatively, some of the overlapped bandwidths may be the same while some of the overlapped bandwidths may be different. For example, according to Table 1, if the c-SRS is 4, the total bandwidth for SRS may be 240 RBs, there may be 4 times frequency hopping, the bandwidth of each hop may be 68 RBs. In this case, the number of overlapping RB may be floor((68*4-240)/(4-1)) = 10 RBs, but the calculated total bandwidth for the reference signal may be more than 240 RBs since the floor operation. In this case, the number of overlapping RB for each hop may be adjusted to 10, 10, 12. For example, as shown in Fig. 3, the overlapped bandwidth 330-1 may be 10 RBs, the overlapped bandwidth 330-2 may be 10 RBs and the overlapped bandwidth 330-3 may be 12 RBs.

[0054] In some embodiments, the reference signal bandwidth configuration may explicitly indicate the overlapped bandwidth between the frequency hops. Table 2 below shows an example of reference signal bandwidth configuration. It is noted that values and parameters in Table 2 are only examples not limitations.

Table 2

C_{SRS}	$B_{SRS}=0$		$B_{SRS}=1$	
	$m_{SRS,0}$	N_0	$m_{SRS,1}$	N_1
0	96	1	32	3
1	96	1	24	4

2	120	1	40	3
3	160	1	40	4
4	240	1	80	3
5	256	1	64	4

[0055] As shown in Table 2, the parameter "C_{SRS}" may represent the index of the reference bandwidth configuration . If there is not an extra indication for enabling a frequency hopping for positioning, the parameter "B_{SRS}" may represent whether the frequency hopping is enabled for positioning, if there is an extra indication for enabling a frequency hopping for positioning, the parameter "B_{SRS}" may be default set to 1 if not configured. The parameter "$m_{SRS,0}$" may represent the number of RBs (i.e., the total bandwidth) for the frequency hopping, the parameter "$m_{SRS,1}$" may represent the number of non-overlapped RBs (i.e., the non-overlapped subband bandwidth) for one frequency hopping, and the parameter "N_1" may represent the number of frequency hops in the frequency hopping scheme. By way of example, according to Table 2, if the c-SRS is 2, the total bandwidth for the reference signal after combine receiving may be 120 RBs, and there may be 3 times hopping, the bandwidth of each non-overlapped sub-band may be 40 RBs. In this case, the partial overlapping RBs in frequency domain between each hop may be explicitly configured in SRS-PosResource information element (IE).

[0056] In some example embodiments, the terminal device 110-1 may determine 2030 a counter for inter slot hopping for each hop. In some embodiment, if a resource for the reference signal is configured as aperiodic, the terminal device 110-1 may determine the counter for inter slot hopping for each hop based on the number of frequency hops. For example, the counter of inter slot hopping for each hop may be determined as: $n_{\text{SRS}} = n'$, $n'= 0, 1, \ldots, N_{hops}-1$, where, N_{hops} may represent the number of frequency hops.

[0057] Alternatively, if a resource for the reference signal is configured as periodic or semi-persistent, the terminal device 110-1 may determine the counter for inter slot hopping for each hop based on:

$$\left(\frac{N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}}{T_{\text{SRS}}}\right) * \text{k} + n', \qquad n'= 0, 1, \ldots, N_{hops} - 1;$$

where n_{SRS} represents the counter for inter slot hopping for each hop, $N_{slot}^{frame,\mu}$ represents the number of slots per frame for subcarrier spacing of μ, $n^{\mu}_{s,f}$ represent a slot number within a frame for subcarrier spacing of μ, and n_f represents a system frame number, k represents a scaling factor, N_{hops} represents the number of frequency hops, T_{offset} represents a slot offset, T_{SRS} represent a periodicity of the resource for the reference signal.

[0058] In some example embodiments, the terminal device 110-1 may determine 2040 a starting position of the reference signal in frequency-domain based at least partly on the overlapped bandwidth. For example, if there may be overlapping RBs for each frequency hop, the starting position of the reference signal in the frequency-domain may consider the overlapping RBs and may be determined as:

$$k_0^{(p_i)} = \bar{k}_0^{(p_i)} + n_{\text{offset}}^{\text{FH}} + n_{\text{offset}}^{\text{RPFS}},$$

$$n_{\text{offset}}^{\text{FH}} = \sum_{b=0}^{B_{\text{SRS}}} (m_{\text{SRS},b} - n_{overlap})\, N_{\text{sc}}^{\text{RB}} * i,$$

i $= n_b$ if hopping sequence is determined by n_b formula, or

i $= 0, 1, \ldots, N_{hops} - 1,$ if hopping sequence is in order;

where $n_{overlap}$ may represent the number of overlapping RBs, which may be implicitly indicated or explicitly configured by higher layer, $k_0^{(p_i)}$ may represent the starting position, $\bar{k}_0^{(p_i)} = n_{\text{shift}} N_{\text{sc}}^{\text{RB}} + \left(k_{\text{TC}}^{(p_i)} + k_{\text{offset}}^{l'}\right) \bmod K_{\text{TC}}$,

$$k_{\text{TC}}^{(p_i)} = \begin{cases} (\bar{k}_{\text{TC}} + K_{\text{TC}}/2) \bmod K_{\text{TC}} & \text{if } N_{\text{ap}}^{\text{SRS}} = 4,\ p_i \in \{1001, 1003\}, \text{ and } n_{\text{SRS}}^{\text{cs,max}} = 6 \\ (\bar{k}_{\text{TC}} + K_{\text{TC}}/2) \bmod K_{\text{TC}} & \text{if } N_{\text{ap}}^{\text{SRS}} = 4,\ p_i \in \{1001, 1003\}, \text{ and } n_{\text{SRS}}^{\text{cs}} \in \{n_{\text{SRS}}^{\text{cs,max}}/2, \ldots, n_{\text{SRS}}^{\text{cs,max}} - 1\}, \\ \bar{k}_{\text{TC}} & \text{otherwise} \end{cases}$$

$n_{\text{offset}}^{\text{RPFS}} = N_{\text{sc}}^{\text{RB}}\, m_{\text{SRS},B_{\text{SRS}}} \left((k_{\text{F}} + k_{\text{hop}}) \bmod P_{\text{F}}\right)/P_{\text{F}}$, $k_{\text{F}} \in \{0,1,\ldots,P_{\text{F}}-1\}$ is given by the higher-layer parameter *StartRBIndex* if configured, otherwise $k_{\text{F}} = 0$, k_{hop} may be given with $\bar{k}_{\text{hop}} = \left\lfloor \frac{n_{\text{SRS}}}{\prod_{b'=b_{\text{hop}}}^{B_{\text{SRS}}} N_{b'}} \right\rfloor \bmod P_{\text{F}}$, $N_{b_{\text{hop}}} = 1$, if the higher-layer parameter EnableStartRBHopping is configured, otherwise $k_{\text{hop}} = 0$, $N_{\text{ap}}^{\text{SRS}} \in \{1,2,4\}$ may represent the antenna ports, $n_{\text{SRS}}^{\text{cs,max}}$ may represent the maximum number of cyclic shifts, $K_{\text{TC}} \in \{2,4,8\}$ may represent the transmission comb number, $\bar{k}_{\text{TC}} \in \{0,1,\ldots,K_{\text{TC}}-1\}$ may represent the transmission comb offset, n_{SRS} may represent the reference signal counter.

[0059] In some example embodiments, the terminal device 110-1 may generate 2050 a sequence for the reference signal based at least partly on a total bandwidth for the transmission of the reference signal. For example, each frequency hop may be combined to receive in positioning reference signal transmission, the sequence in each hop may not be a repeat signal, it may be a continuous sequence in frequency domain. For the combined hops, the reference signal sequence for an SRS resource may be generated according to:

$$r^{(p_i)}(n, l') = r_{u,v}^{(\alpha_i,\delta)}(n)$$

$$0 \leq n \leq M_{\mathrm{sc},0}^{\mathrm{SRS}} - 1$$

$$l' \in \{0,1, \dots, N_{\mathrm{symb}}^{\mathrm{SRS}} - 1\}$$

, the total length of the sounding reference signal sequence may be given by $M_{\mathrm{sc},0}^{\mathrm{SRS}} = m_{\mathrm{SRS},0} N_{\mathrm{sc}}^{\mathrm{RB}} / (K_{\mathrm{TC}} P_{\mathrm{F}})$, where $r_{u,v}^{(\alpha,\delta)}(n)$ may be given by clause 5.2.2 of TS 38.211 with $\delta = \log_2(K_{\mathrm{TC}})$ and the transmission comb number $K_{\mathrm{TC}} \in \{2,4,8\}$ is contained in the higher-layer parameter *transmissionComb*. The cyclic shift α_i for antenna port p_i may be given as $\alpha_i = 2\pi \frac{n_{\mathrm{SRS}}^{\mathrm{cs},i}}{n_{\mathrm{SRS}}^{\mathrm{cs,max}}}$,

$$n_{\mathrm{SRS}}^{\mathrm{cs},i} = \begin{cases} \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \frac{n_{\mathrm{SRS}}^{\mathrm{cs,max}} \lfloor (p_i - 1000)/2 \rfloor}{N_{\mathrm{ap}}^{\mathrm{SRS}}/2} \right) \bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}} & \text{if } N_{\mathrm{ap}}^{\mathrm{SRS}} = 4 \text{ and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \frac{n_{\mathrm{SRS}}^{\mathrm{cs,max}} (p_i - 1000)}{N_{\mathrm{ap}}^{\mathrm{SRS}}} \right) \bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}} & \text{otherwise} \end{cases},$$

where $n_{\mathrm{SRS}}^{\mathrm{cs}} \in \{0,1, \dots, n_{\mathrm{SRS}}^{\mathrm{cs,max}} - 1\}$ may be contained in the higher layer parameter *transmissionComb*.

[0060] In some example embodiments, the terminal device 110-1 may map 2060 a sequence for the reference signal to a physical resource based at least partly on the overlapped bandwidth. For example, when the reference signal is transmitted on a given resource, the sequence $r^{(p_i)}(n, l')$ for each OFDM symbol l' and for each of the antenna ports of the resource may be mapped in sequence starting with $r^{(p_i)}(ki', l')$ to resource elements (k, l) in a slot for each of the antenna ports p_i according to:

$$a_{K_{\mathrm{TC}}k' + k_0^{(p_i)}, l' + l_0}^{(p_i)} = \begin{cases} \frac{1}{\sqrt{N_{\mathrm{ap}}}} \beta_{\mathrm{SRS}} r^{(p_i)}(k' + M_{\mathrm{SC},i}^{\mathrm{SRS}}, l') & k' = 0,1,\dots,M_{\mathrm{sc},b}^{\mathrm{SRS}} - 1 \quad l' = 0,1,\dots,N_{\mathrm{symb}}^{\mathrm{SRS}} - 1 \\ 0 & \text{otherwise} \end{cases}$$

$$M_{\mathrm{SC},i}^{\mathrm{SRS}} = i * (m_{\mathrm{SRS},b} - n_{overlap}) N_{\mathrm{SC}}^{\mathrm{RB}} / (K_{\mathrm{TC}} P_{\mathrm{F}})$$

$i = n_b$ if hopping sequence is determined by n_b formula, or

$i = 0, 1, \dots, N_{hops} - 1$; if hopping sequence is in order.

where $m_{\mathrm{SRS},b}$ is given by a selected row (for example, a row from Table 1 or Table 2 above) with $b = B_{\mathrm{SRS}}$ where $B_{\mathrm{SRS}} \in \{0,1,2,3\}$ is given by the field *b-SRS* contained in the higher-layer parameter *freqHopping* if configured, otherwise $B_{\mathrm{SRS}} = 0$, if there is not an extra indication for enabling a frequency hopping for positioning. If there is an extra indication for enabling a frequency hopping for positioning, the parameter "B_{SRS}" may be default set to 1 if not configured. The row of the table may be selected according to the index $C_{\mathrm{SRS}} \in \{0,1,\ldots,63\}$ given by the field *c-SRS* contained in the higher-layer parameter *freqHopping*. The quantity $P_{\mathrm{F}} \in \{2, 4\}$ may be given by the higher-layer parameter *FreqScalingFactor* if configured, otherwise $P_{\mathrm{F}} = 1$. When *FreqScalingFactor* is configured, the terminal device 110-1 may expect the length of the sequence to be a multiple of 6.

[0061] By way of example, as shown in Fig. 4, the numbers of sequence 50, 51, 52 and 53 may be transmitted in a frequency hop and the numbers of sequence 52, 53, 54 and 55 may be transmitted in a next frequency hop. In other words, the frequency hop and the next frequency hop may have the overlapped numbers of sequences 52 and 53.

[0062] It is noted that the order of steps 2030, 2040, 2050 and 2060 shown in Fig. 2 is only an example not limitation. For example, in some embodiments, the determination step 2040 may be before the determination step 2030. Embodiments of the present disclosure are not limited to this aspect.

[0063] The terminal device 110-1 transmits 2070 a first portion of the reference signal to the network device 120 at a first frequency hop. The terminal device 110-1 transmits 2080 a second portion of the reference signal to the network device 120 based on the overlapped bandwidth at a second frequency hop. In some embodiments, the first frequency hop and the second frequency hop may be in order. For example, as shown in Fig. 3, the terminal device 110-1 may transmit the first portion of the reference signal to the network device 120 at the frequency hop 320-1 and transmit the second portion of the reference signal to the network device 120 at the frequency hop 320-2 based on the overlapped bandwidth 330-1. Alternatively, the first frequency hop and the second frequency hop may not be in order. For example, as shown in Fig. 3, the terminal device 110-1 may transmit the first portion of the reference signal to the network device 120 at the frequency hop 320-2 and transmit the second portion of the reference signal to the network device 120 at the frequency hop 320-4 based on the overlapped bandwidths 330-2 and 330-3.

[0064] According to embodiments described with reference to Figs. 2-4, a special reference signal bandwidth configuration may be generated for sounding hopping outside the active BWP. The inter slot hopping counter for positioning sounding may be updated. For each hop with overlapping RBs, the frequency-domain starting position and physical resources mapping may be determined. In this way, for the periodic or semi-persistent mode, the hopping subbands can be flexible and not in a fixed position, and the frequency diversity gain may be obtained. For the overlapping subbands, the frequency-domain starting position and physical resources mapping manner may be identified.

[0065] Reference is first made to Fig. 5, which shows a signaling chart illustrating process 500 among the terminal device and the network device according to some example embodiments of the present disclosure. Only for the purpose of discussion, the process 500 will be described with reference to Fig. 1. For example, the process 500 may involve the terminal device 110-1 and the network device 120. It is noted that the term “slot” may also refer to symbol-level.

[0066] The network device 120 transmits 5010 a reference signal configuration to the terminal device 110-1. The reference signal configuration indicates a frequency hopping scheme for a transmission of a reference signal. One or more frequency hop in the frequency hopping scheme may be outside an active bandwidth part (BWP) of the terminal device 110-1. The term “active BWP” used herein can refer to a UE specific bandwidth part that can be used to BWP performs data transmission. The active BWP may be the first BWP where the terminal device starts data transfer after radio resource control (RRC) configuration/reconfiguration. The active BWP may be different from a default BWP.

[0067] By way of example, as shown in Fig. 6, the terminal device 110-1 may be configured with the active BWP 620. The frequency hop 610-1 may be within the active BWP 620 and the frequency hops 610-2, 610-3 and 610-4 may be outside the active BWP 620. In this case, for example, if the terminal device 110-1 transmits a portion of the reference signal at the frequency hop 610-2, the terminal device 110-1 may perform a radio frequency (RF) tuning since the frequency hop 610-2 is outside the active BWP 620.

[0068] In some embodiments, the reference signal configuration may comprise an indication for enabling a frequency hopping for position. Alternatively, or in addition, the reference signal configuration may comprise an index of the frequency hopping scheme. In some embodiments, the frequency hopping scheme may indicate a total bandwidth for the transmission of the reference signal. Alternatively, or in addition, the frequency hopping scheme may indicate a number of frequency hops for the transmission of the reference signal. The frequency hopping scheme may also indicate a bandwidth of a subband associated with one frequency hop.

[0069] The terminal device 110-1 determines 5020 whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop. For example, the first collision may occur due to the RF tuning. By way of example, as shown in Fig. 6, the terminal device 110-1 may transmit a portion of the reference signal at the frequency hop 610-2 in a slot 630-2. Due to the RF tuning, the collision may occur at slots 630-1 and 630-3.

[0070] The terminal device 110-1 transmits 5030 at least a part of the first portion of the reference signal at the first frequency hop based on a predetermined condition. In some embodiments, the terminal device 110-1 may determine whether a second collision between transmitting a second portion of the reference signal and a second communication with the network device occurs at a second frequency hop. If this case, if the second collision occurs, the terminal device 110-1 may transmit 5040 at least a part of the second portion of the reference signal at the second frequency hop based on the predetermined condition. In other words, the predetermined condition for handling the collisions may be applied for all frequency hops.

[0071] In some embodiments, if the first collision occurs, the terminal device 110-1 may transmit the first portion of the reference signal to the network device 120. The terminal device 110-1 may drop the first communication with the network device 120. In this case, for example, the predetermined condition may indicate that the reference signal for positioning transmission may be highest priority in the symbol(s) where the overlap occurs, the downlink (DL) reception or uplink (UL) transmission may be cancelled in the overlapping symbols or in the whole slot. For example, as shown in Fig. 7A, the terminal device 110-1 may transmit the first portion of the reference signal at the frequency hop 610-1 in the slot 630-2 and may drop the communications in the slots 630-1 and 630-3. In this case, the terminal device 110-1 may perform the RF tunning in the slots 630-1 and 630-3. In some embodiments, the first frequency hop may be at a first slot and the collision may occur in a second slot which is ahead of the first slot and a third slot which is after the first slot. For example, the frequency hop may be at the slot 630-2 and the collisions may occur in the slots 630-1 and 630-3.

[0072] In some embodiments, the terminal device 110-1 may transmit a first part of the first portion of the reference signal on a first set of symbols of the first slot. The terminal device 110-1 may drop a second part of the first portion of the reference signal on a second set of symbols of the first slot. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. The terminal device 110-1 may perform the first communication in the third slot and drop the first communication in the second slot. In this case, for example, the predetermined condition may indicate that if the former slot and the latter slot are dynamic scheduling or semi-static scheduling, the former scheduling may be cancelled, and the reference signal symbols with the RF tuning time collided with latter scheduling may be dropped. For example, as shown in Fig. 7B, the terminal device 110-1 may transmit the part 6101 of the portion of the reference signal on the set of symbols 6301 and drop the part 6102 of the portion of the reference signal on the set of symbols 6302 in the slot 630-2. The set of symbols 6301 may be closer to the slot 630-1 and farther from the slot 630-3 than the set of symbols 6302. The communication in the slot 630-1 may be dropped due to the RF tuning for reference signal transmission. The terminal device 110-1 may perform the communication in the slot 630-3.

[0073] Alternatively, the terminal device 110-1 may drop the first part of the first portion of the reference signal on the first set of symbols of the first slot. The terminal device 110-1 may transmit the second part of the first portion of the reference signal on the second set of symbols of the first slot. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. In this case, the terminal device 110-1 may perform the first communication in the second slot and drop the first communication in the third slot. In this case, for example, the predetermined condition may indicate that: if the former slot and the latter slot are dynamic scheduling or semi-static scheduling, the latter scheduling may be cancelled, and the reference signal symbols with the RF tuning time collided with former scheduling may be dropped. For example, as shown in Fig. 7C, the terminal device 110-1 may drop the part 6101 of the portion of the reference signal on the set of symbols 6301 and transmit the part 6102 of the portion of the reference signal on the set of symbols 6302 in the slot 630-2. The set of symbols 6301 may be closer to the slot 630-1 and farther from the slot 630-3 than the set of symbols 6302. The terminal device 110-1 may perform the communication in the slot 630-1. The communication in the slot 630-3 may be dropped due to the RF tuning for reference signal transmission.

[0074] In some embodiments, the first frequency hop may be at a first slot and the collision may occur in a second slot which is semi-static scheduling and a third slot which is dynamic scheduling. In this case, the terminal device 110-1 may transmit a first part of the first portion of the reference signal on a first set of symbols of the first slot. The terminal device 110-1 may drop a second part of the first portion of the reference signal on a second set of symbols of the first slot. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. The terminal device 110-1 may drop the first communication in the second slot and transmit the first communication in the third slot. In this case, for example, the predetermined condition may indicate that: if the former slot and the latter slot may be semi-static scheduling and dynamic scheduling, the semi-static scheduling may be cancelled, and the reference signal symbols with the RF tuning time collided with dynamic scheduling may be dropped. For example, as shown in Fig. 7D, the terminal device 110-1 may transmit the part 6101 of the portion of the reference signal on the set of symbols 6301 and drop the part 6102 of the portion of the reference signal on the set of symbols 6302 in the slot 630-2. The set of symbols 6301 may be closer to the slot 630-1 and farther from the slot 630-3 than the set of symbols 6302. The communication in the slot 630-1 may be dropped due to the RF tuning for reference signal transmission. The terminal device 110-1 may perform the communication in the slot 630-3.

[0075] In some embodiments, the first frequency hop may be at a first slot. In this case, in some embodiments, the terminal device 110-1 may transmit the first part of the first portion of the reference signal in the first set of symbols of the first slot and drop a second part of the first portion of the reference signal in a second set of symbols of the first slot. In other words, the communication in the slot(s) adjacent to the first slot may be not affected. For example, as shown in Fig. 6, the terminal device 110-1 may transmit the first part of the first portion of the reference signal in the first set of symbols of the slot 630-2 and drop a second part of the first portion of the reference signal in a second set of symbols of the slot 630-2. The terminal device 110-1 may also perform the communication in the slots 630-1 and 630-3.

[0076] In some embodiments, the terminal device 110-1 may receive from the network device 120, downlink control information (DCI) which schedules a downlink transmission. In this case, in some embodiments, if a portion of transmission of the reference signal is within a preparation time relative to a last symbol of a control resource set (CORSET) where the terminal device 110-1 detects a DCI format for the downlink transmission, the terminal device 110-1 may transmit the reference signal to the network device 120. For example, as shown in Fig. 8, the terminal device 110-1 may receive the DCI 810 which schedules a downlink transmission. The portion of transmission 840 of the reference signal may be within a preparation time 830 relative to a last symbol of a control resource set (CORSET) where the terminal device 110-1 detects a DCI format for the downlink transmission. In this case, the terminal device 110-1 may transmit the reference signal to the network device 120 For example, for operation on a single carrier in unpaired spectrum, if the UE is configured by higher layers to transmit SRS hopping sub-band in a set of symbols of a slot and the UE detects a DCI format indicating to the UE to receive channel state information reference signal (CSI-RS) or physical downlink shared channel (PDSCH) in a subset of symbols from the set of symbols, the UE does not expect to cancel the transmission of the reference signal in the set of symbols if the first symbol in the set occurs within $T_{proc,2}$ relative to a last symbol of a CORESET where the UE detects the DCI format; otherwise, the UE cancels the SRS in the set of symbols, determined from clauses 9, 9.2.5 and 9.2.6 or clause 6.1 of [6, TS 38.214]. The parameter $\mathrm{T}_{\mathrm{proc,2}}$ is the PUSCH preparation time for the corresponding UE processing capability [6, TS 38.214] assuming $\mathrm{d}_{2,1} = 1$ and μ corresponds to the smallest subcarrier spacing (SCS) configuration between the SCS configuration of the PDCCH carrying the DCI format and the SCS configuration of the SRS, PUCCH, PUSCH or μ_{r}, where μ_{r} corresponds to the SCS configuration of the PRACH if it is 15kHz or higher; otherwise $\mu_{\mathrm{r}} = 0$.

[0077] In some embodiments, the terminal device 110-1 may receive from the network device 120, a configuration of a processing time window. In this case, if the first collision occurs in the processing time window, the terminal device 110-1 may transmit the first portion of the reference signal to the network device 120. The first communication within the processing time window may be dropped. In some embodiments, a processing window may be configured from higher layer to transmit reference signal sub-bands. In this window, the reference signal transmission for positioning may be the highest priority, and the reference signal transmission may be expected. Other DL and UL signals may not be expected to receive or transmit. In some example embodiments, at least one frequency hop may be within the processing time window. For example, as shown in Fig. 9, the terminal device 110-1 may be configured with the processing time window 910. In this case, the terminal device 110-1 may ensure the transmission of the reference signal.

[0078] According to embodiments described with reference to Figs. 5-9, a collision handling rule for the symbols overlapping with the RF retuning time is proposed. In this way, considering the several hops may be combined reception, the collision handling rule can ensure that each sub-band has at least 2 or 4 common symbols. In the flexible slot of unpaired spectrum, if the reference signal subband transmission which needs RF retuning is prepared earlier than DL dynamic scheduling, the DL dynamic scheduling may be cancelled. Moreover, a dedicated processing window may be configured to transmit SRS sub-bands.

[0079] Fig. 10 shows a flowchart of an example method 1000 in accordance with an embodiment of the present disclosure. The method 1000 can be implemented at any suitable terminal devices. Only for the purpose of illustrations, the method 1000 can be implemented at a terminal device 110-1 as shown in Fig. 1.

[0080] At block 1010, the terminal device 110-1 receives a reference signal bandwidth configuration from the network device 120. The reference signal bandwidth configuration indicates a frequency hopping scheme for a transmission of a reference signal. In some embodiments, the frequency hopping scheme may comprise one or more of: a total bandwidth for the transmission of the reference signal, a number of frequency hops for the transmission of the reference signal, and a bandwidth of a subband associated with one frequency hop. In some embodiments, the reference signal bandwidth configuration may comprise one or more of: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme.

[0081] At block 1020, the terminal device 110-1 determines, based on the reference signal bandwidth configuration, an overlapped bandwidth between frequency hops in the frequency hopping scheme. In some embodiments, the terminal device 110-1 may determine the overlapped bandwidth based on: the total bandwidth, the number of frequency hops and the bandwidth of the subband associated with one frequency hop. In some embodiments, the reference signal bandwidth configuration may explicitly indicate the overlapped bandwidth between the frequency hops.

[0082] At block 1030, the terminal device 110-1 transmits to the network device 120, a first portion of the reference signal at a first frequency hop.

[0083] At block 1040, the terminal device 110-1 transmits, to the network device, a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth. In some embodiments, a first overlapped bandwidth between the first and second frequency hops may be same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop. Alternatively, the first overlapped between the first and second frequency hops may be different from the second overlapped between the third and fourth frequency hops.

[0084] In some embodiments, if a resource for the reference signal is configured as aperiodic, the terminal device 110-1 may determine a counter for inter slot hopping for each hop based on the number of frequency hops. Alternatively, if a resource for the reference signal is configured as periodic or semi-persistent, the termina device 110-1 may determine a counter for inter slot hopping for each hop based on:

$$n_{SRS} = \left(\frac{N_{slot}^{frame,\mu} n_f + n_{s,f}^{\mu} - T_{offset}}{T_{SRS}} \right) * k + n', \quad n' = 0, 1, \ldots, N_{hops} - 1,$$

where n_{SRS} represents the counter for inter slot hopping for each hop, $N_{slot}^{frame,\mu}$ represents the number of slots per frame for subcarrier spacing of μ, $n^{\mu}_{s,f}$ represent a slot number within a frame for subcarrier spacing of μ, and n_f represents a system frame number, k represents a scaling factor, N_{hops} represents the number of frequency hops, T_{offset} represents a slot offset, T_{SRS} represents a periodicity of the resource for the reference signal.

[0085] In some embodiments, the termina device 110-1 may determine a starting position of the reference signal in frequency-domain based at least partly on the overlapped bandwidth. In some embodiments, the termina device 110-1 may generate a sequence for the reference signal based at least partly on a total bandwidth for the transmission of the reference signal. In some embodiments, the termina device 110-1 may map a sequence for the reference signal to a physical resource based at least partly on the overlapped bandwidth.

[0086] Fig. 11 shows a flowchart of an example method 1100 in accordance with an embodiment of the present disclosure. The method 1100 can be implemented at any suitable network devices. Only for the purpose of illustrations, the method 1100 can be implemented at a network device 120 as shown in Fig. 1.

[0087] At block 1110, the network device 120 transmits a reference signal bandwidth configuration from the terminal device 110-1. The reference signal bandwidth configuration indicates a frequency hopping scheme for a transmission of a reference signal. In some embodiments, the frequency hopping scheme may comprise one or more of: a total bandwidth for the transmission of the reference signal, a number of frequency hops for the transmission of the reference signal, and a bandwidth of a subband associated with one frequency hop. In some embodiments, the reference signal bandwidth configuration may comprise one or more of: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme. In some embodiments, the reference signal bandwidth configuration may explicitly indicate the overlapped bandwidth between the frequency hops.

[0088] At block 1120, the network device 120 receives from the terminal device 110-1 a first portion of the reference signal at a first frequency hop.

[0089] At block 1130, the network device 120 receives from the terminal device 110-1 a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth. In some embodiments, a first overlapped bandwidth between the first and second frequency hops may be same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop. Alternatively, the first overlapped between the first and second frequency hops may be different from the second overlapped between the third and fourth frequency hops.

[0090] Fig. 12 shows a flowchart of an example method 1200 in accordance with an embodiment of the present disclosure. The method 1200 can be implemented at any suitable terminal devices. Only for the purpose of illustrations, the method 1200 can be implemented at a terminal device 110-1 as shown in Fig. 1.

[0091] At block 1210, the terminal device 110-1 receives, from the network device 120, a reference signal configuration indicating a frequency hopping scheme for a transmission of a reference signal. At least one hop in the frequency hopping scheme is outside an active BWP of the terminal device.

[0092] At block 1220, the terminal device 110-1 determines whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop.

[0093] At block 1230, the terminal device 110-1 transmits, based on a predetermined condition, at least a part of the first portion of the reference signal at the first frequency hop. In some embodiments, if a second collision between transmitting a second portion of the reference signal and a second communication with the network device occurs at a second frequency hop, the terminal device 110-1 may transmit, based on the predetermined condition, at least a part of the second portion of the reference signal at the second frequency hop.

[0094] In some embodiments, if the first collision occurs, the terminal device 110-1 may transmit the first portion of the reference signal. The terminal device 110-1 may cause the first communication with the network device to be dropped.

[0095] In some embodiments, the first frequency hop may be at a first slot and the collision occurs in a second slot which is ahead of the first slot and a third slot which is after the first slot. In some embodiments, the terminal device 110-1 may transmit a first part of the first portion of the reference signal on a first set of symbols of the first slot. The terminal device 110-1 may cause a second part of the first portion of the reference signal on a second set of symbols of the first slot to be dropped. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. The terminal device 110-1 may perform the first communication in the third slot and cause the first communication in the second slot to be dropped.

[0096] In some embodiments, the first frequency hop may be at a first slot and the collision occurs in a second slot which is ahead of the first slot and a third slot which is after the first slot. In some embodiments, the terminal device 110-1 may cause a firs part of the first portion of the reference signal on a first set of symbols of the first slot to be dropped. In some embodiments, the terminal device 110-1 may transmit a second part of the first portion of the reference signal on a second set of symbols of the first slot. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. The terminal device 110-1 may perform the first communication in the second slot and cause the first communication in the third slot to be dropped.

[0097] In some embodiments, the first frequency hop may be at a first slot and the collision occurs in a second slot which is semi-static scheduling and a third slot which is dynamic scheduling. In some embodiments, the terminal device 110-1 may cause a firs part of the first portion of the reference signal on a first set of symbols of the first slot to be dropped. In some embodiments, the terminal device 110-1 may transmit a second part of the first portion of the reference signal on a second set of symbols of the first slot. The first set of symbols may be closer to the second slot and farther from the third slot than the second set of symbols. The terminal device 110-1 may perform the first communication in the third slot and cause the first communication in the second slot to be dropped.

[0098] In some embodiments, the first frequency hop may be at a first slot. In some embodiments, the terminal device 110-1 may transmit a first part of the first portion of the reference signal in a first set of symbols of the first slot cause a second part of the first portion of the reference signal in a second set of symbols of the first slot to be dropped.

[0099] In some embodiments, the terminal device 110-1 may receive, from the network device 120, downlink control information (DCI) which schedules a downlink transmission. In this case, in some embodiments, if a portion of transmission of the reference signal is within a preparation time relative to a last symbol of a control resource set where the terminal device detects a DCI format for the downlink transmission, the terminal device 110-1 may transmit the reference signal to the network device.

[00100] In some embodiments, the terminal device 110-1 may receive, from the network device, a configuration of a processing time window. In this case, in some embodiments, if the first collision occurs in the processing time window, the terminal device 110-1 may transmit the first portion of the reference signal to the network device and cause the first communication within the processing time window to be dropped.

[00101] In some embodiments, a terminal device comprises circuitry configured to perform: receiving, from a network device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; determining, based on the reference signal bandwidth configuration, an overlapped bandwidth between frequency hops in the frequency hopping scheme; transmitting, to the network device, a first portion of the reference signal at a first frequency hop; and transmitting, to the network device, a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth.

[00102] In some embodiments, the frequency hopping scheme comprises: a total bandwidth for the transmission of the reference signal, a number of frequency hops for the transmission of the reference signal, and a bandwidth of a subband associated with one frequency hop.

[00103] In some embodiments, the reference signal bandwidth configuration comprises: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme.

[00104] In some embodiments, the terminal device comprises circuitry configured to perform: determining the overlapped bandwidth based on the total bandwidth, the number of frequency hops and the bandwidth of the subband associated with one frequency hop.

[00105] In some embodiments, a first overlapped bandwidth between the first and second frequency hops is same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop, or wherein the first overlapped bandwidth between the first and second frequency hops is different from the second overlapped bandwidth between the third and fourth frequency hops.

[00106] In some embodiments, the reference signal bandwidth configuration explicitly indicates the overlapped bandwidth between the frequency hops.

[00107] In some embodiments, the terminal device comprises circuitry configured to perform: in accordance with a determination that a resource for the reference signal is configured as aperiodic, determining a counter for inter slot hopping for each hop based on the number of frequency hops.

[00108] In some embodiments, the terminal device comprises circuitry configured to perform: in accordance with a determination that a resource for the reference signal is configured as periodic or semi-persistent, determining a counter for inter slot hopping for each hop based on:

$$n_{\mathrm{SRS}} = \left\lfloor \frac{N_{\mathrm{slot}}^{\mathrm{frame},\mu} n_{\mathrm{f}} + n_{\mathrm{s,f}}^{\mu} - T_{\mathrm{offset}}}{T_{\mathrm{SRS}}} \right\rfloor * \mathrm{k} + n', \quad n' = 0, 1, \ldots, N_{hops}-1,$$

wherein n_{SRS} represents the counter for inter slot hopping for each hop, $N_{slot}^{frame,\mu}$ represents the number of slots per frame for subcarrier spacing of μ, $n^{\mu}_{s,f}$ represent a slot number within a frame for subcarrier spacing of μ, and n_f represents a system frame number, k represents a scaling factor, N_{hops} represents the number of frequency hops, T_{offset} represents a slot offset, T_{SRS} represents a periodicity of the resource for the reference signal.

[00109] In some embodiments, the terminal device comprises circuitry configured to perform: determining a starting position of the reference signal in frequency-domain based at least partly on the overlapped bandwidth.

[00110] In some embodiments, the terminal device comprises circuitry configured to perform: generating a sequence for the reference signal based at least partly on a total bandwidth for the transmission of the reference signal.

[00111] In some embodiments, the terminal device comprises circuitry configured to perform: mapping a sequence for the reference signal to a physical resource based at least partly on the overlapped bandwidth.

[00112] In some embodiments, a network device comprises circuitry configured to perform: transmitting, to a terminal device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal; receiving, from the terminal device, a first portion of the reference signal at a first frequency hop; and receiving, from the terminal device, a second portion of the reference signal at a second frequency hop based on an overlapped bandwidth between frequency hops in the frequency hopping scheme.

[00113] In some embodiments, the frequency hopping scheme comprises: a total bandwidth for the transmission of the reference signal, a number of frequency hops for the transmission of the reference signal, and a bandwidth of a subband associated with one frequency hop.

[00114] In some embodiments, the reference signal bandwidth configuration comprises: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme.

[00115] In some embodiments, a first overlapped bandwidth between the first and second frequency hops is same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop, or wherein the first overlapped bandwidth between the first and second frequency hops is difference from the second overlapped bandwidth between the third and fourth frequency hops.

[00116] In some embodiments, the reference signal bandwidth configuration explicitly indicates the overlapped bandwidth between the frequency hops.

[00117] In some embodiments, a terminal device comprises circuitry configured to perform: receiving, from a network device, a reference signal configuration indicating a frequency hopping scheme for a transmission of a reference signal, wherein at least one hop in the frequency hopping scheme is outside an active BWP of the terminal device; determining whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop; and transmitting, based on a predetermined condition, at least a part of the first portion of the reference signal at the first frequency hop.

[00118] In some embodiments, the terminal device comprises circuitry configured to perform: in accordance with a determination that a second collision between transmitting a second portion of the reference signal and a second communication with the network device occurs at a second frequency hop, transmitting, based on the predetermined condition, at least a part of the second portion of the reference signal at the second frequency hop.

[00119] In some embodiments, the terminal device comprises circuitry configured to perform: in accordance with a determination that the first collision occurs, transmitting the first portion of the reference signal; and causing the first communication with the network device to be dropped.

[00120] In some embodiments, the first frequency hop is at a first slot and the collision occurs in a second slot which is ahead of the first slot and in a third slot which is after the first slot. In some embodiments, the terminal device comprises circuitry configured to perform: transmitting a first part of the first portion of the reference signal on a first set of symbols of the first slot; causing a second part of the first portion of the reference signal on a second set of symbols of the first slot to be dropped, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols; performing the first communication in the third slot; and causing the first communication in the second slot to be dropped.

[00121] In some embodiments, the first frequency hop is at a first slot and the collision occurs in a second slot which is ahead of the first slot and in a third slot which is after the first slot. In some embodiments, the terminal device comprises circuitry configured to perform: causing a first part of the first portion of the reference signal on a first set of symbols of the first slot to be dropped; transmitting a second part of the first portion of the reference signal on a second set of symbols of the first slot, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols; performing the first communication in the second slot; and causing the first communication in the third slot to be dropped.

[00122] In some embodiments, the first frequency hop is at a first slot and the collision occurs in a second slot which is semi-static scheduling and in a third slot which is dynamic scheduling. In some embodiments, the terminal device comprises circuitry configured to perform: transmitting a first part of the first portion of the reference signal on a first set of symbols of the first slot; causing a second part of the first portion of the reference signal on a second set of symbols of the first slot to be dropped, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols; performing the first communication in the third slot; and causing the first communication in the second slot to be dropped.

[00123] In some embodiments, the first frequency hop is at a first slot. In some embodiments, the terminal device comprises circuitry configured to perform transmitting a first part of the first portion of the reference signal in a first set of symbols of the first slot;

and causing a second part of the first portion of the reference signal in a second set of symbols of the first slot to be dropped.

[00124] In some embodiments, the terminal device comprises circuitry configured to perform: receiving, from the network device, downlink control information (DCI) which schedules an downlink transmission; and in accordance with a determination that a portion of transmission of the reference signal is within a preparation time relative to a last symbol of a control resource set where the terminal device detects a DCI format for the downlink transmission, transmitting the reference signal to the network device.

[00125] In some embodiments, the terminal device comprises circuitry configured to perform receiving, from the network device, a configuration of a processing time window; and in accordance with a determination that the first collision occurs in the processing time window, transmitting the first portion of the reference signal to the network device; and causing the first communication within the processing time window to be dropped.

[00126] Fig. 13 is a simplified block diagram of a device 1300 that is suitable for implementing embodiments of the present disclosure. The device 1300 can be considered as a further example implementation of the terminal devices 110 as shown in Fig. 1. Accordingly, the device 1300 can be implemented at or as at least a part of the terminal device 110-1 or the terminal device 110-2.

[00127] As shown, the device 1300 includes a processor 1310, a memory 1320 coupled to the processor 1310, a suitable transmitter (TX) and receiver (RX) 1340 coupled to the processor 1310, and a communication interface coupled to the TX/RX 1340. The memory 1320 stores at least a part of a program 1330. The TX/RX 1340 is for bidirectional communications. The TX/RX 1340 has at least one antenna to facilitate communication, though in practice an Access Node mentioned in this application may have several ones. The communication interface may represent any interface that is necessary for communication with other network elements, such as X2 interface for bidirectional communications between eNBs, S1 interface for communication between a Mobility Management Entity (MME)/Serving Gateway (S-GW) and the eNB, Un interface for communication between the eNB and a relay node (RN), or Uu interface for communication between the eNB and a terminal device.

[00128] The program 1330 is assumed to include program instructions that, when executed by the associated processor 1310, enable the device 1300 to operate in accordance with the embodiments of the present disclosure, as discussed herein with reference to Fig. 2 to 12. The embodiments herein may be implemented by computer software executable by the processor 1310 of the device 1300, or by hardware, or by a combination of software and hardware. The processor 1310 may be configured to implement various embodiments of the present disclosure. Furthermore, a combination of the processor 1310 and memory 1320 may form processing means 1350 adapted to implement various embodiments of the present disclosure.

[00129] The memory 1320 may be of any type suitable to the local technical network and may be implemented using any suitable data storage technology, such as a non-transitory computer readable storage medium, semiconductor-based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory, as non-limiting examples. While only one memory 1320 is shown in the device 1300, there may be several physically distinct memory modules in the device 1300. The processor 1310 may be of any type suitable to the local technical network, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on multicore processor architecture, as non-limiting examples. The device 1300 may have multiple processors, such as an application specific integrated circuit chip that is slaved in time to a clock which synchronizes the main processor.

[00130] Generally, various embodiments of the present disclosure may be implemented in hardware or special purpose circuits, software, logic or any combination thereof. Some aspects may be implemented in hardware, while other aspects may be implemented in firmware or software which may be executed by a controller, microprocessor or other computing device. While various aspects of embodiments of the present disclosure are illustrated and described as block diagrams, flowcharts, or using some other pictorial representation, it will be appreciated that the blocks, apparatus, systems, techniques or methods described herein may be implemented in, as non-limiting examples, hardware, software, firmware, special purpose circuits or logic, general purpose hardware or controller or other computing devices, or some combination thereof.

[00131] The present disclosure also provides at least one computer program product tangibly stored on a non-transitory computer readable storage medium. The computer program product includes computer-executable instructions, such as those included in program modules, being executed in a device on a target real or virtual processor, to carry out the process or method as described above with reference to Figs. 2 to 12. Generally, program modules include routines, programs, libraries, objects, classes, components, data structures, or the like that perform particular tasks or implement particular abstract data types. The functionality of the program modules may be combined or split between program modules as desired in various embodiments. Machine-executable instructions for program modules may be executed within a local or distributed device. In a distributed device, program modules may be located in both local and remote storage media.

[00132] Program code for carrying out methods of the present disclosure may be written in any combination of one or more programming languages. These program codes may be provided to a processor or controller of a general purpose computer, special purpose computer, or other programmable data processing apparatus, such that the program codes, when executed by the processor or controller, cause the functions/operations specified in the flowcharts and/or block diagrams to be implemented. The program code may execute entirely on a machine, partly on the machine, as a stand-alone software package, partly on the machine and partly on a remote machine or entirely on the remote machine or server.

[00133] The above program code may be embodied on a machine readable medium, which may be any tangible medium that may contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device. The machine readable medium may be a machine readable signal medium or a machine readable storage medium. A machine readable medium may include but not limited to an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples of the machine readable storage medium would include an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing.

[00134] Further, while operations are depicted in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Likewise, while several specific implementation details are contained in the above discussions, these should not be construed as limitations on the scope of the present disclosure, but rather as descriptions of features that may be specific to particular embodiments. Certain features that are described in the context of separate embodiments may also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment may also be implemented in multiple embodiments separately or in any suitable sub-combination.

[00135] Although the present disclosure has been described in language specific to structural features and/or methodological acts, it is to be understood that the present disclosure defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

[00136] As used herein, the term ‘terminal device’ refers to any device having wireless or wired communication capabilities. Examples of the terminal device include, but not limited to, user equipment (UE), personal computers, desktops, mobile phones, cellular phones, smart phones, personal digital assistants (PDAs), portable computers, tablets, wearable devices, internet of things (IoT) devices, Ultra-reliable and Low Latency Communications (URLLC) devices, Internet of Everything (IoE) devices, machine type communication (MTC) devices, device on vehicle for V2X communication where X means pedestrian, vehicle, or infrastructure/network, devices for Integrated Access and Backhaul (IAB), Small Data Transmission (SDT), mobility, Multicast and Broadcast Services (MBS), positioning, dynamic/flexible duplex in commercial networks, reduced capability (RedCap), Space borne vehicles or Air borne vehicles in Non-terrestrial networks (NTN) including Satellites and High Altitude Platforms (HAPs) encompassing Unmanned Aircraft Systems (UAS), eXtended Reality (XR) devices including different types of realities such as Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR), the unmanned aerial vehicle (UAV) commonly known as a drone which is an aircraft without any human pilot, devices on high speed train (HST), or image capture devices such as digital cameras, sensors, gaming devices, music storage and playback appliances, or Internet appliances enabling wireless or wired Internet access and browsing and the like. The ‘terminal device’ can further has ‘multicast/broadcast’ feature, to support public safety and mission critical, V2X applications, transparent IPv4/IPv6 multicast delivery, IPTV, smart TV, radio services, software delivery over wireless, group communications and IoT applications. It may also incorporate one or multiple Subscriber Identity Module (SIM) as known as Multi-SIM. The term “terminal device" can be used interchangeably with a UE, a mobile station, a subscriber station, a mobile terminal, a user terminal or a wireless device.

[00137] The term "network device" refers to a device which is capable of providing or hosting a cell or coverage where terminal devices can communicate. Examples of a network device include, but not limited to, a Node B (NodeB or NB), an evolved NodeB (eNodeB or eNB), a next generation NodeB (gNB), a transmission reception point (TRP), a remote radio unit (RRU), a radio head (RH), a remote radio head (RRH), an IAB node, a low power node such as a femto node, a pico node, a reconfigurable intelligent surface (RIS), Network-controlled Repeaters, and the like.

[00138] The terminal device or the network device may have Artificial intelligence (AI) or Machine learning capability. It generally includes a model which has been trained from numerous collected data for a specific function, and can be used to predict some information.

[00139] The terminal or the network device may work on several frequency ranges, e.g. FR1 (410 MHz – 7125 MHz), FR2 (24.25GHz to 71GHz), frequency band larger than 100GHz as well as Tera Hertz(THz). It can further work on licensed/unlicensed/shared spectrum. The terminal device may have more than one connections with the network devices under Multi-Radio Dual Connectivity (MR-DC) application scenario. The terminal device or the network device can work on full duplex, flexible duplex and cross division duplex modes.

[00140] The network device may have the function of network energy saving, Self-Organising Networks (SON)/ Minimization of Drive Tests (MDT). The terminal may have the function of power saving.

[00141] The embodiments of the present disclosure may be performed in test equipment, e.g. signal generator, signal analyzer, spectrum analyzer, network analyzer, test terminal device, test network device, channel emulator.

[00142] The embodiments of the present disclosure may be performed according to any generation communication protocols either currently known or to be developed in the future. Examples of the communication protocols include, but not limited to, the first generation (1G), the second generation (2G), 2.5G, 2.75G, the third generation (3G), the fourth generation (4G), 4.5G, the fifth generation (5G) communication protocols, 5.5G, 5G-Advanced networks, or the sixth generation (6G) networks.

I/We Claim:

1. A communication method, comprising:

receiving, at a terminal device and from a network device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal;

determining, based on the reference signal bandwidth configuration, an overlapped bandwidth between frequency hops in the frequency hopping scheme;

transmitting, to the network device, a first portion of the reference signal at a first frequency hop; and

transmitting, to the network device, a second portion of the reference signal at a second frequency hop based on the overlapped bandwidth.

2. The method of claim 1, wherein the frequency hopping scheme comprises:

a total bandwidth for the transmission of the reference signal,

a number of frequency hops for the transmission of the reference signal, and

a bandwidth of a subband associated with one frequency hop.

3. The method of claim 1, wherein the reference signal bandwidth configuration comprises: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme.

4. The method of claim 2, wherein determining the overlapped bandwidth between the frequency hops comprises:

determining the overlapped bandwidth based on:

the total bandwidth,

the number of frequency hops and

the bandwidth of the subband associated with one frequency hop.

5. The method of claim 1, wherein a first overlapped bandwidth between the first and second frequency hops is same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop, or

wherein the first overlapped bandwidth between the first and second frequency hops is different from the second overlapped bandwidth between the third and fourth frequency hops.

6. The method of claim 1, wherein the reference signal bandwidth configuration explicitly indicates the overlapped bandwidth between the frequency hops.

7. The method of claim 1, further comprising:

in accordance with a determination that a resource for the reference signal is configured as aperiodic, determining a counter for inter slot hopping for each hop based on the number of frequency hops.

8. The method of claim 1, further comprising:

in accordance with a determination that a resource for the reference signal is configured as periodic or semi-persistent, determining a counter for inter slot hopping for each hop based on:

$$n_{\mathrm{SRS}} = \left(\frac{N_{\mathrm{slot}}^{\mathrm{frame},\mu} n_{\mathrm{f}} + n_{\mathrm{s,f}}^{\mu} - T_{\mathrm{offset}}}{T_{\mathrm{SRS}}} \right) * \mathrm{k} + n', \quad n' = 0, 1, \ldots, N_{hops}\text{-}1,$$

wherein n_{SRS} represents the counter for inter slot hopping for each hop, $N_{\mathrm{slot}}^{\mathrm{frame},\mu}$ represents the number of slots per frame for subcarrier spacing of μ, $n^{\mu}_{\mathrm{s,f}}$ represent a slot number within a frame for subcarrier spacing of μ, and n_{f} represents a system frame number, k represents a scaling factor, N_{hops} represents the number of frequency hops, T_{offset} represents a slot offset, T_{SRS} represent a periodicity of the resource for the reference signal.

9. The method of claim 1, further comprising:

determining a starting position of the reference signal in frequency-domain based at least partly on the overlapped bandwidth.

10. The method of claim 1, further comprising:

generating a sequence for the reference signal based at least partly on a total bandwidth for the transmission of the reference signal.

11. The method of claim 1, further comprising:

mapping a sequence for the reference signal to a physical resource based at least partly on the overlapped bandwidth.

12. A communication method, comprising:

transmitting, at a network device and to a terminal device, a reference signal bandwidth configuration indicating a frequency hopping scheme for a transmission of a reference signal;

receiving, from the terminal device, a first portion of the reference signal at a first frequency hop; and

receiving, from the terminal device, a second portion of the reference signal at a second frequency hop based on an overlapped bandwidth between frequency hops in the frequency hopping scheme.

13. The method of claim 12, wherein the frequency hopping scheme comprises:

a total bandwidth for the transmission of the reference signal,

a number of frequency hops for the transmission of the reference signal, and

a bandwidth of a subband associated with one frequency hop.

14. The method of claim 12, wherein the reference signal bandwidth configuration comprises: an indication for enabling a frequency hopping for positioning and an index of the frequency hopping scheme.

15. The method of claim 12, wherein a first overlapped bandwidth between the first and second frequency hops is same as a second overlapped bandwidth between a third frequency hop and a fourth frequency hop, or

wherein the first overlapped bandwidth between the first and second frequency hops is difference from the second overlapped bandwidth between the third and fourth frequency hops.

16. The method of claim 12, wherein the reference signal bandwidth configuration explicitly indicates the overlapped bandwidth between the frequency hops.

17. A communication method, comprising:

receiving, at a terminal device and from a network device, a reference signal configuration indicating a frequency hopping scheme for a transmission of a reference signal, wherein at least one hop in the frequency hopping scheme is outside an active BWP of the terminal device;

determining whether a first collision between transmitting a first portion of the reference signal and a first communication with the network device occurs at a first frequency hop; and

transmitting, based on a predetermined condition, at least a part of the first portion of the reference signal at the first frequency hop.

18. The method of claim 17, further comprising:

in accordance with a determination that a second collision between transmitting a second portion of the reference signal and a second communication with the network device occurs at a second frequency hop, transmitting, based on the predetermined condition, at least a part of the second portion of the reference signal at the second frequency hop.

19. The method of claim 17, wherein transmitting the at least a part of the first portion of the reference signal at the first frequency hop comprises:

in accordance with a determination that the first collision occurs, transmitting the first portion of the reference signal; and

causing the first communication with the network device to be dropped.

20. The method of claim 17, wherein the first frequency hop is at a first slot and the collision occurs in a second slot which is ahead of the first slot and in a third slot which is after the first slot, and

wherein transmitting at least a part of the first portion of the reference signal at the first frequency hop comprises:

transmitting a first part of the first portion of the reference signal on a first set of symbols of the first slot;

causing a second part of the first portion of the reference signal on a second set of symbols of the first slot to be dropped, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols;

performing the first communication in the third slot; and

causing the first communication in the second slot to be dropped.

21. The method of claim 17, wherein the first frequency hop is at a first slot and the collision occurs in a second slot which is ahead of the first slot and in a third slot which is after the first slot, and

wherein transmitting at least a part of the first portion of the reference signal at the first frequency hop comprises:

causing a first part of the first portion of the reference signal on a first set of symbols of the first slot to be dropped;

transmitting a second part of the first portion of the reference signal on a second set of symbols of the first slot, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols;

performing the first communication in the second slot; and

causing the first communication in the third slot to be dropped.

22. The method of claim 17, wherein the first frequency hop is at a first slot and the collision occurs in a second slot which is semi-static scheduling and in a third slot which is dynamic scheduling, and

wherein transmitting at least a part of the first portion of the reference signal at the first frequency hop comprises:

transmitting a first part of the first portion of the reference signal on a first set of symbols of the first slot;

causing a second part of the first portion of the reference signal on a second set of symbols of the first slot to be dropped, wherein the first set of symbols is closer to the second slot and farther from the third slot than the second set of symbols;

performing the first communication in the third slot; and

causing the first communication in the second slot to be dropped.

23. The method of claim 17, wherein the first frequency hop is at a first slot, and

wherein transmitting at least a part of the first portion of the reference signal at the first frequency hop comprises:

transmitting a first part of the first portion of the reference signal in a first set of symbols of the first slot; and

causing a second part of the first portion of the reference signal in a second set of symbols of the first slot to be dropped.

24. The method of claim 17, further comprising:

receiving, from the network device, downlink control information (DCI) which schedules an downlink transmission; and

in accordance with a determination that a portion of transmission of the reference signal is within a preparation time relative to a last symbol of a control resource set where the terminal device detects a DCI format for the downlink transmission, transmitting the reference signal to the network device.

25. The method of claim 17, further comprising:

receiving, from the network device, a configuration of a processing time window; and

wherein transmitting at least a part of the first portion of the reference signal comprises:

in accordance with a determination that the first collision occurs in the processing time window, transmitting the first portion of the reference signal to the network device; and

causing the first communication within the processing time window to be dropped.

26. A terminal device comprising:

a processor; and

a memory coupled to the processor and storing instructions thereon, the instructions, when executed by the processor, causing the terminal device to perform acts comprising the method according to any of claims 1-11 or any of claims 17-25.

27. A network device comprising:

a processor; and

a memory coupled to the processor and storing instructions thereon, the instructions, when executed by the processor, causing the network device to perform acts comprising the method according to any of claims 12-16.

28. A computer readable medium having instructions stored thereon, the instructions, when executed on at least one processor, causing the at least one processor to perform the method according to any of claims 1-11, or any of claims 12-16, or any of claims 17-25.

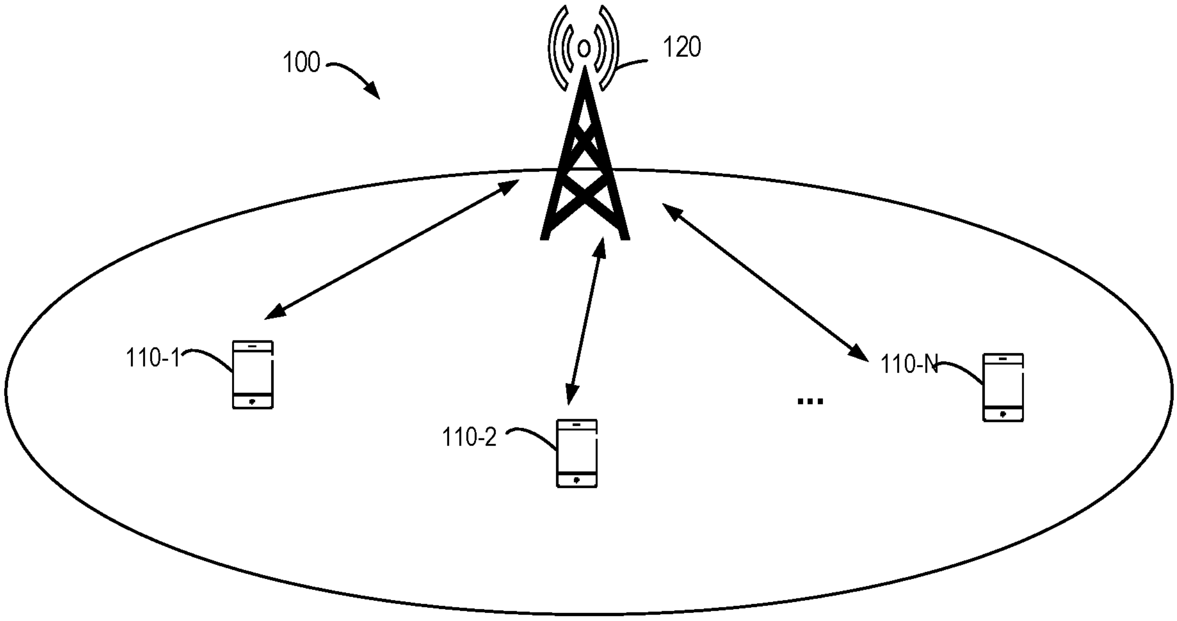


Fig. 1

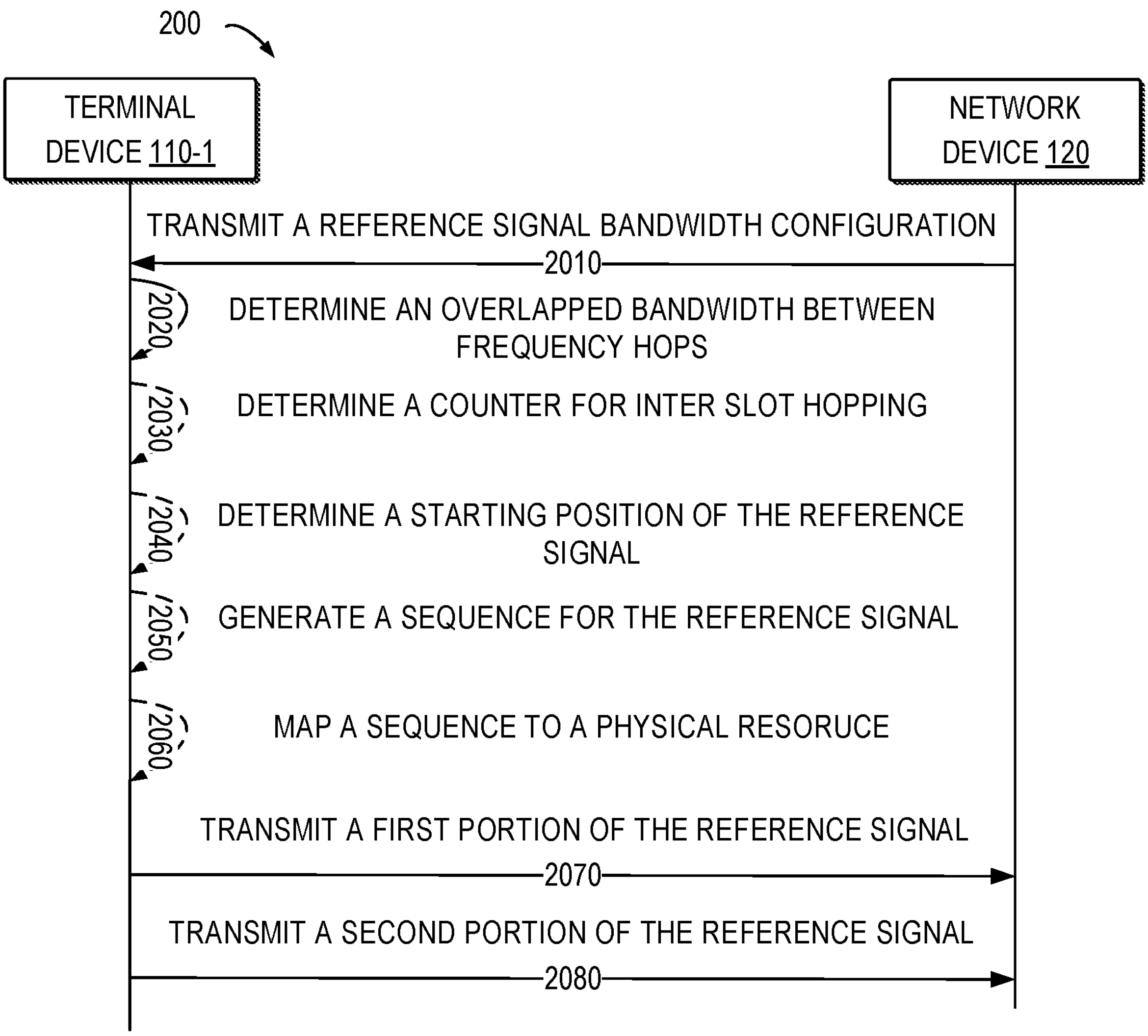

200
TERMINAL DEVICE 110-1
NETWORK DEVICE 120
TRANSMIT A REFERENCE SIGNAL BANDWIDTH CONFIGURATION
2010
2020
DETERMINE AN OVERLAPPED BANDWIDTH BETWEEN FREQUENCY HOPS
2030
DETERMINE A COUNTER FOR INTER SLOT HOPPING
2040
DETERMINE A STARTING POSITION OF THE REFERENCE SIGNAL
2050
GENERATE A SEQUENCE FOR THE REFERENCE SIGNAL
2060
MAP A SEQUENCE TO A PHYSICAL RESORUCE
TRANSMIT A FIRST PORTION OF THE REFERENCE SIGNAL
2070
TRANSMIT A SECOND PORTION OF THE REFERENCE SIGNAL
2080

Fig. 2

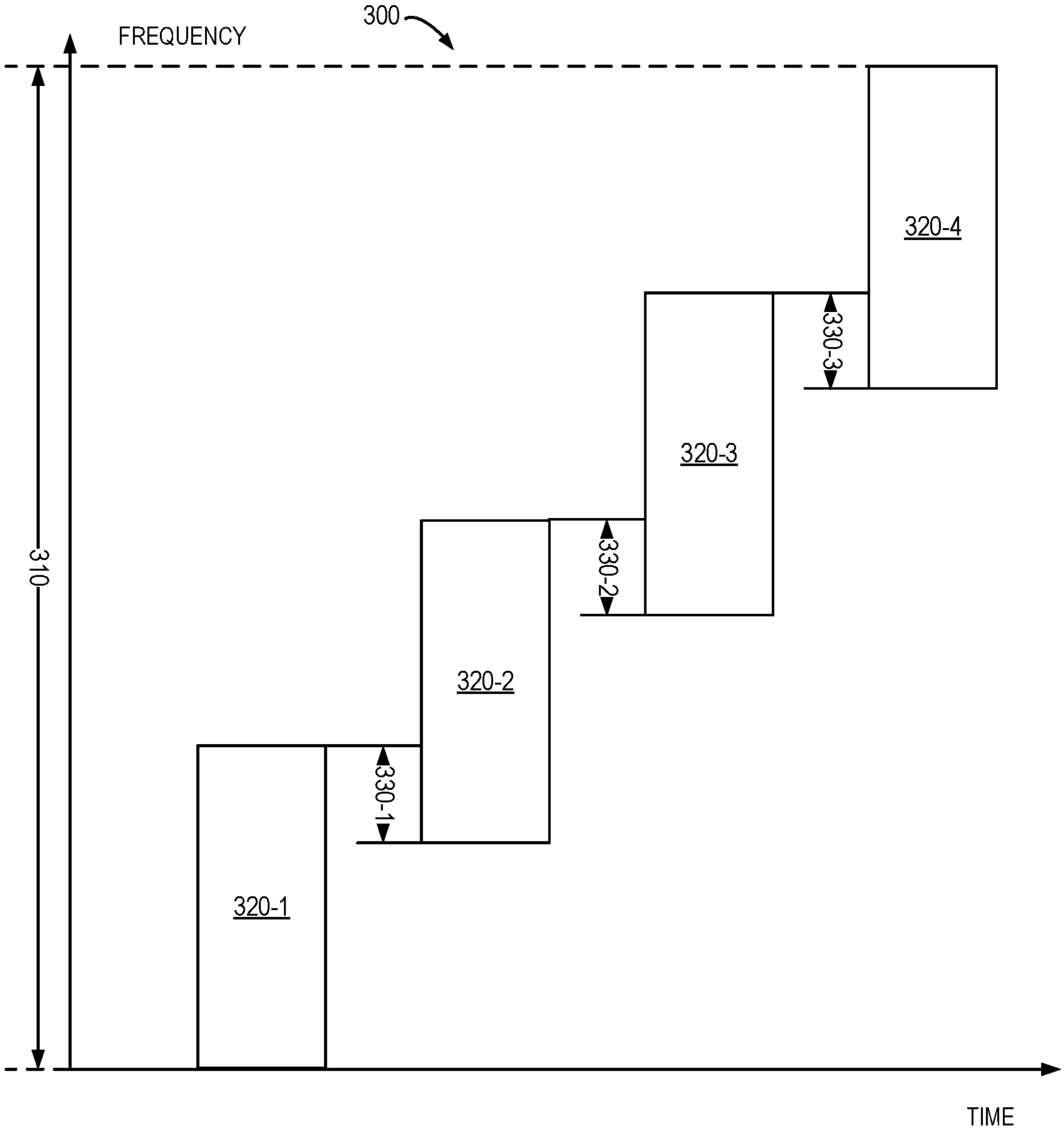


Fig. 3

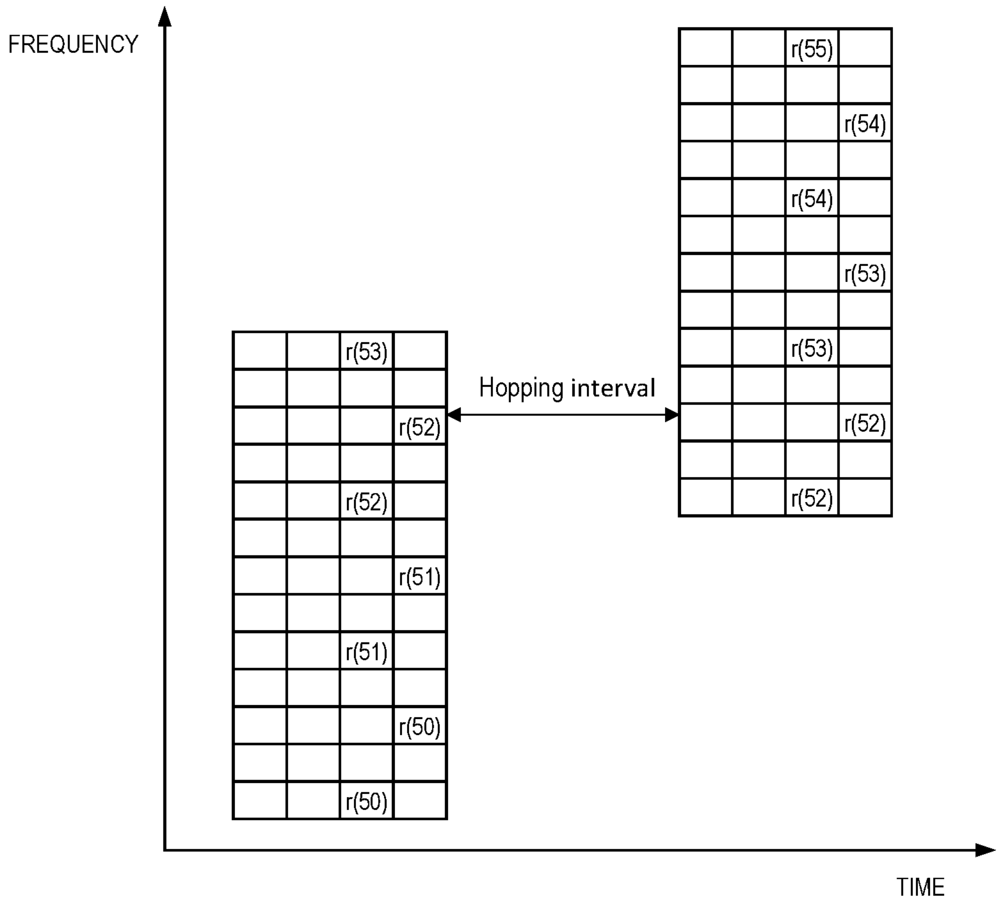

FREQUENCY
r(55)
r(54)
r(54)
r(53)
r(53)
r(52)
r(52)
r(53)
Hopping interval
r(52)
r(52)
r(51)
r(51)
r(50)
r(50)
TIME

Fig. 4

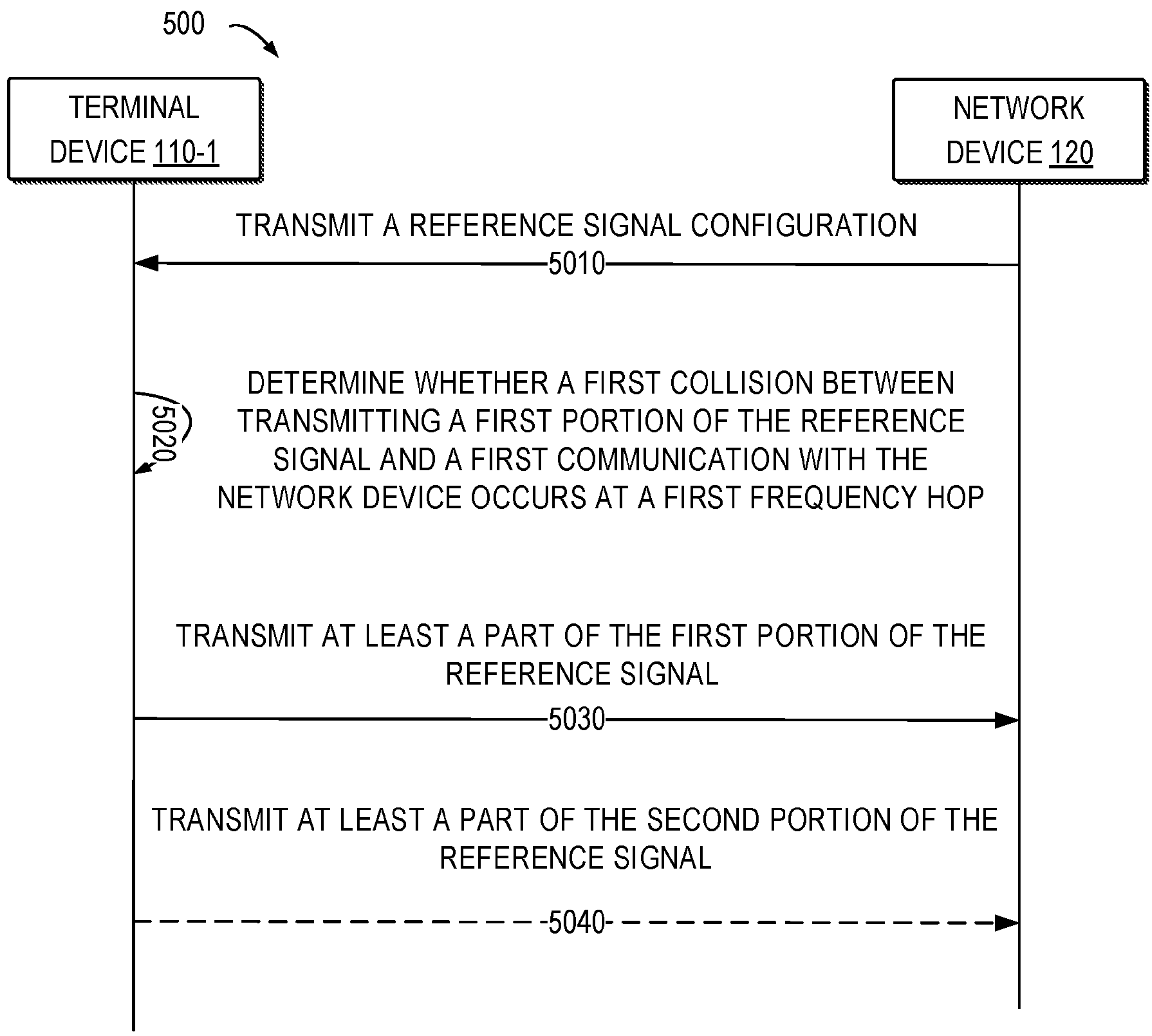

500
TERMINAL DEVICE 110-1
NETWORK DEVICE 120
TRANSMIT A REFERENCE SIGNAL CONFIGURATION
5010
DETERMINE WHETHER A FIRST COLLISION BETWEEN TRANSMITTING A FIRST PORTION OF THE REFERENCE SIGNAL AND A FIRST COMMUNICATION WITH THE NETWORK DEVICE OCCURS AT A FIRST FREQUENCY HOP
5020
TRANSMIT AT LEAST A PART OF THE FIRST PORTION OF THE REFERENCE SIGNAL
5030
TRANSMIT AT LEAST A PART OF THE SECOND PORTION OF THE REFERENCE SIGNAL
5040

Fig. 5

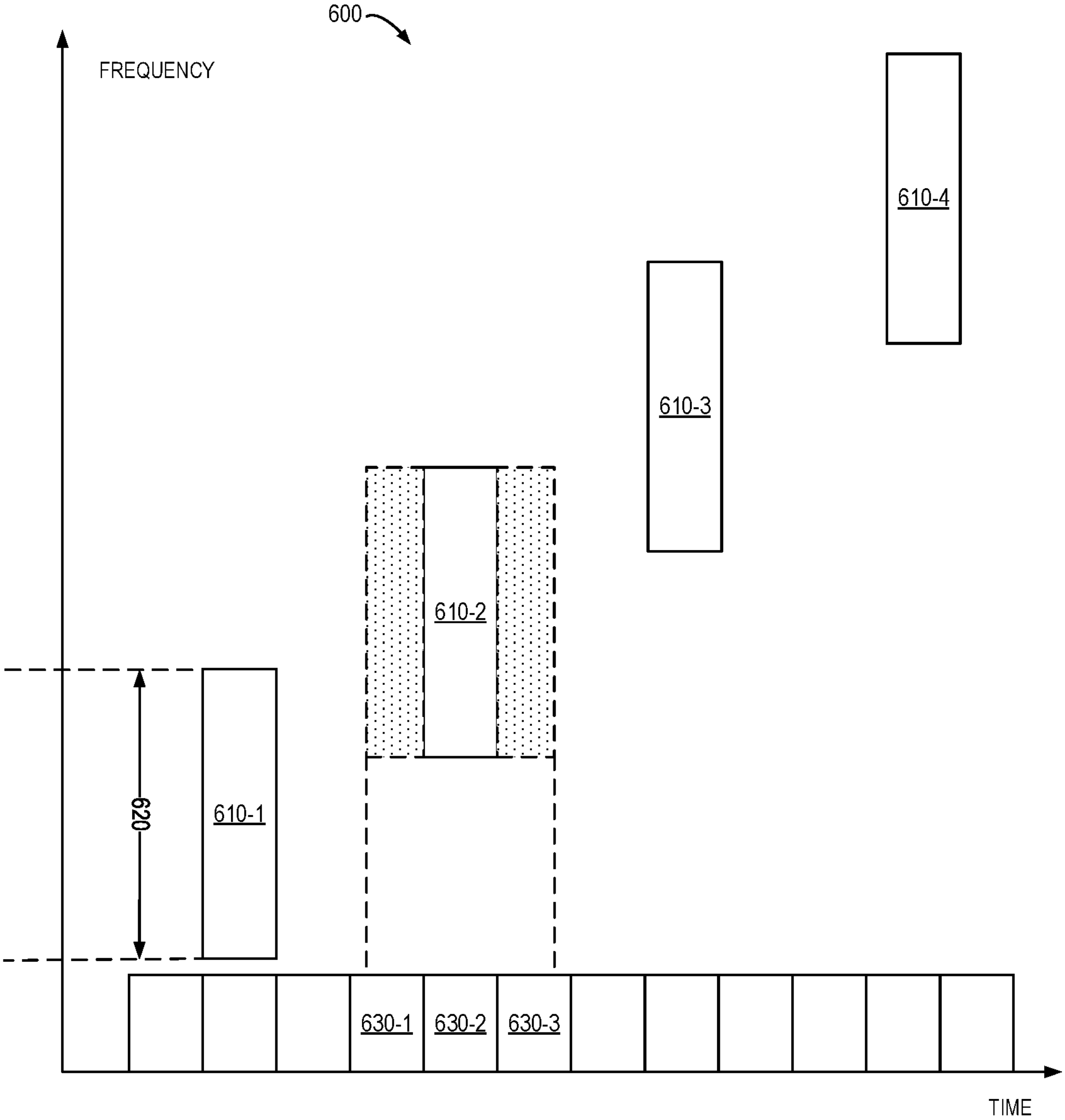


Fig. 6

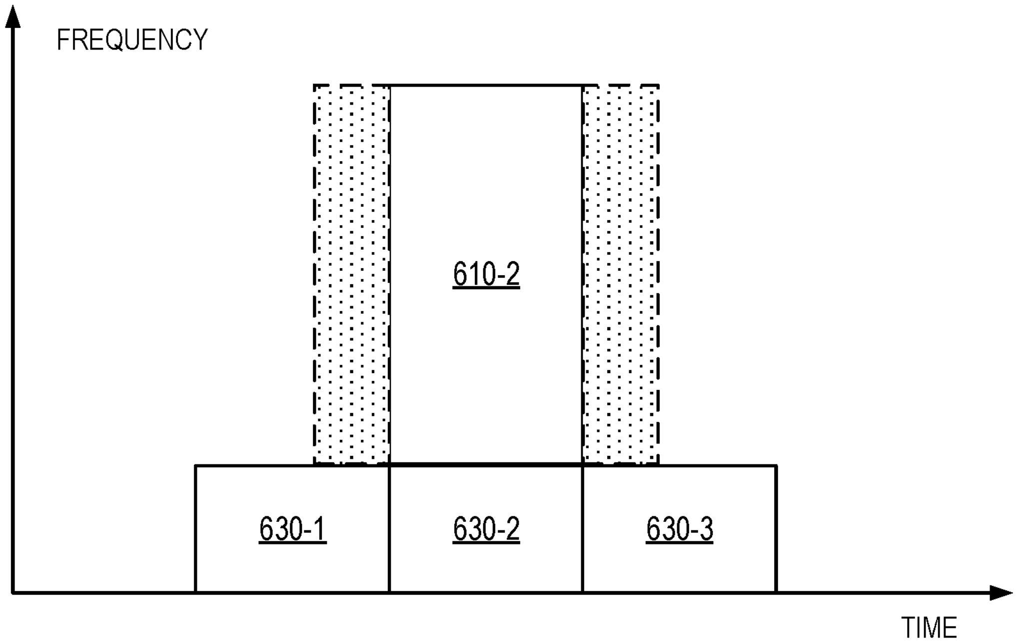

FREQUENCY
610-2
630-1
630-2
630-3
TIME

Fig. 7A

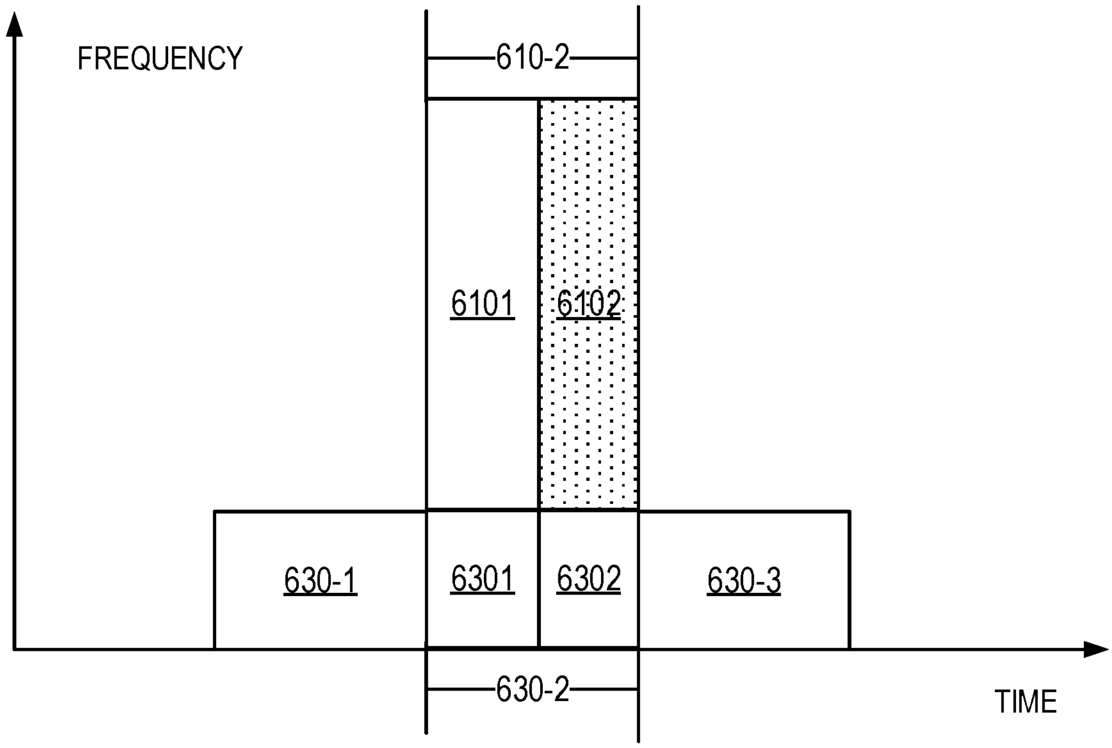
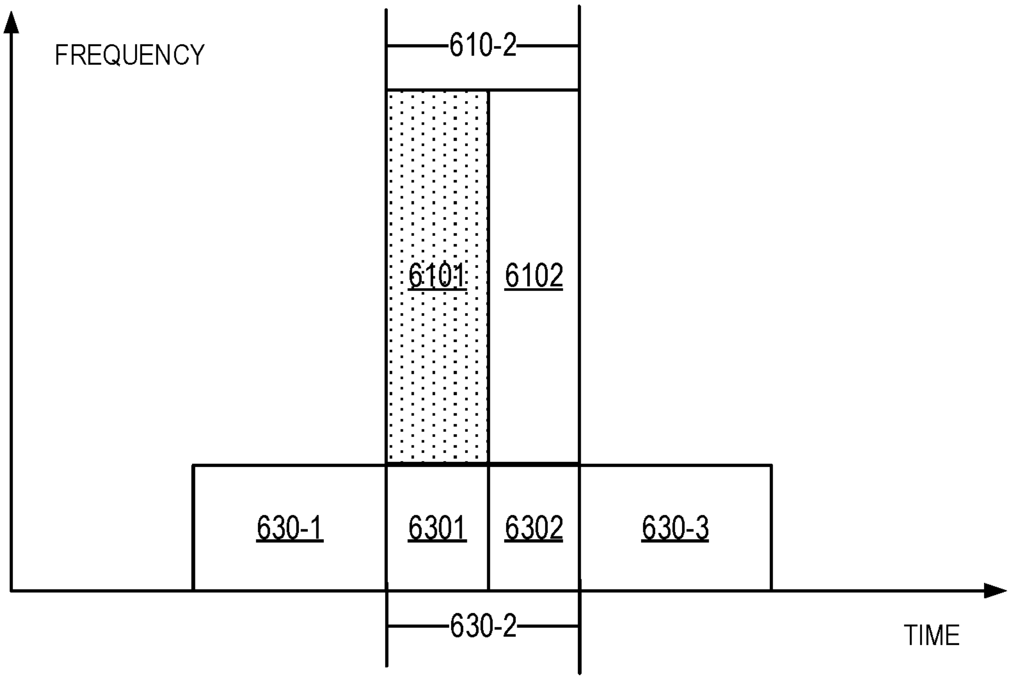

FREQUENCY
610-2
6101
6102
630-1
6301
6302
630-3
630-2
TIME

Fig. 7B


FREQUENCY
610-2
6101
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630-1
6301
6302
630-3
630-2
TIME

Fig. 7C

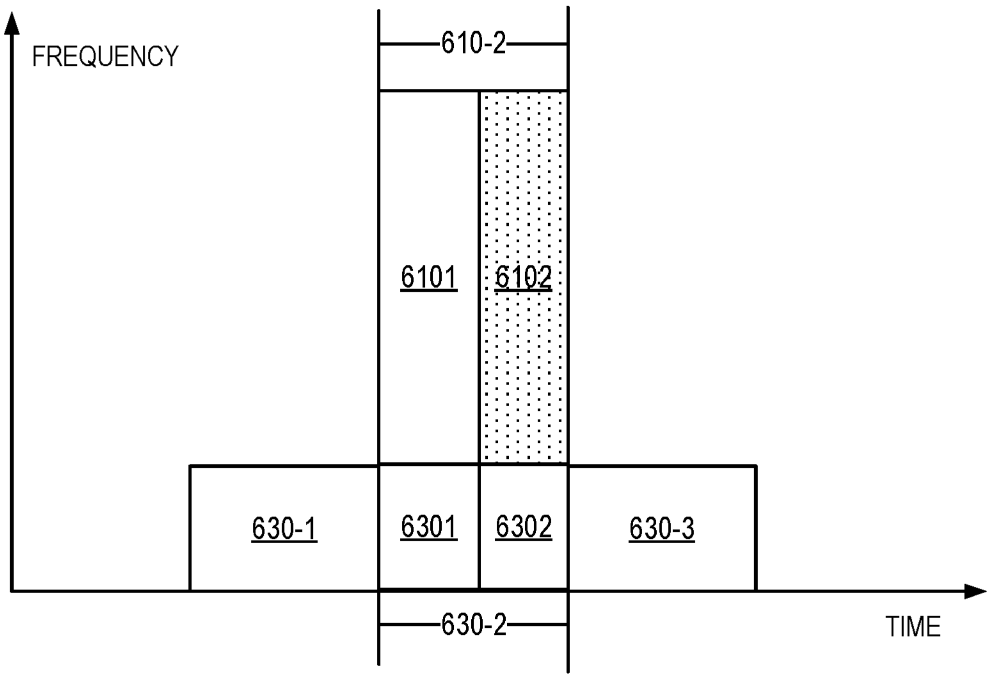
FREQUENCY
610-2
6101
6102
630-1
6301
6302
630-3
630-2
TIME

Fig. 7D

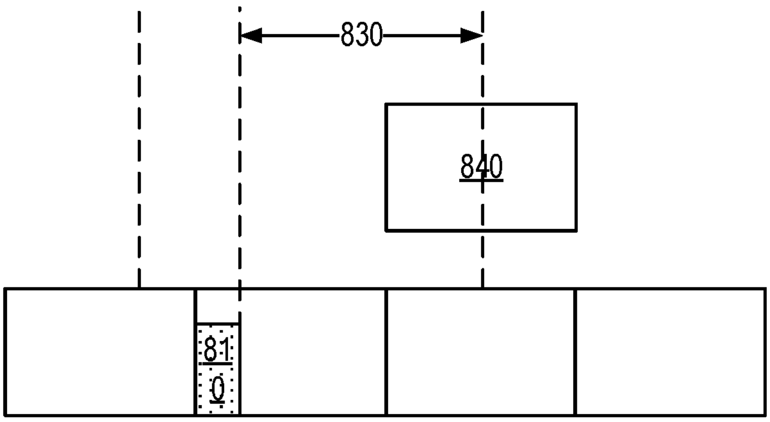

Fig. 8

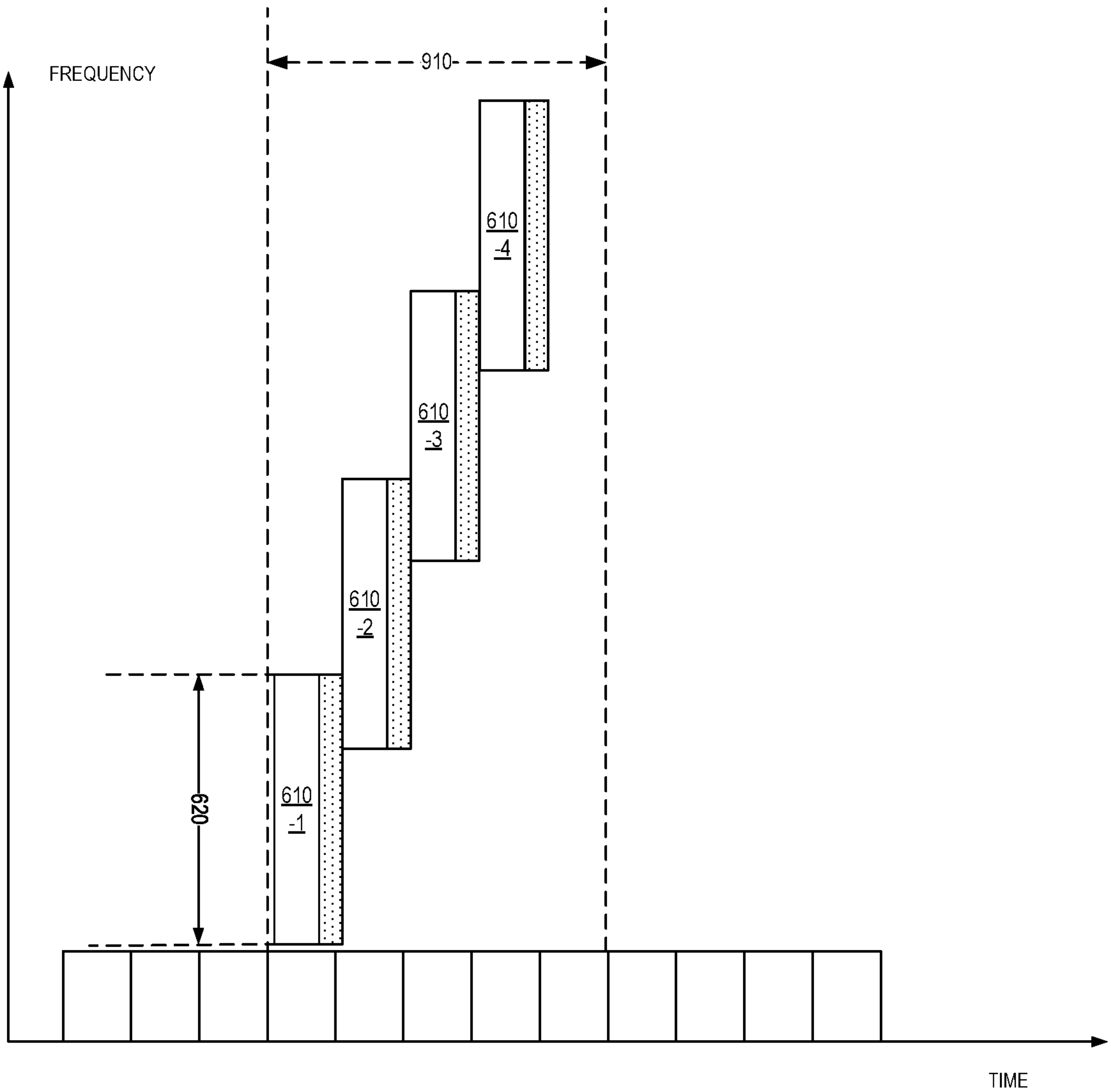

Fig. 9

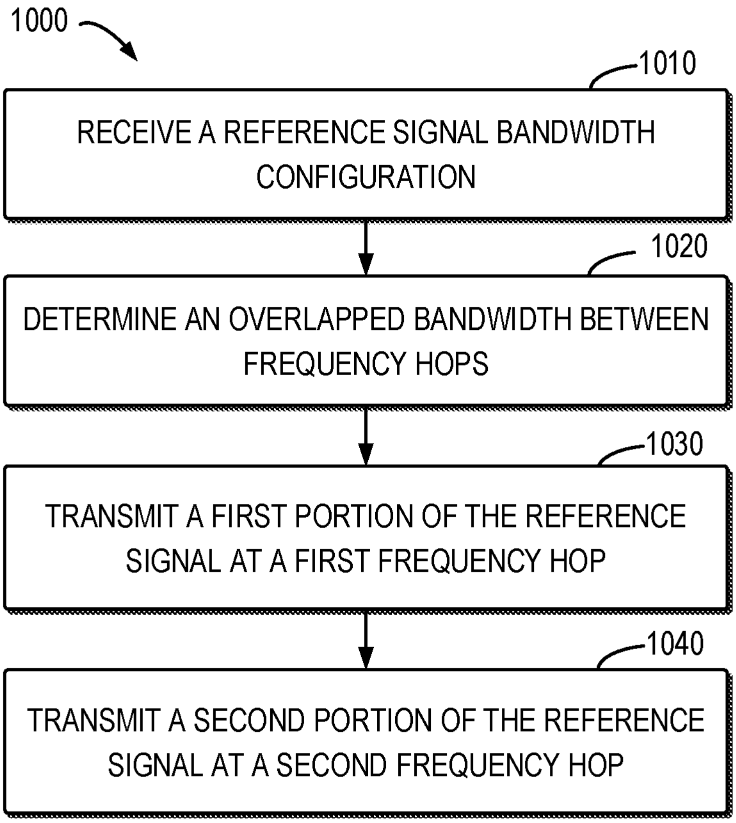
1000
1010
RECEIVE A REFERENCE SIGNAL BANDWIDTH CONFIGURATION
1020
DETERMINE AN OVERLAPPED BANDWIDTH BETWEEN FREQUENCY HOPS
1030
TRANSMIT A FIRST PORTION OF THE REFERENCE SIGNAL AT A FIRST FREQUENCY HOP
1040
TRANSMIT A SECOND PORTION OF THE REFERENCE SIGNAL AT A SECOND FREQUENCY HOP

Fig. 10

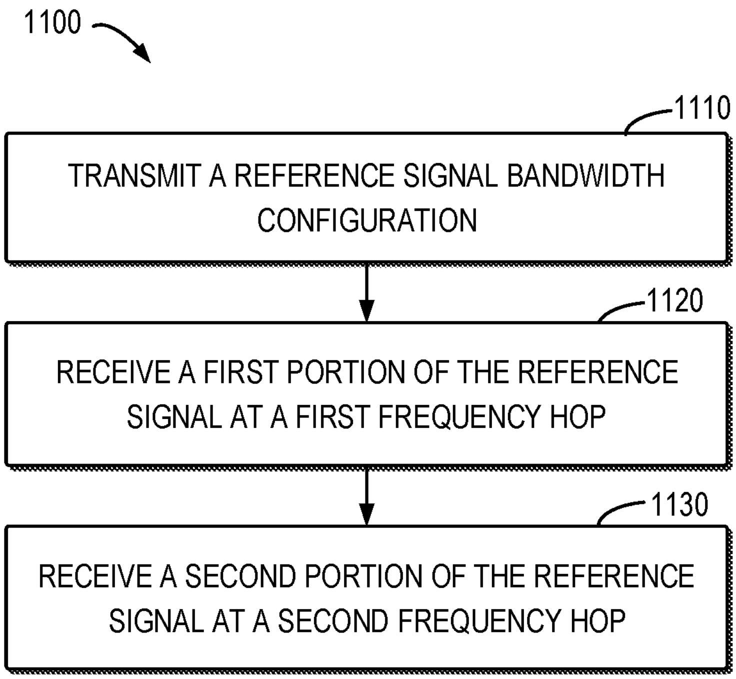
1100
1110
TRANSMIT A REFERENCE SIGNAL BANDWIDTH CONFIGURATION
1120
RECEIVE A FIRST PORTION OF THE REFERENCE SIGNAL AT A FIRST FREQUENCY HOP
1130
RECEIVE A SECOND PORTION OF THE REFERENCE SIGNAL AT A SECOND FREQUENCY HOP

Fig. 11

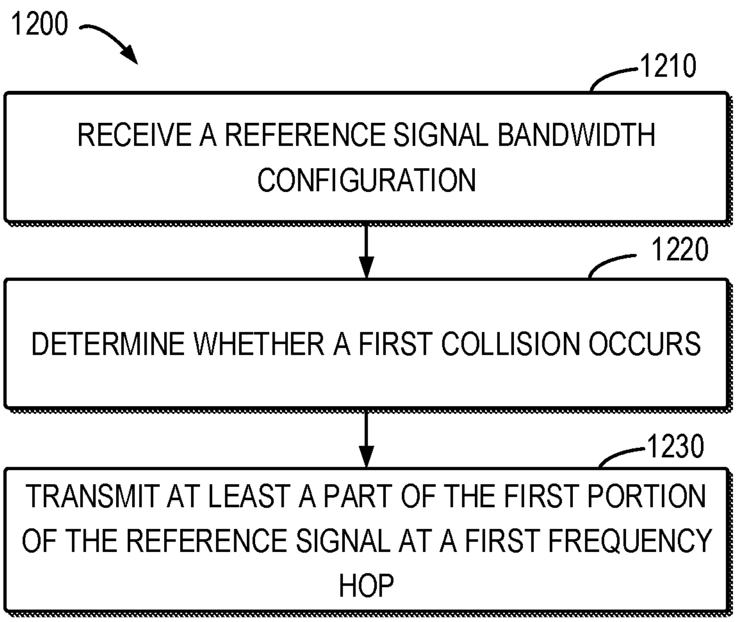
1200
1210
RECEIVE A REFERENCE SIGNAL BANDWIDTH CONFIGURATION
1220
DETERMINE WHETHER A FIRST COLLISION OCCURS
1230
TRANSMIT AT LEAST A PART OF THE FIRST PORTION OF THE REFERENCE SIGNAL AT A FIRST FREQUENCY HOP

Fig. 12

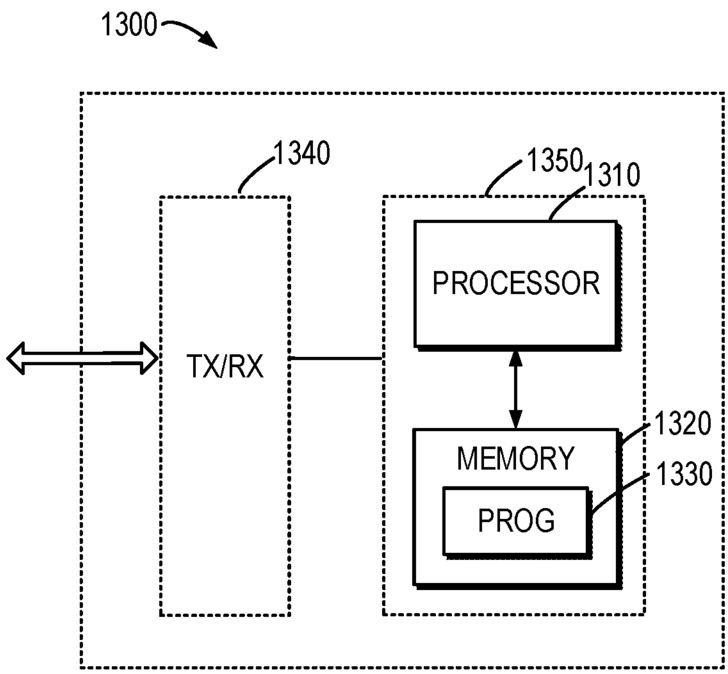
1300
1340
1350
1310
PROCESSOR
TX/RX
1320
MEMORY
1330
PROG

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/114936

A. CLASSIFICATION OF SUBJECT MATTER

H04L 5/00(2006.01)i;H04W 72/12(2023.01)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)

IPC: H04L,H04W

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

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

CNABS,CNTXT,VEN,ENTXT,3GPP: reference signal, RS, terminal, network device, bandwidth, configuration, frequency, hopping, overlay, first, second, transmit, portion, number, subband,index

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021178985 A2 (FUTUREWEI TECHNOLOGIES INC.) 10 September 2021 (2021-09-10) see description, page 15 line 17 to page 32 line 27, figures 4-13	1-16,26-28
Y	WO 2021178985 A2 (FUTUREWEI TECHNOLOGIES INC.) 10 September 2021 (2021-09-10) see description, page 15 line 17 to page 32 line 27, figures 4-13	17-25
Y	WO 2020164323 A1 (ZTE CORP.) 20 August 2020 (2020-08-20) see description, page 5 line 6 to page 19 line 15, figures 2-8	17-25
X	WO 2022036585 A1 (QUALCOMM INC.) 24 February 2022 (2022-02-24) see description, paragraphs [0137]-[0156], figures 12-14	1-16,26-28
X	CN 108632006 A (HUAWEI TECHNOLOGIES CO., LTD.) 09 October 2018 (2018-10-09) see description, paragraphs [0338]-[0606], figures 5-25	1-16,26-28
A	US 11329787 B2 (LG ELECTRONICS INC.) 10 May 2022 (2022-05-10) the whole document	1-28

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 May 2023	**10 May 2023**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**LI,ZhenHua** Telephone No. **(+86) 010-62087678**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Ericsson. "R1-2000237 "Correction of SRS bandwidth"" *3GPP tsg_ran\wg1_rl1,* No. tsgr1_100_e, 14 February 2020 (2020-02-14), pages 1-5	1-28

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/114936

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2021178985	A2	10 September 2021	WO	2021178985	A3	25 November 2021
WO	2020164323	A1	20 August 2020	AU	2019428888	A1	14 October 2021
				EP	3927001	A1	22 December 2021
				EP	3927001	A4	20 April 2022
WO	2022036585	A1	24 February 2022	None			
CN	108632006	A	09 October 2018	US	2021385113	A1	09 December 2021
				EP	3606219	A1	05 February 2020
				EP	3606219	A4	18 March 2020
				EP	3606219	B1	08 March 2023
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				JP	2020516134	A	28 May 2020
				JP	7217234	B2	02 February 2023
				US	2020021470	A1	16 January 2020
				US	11153134	B2	19 October 2021
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				KR	102308693	B1	05 October 2021
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				KR	20190127899	A	13 November 2019
				KR	102305312	B1	28 September 2021
				CA	3057550	A1	27 September 2018
				BR	112019019840	A2	22 April 2020
				CA	3057552	A1	27 September 2018
				EP	3605977	A1	05 February 2020
				EP	3605977	A4	26 February 2020
US	11329787	B2	10 May 2022	WO	2019066581	A1	04 April 2019
				US	2020280421	A1	03 September 2020