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(71) Applicant: **SHENZHEN TCL NEW TECHNOLOGY CO., LTD.** [CN/CN]; Building D4, TCL International E City No. 1001, Zhongshan Park Road, Xili Street, Nanshan District, Shenzhen, Guangdong 518052 (CN).

(72) Inventors: **LIU, Kai**; Building D4, TCL International E City No. 1001, Zhongshan Park Road, Xili Street, Nanshan District, Shenzhen, Guangdong 518052 (CN). **DENG, Yiwei**; Building D4, TCL International E City No. 1001, Zhongshan Park Road, Xili Street, Nanshan District, Shenzhen, Guangdong 518052 (CN).

(74) Agent: **PURPLEVINE INTELLECTUAL PROPERTY (SHENZHEN) CO., LTD.**; 2901, Block C, China Resources Land Building, Dachong Community, Yuehai Street, Nanshan District, Shenzhen, Guangdong 518052 (CN).

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performing VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a Bandwidth Part (BWP) in a SBFD duration

S110

Figure 7

(57) Abstract: A method of virtual resource blocks to physical resource blocks (VRB-to-PRB) interleaver in sub-band full duplex (SBFD) duration and related devices are provided. The method includes performing VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a first DL frequency domain and a second DL frequency domain in the SBFD duration. With the method, the VRB-to-PRB interleaver is enhanced for SBFD operation, which can benefit from less frequency selective fading.

METHOD OF VRB-TO-PRB INTERLEAVER, MEASUREMENT REPORT, AND SUBBAND PARTITION FOR SBFD OPERATION AND RELATED DEVICES**TECHNICAL FIELD**

The present invention relates to wireless communication technologies, and more particularly, to solutions to enhancements on SBFD operation, including a method of VRB-to-PRB interleaver, measurement report, and subband partition for SBFD operation, and related devices such as a user equipment (UE), and a transmission-reception point (TRP) or a base station (BS) in a network.

BACKGROUND ART

Communication systems and networks have developed towards being a broadband and mobile system. In cellular wireless communication systems developed by the Third Generation Partnership Project (3GPP), user equipment (UE) is connected by a wireless link to a radio access network (RAN). The RAN includes a set of base stations (BSs) which provide wireless links to the UEs located in cells covered by the base station, and an interface to a core network (CN) which provides overall network control. As will be appreciated, the RAN and CN each conduct respective functions in relation to the overall network. The 3GPP has developed the so-called Long Term Evolution (LTE) system, namely, an Evolved Universal Mobile Telecommunication System Territorial Radio Access Network (E-UTRAN), for a mobile access network where one or more macro-cells are supported by a base station known as an eNodeB or eNB (evolved NodeB). Evolved from LTE, the so-called 5G or New radio (NR) systems where one or more cells are supported by a base station known as a gNB.

The 5G NR standard supports a multitude of different services each with very different requirements. These services include Enhanced Mobile Broadband (eMBB) for high data rate transmission, Ultra-Reliable Low Latency Communication (URLLC) for devices requiring low latency and high link reliability and Massive Machine-Type Communication (mMTC) to support a large number of low-power devices for a long life-time requiring highly energy efficient communication.

The diversified use cases and exponential growth of number of UEs in the next generation wireless communication system have increased the data traffic explosively which leads to the high requirements of spectral efficiency. In order to accomplish the requirements of high spectral efficiency, Time Division Duplex (TDD) system is widely adopted in commercial New Radio (NR) deployments. TDD system uses a single spectrum (frequency band) for downlink (DL) and uplink (UL) in different time slots and utilizes the available spectrum more efficiently as compared to the Frequency Division Duplex (FDD) system.

In conventional TDD system, the time domain resources are split between the downlink (DL), uplink (UL) and flexible slots/symbols, where the flexible slots/symbols can be used as DL, UL or as a guard period for DL-UL switching. Allocation of a limited time duration for uplink in conventional TDD would result in reduced coverage, increased latency and reduced capacity. In order to enhance the limitations of conventional TDD operation, 3GPP RAN working group approves a study item in Rel-18, which focus on the feasibility of simultaneous existence of DL and UL, a.k.a. full duplex, or more specifically, sub-band non-overlapping full duplex operation within a conventional TDD band. In sub-band full duplex (SBFD) operation, gNB is operated in full duplex, i.e. the simultaneous DL and UL transmission occurs at gNB side only while the UE operates in half duplex. The study item has specified the objectives regarding the sub-band non-overlapping full duplex and dynamic/flexible TDD operation.

SUMMARY

In a first aspect, an embodiment of the present invention provides a method of virtual resource blocks to physical resource blocks (VRB-to-PRB) interleaver in sub-band full duplex (SBFD) duration, the method comprising:

performing VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a Bandwidth Part (BWP) in a SBFD duration.

In a second aspect, an embodiment of the present invention provides a method of virtual resource blocks to physical resource blocks (VRB-to-PRB) interleaver in sub-band full duplex (SBFD) duration, the method comprising: receiving downlink (DL) signals on PRBs of PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration, wherein resource blocks (RBs) are interleaved and VRB bundles are mapped to the PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration.

In a third aspect, an embodiment of the present invention provides a method of receiving measurement report for sub-band full duplex (SBFD) operation, the method comprising: informing to a user equipment (UE) with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively.

In a fourth aspect, an embodiment of the present invention provides a method of measurement reporting for sub-band full duplex (SBFD) operation, the method comprising: being informed with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively.

In a fifth aspect, an embodiment of the present invention provides a method of subband partition for sub-band full duplex (SBFD) operation the method comprising: dividing subbands in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules.

In a sixth aspect, an embodiment of the present invention provides a method of subband partition for sub-band full duplex (SBFD) operation the method comprising: receiving or transmitting signals using subbands, which are divided in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules.

In a seventh aspect, an embodiment of the present invention provides a TRP, including a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of any of the first aspect, the third aspect and the fifth aspect.

In an eighth aspect, an embodiment of the present invention provides a UE, including a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of any of the second aspect, the fourth aspect and the sixth aspect.

In a ninth aspect, an embodiment of the present invention provides a computer readable storage medium provided for storing a computer program, which enables a computer to execute the method of any of the first to the sixth aspects.

In a tenth aspect, an embodiment of the present invention provides a computer program product, which includes computer program instructions enabling a computer to execute the method of any of the first to the sixth aspects.

In an eleventh aspect, an embodiment of the present invention provides a computer program, when running on a computer, enabling the computer to execute the method of any of the first to the sixth aspects.

DESCRIPTION OF DRAWINGS

In order to more clearly illustrate the embodiments of the present invention or related art, the following figures that will be described in the embodiments are briefly introduced. It is obvious that the drawings are merely some embodiments of the present invention, a person having ordinary skill in this field can obtain other figures according to these figures without paying the premise.

Figure 1 is a schematic diagram illustrating an example of VRB-to-PRB interleaver with $L = 2$ in the existing art.

Figure 2 is a schematic diagram illustrating an existing VRB-to-PRB interleaver which is not applicable to SBFD operation.

Figure 3 is a schematic diagram illustrating an example of frequency resource partition of SBFD operation in some embodiments of the present invention.

Figure 4 is a schematic block diagram illustrating a communication network system according to an embodiment of the present invention.

Figure 5 is a schematic diagram illustrating radio protocol architecture within TRP (or gNB) and UE.

Figure 6 is a schematic diagram illustrating a gNB further including a centralized unit (CU) and a plurality of distributed unit (DUs).

Figure 7 is a flowchart of a method of VRB-to-PRB interleaver in SBFD duration according to some embodiments of the present invention.

Figure 8 is a schematic diagram illustrating an example of the result of VRB-to-PRB interleaver according to some embodiments of the present invention.

Figure 9 is a schematic diagram illustrating another example of the result of VRB-to-PRB interleaver according to some embodiments of the present invention.

Figure 10 is a schematic diagram illustrating still another example of the result of VRB-to-PRB interleaver according to some embodiments of the present invention.

Figure 11 is a flowchart of a method of receiving measurement report for SBFD operation according to some embodiments of the present invention.

Figure 12 is a schematic diagram illustrating an example of non-SBFD and SBFD based antenna port pattern according to some embodiments of the present invention.

Figure 13 is a schematic diagram illustrating an example of procedure of CSI measurement and report for non-SBFD and SBFD operation according to some embodiments of the present invention.

Figure 14 is a schematic diagram illustrating an example of different antenna port patterns in different SBFD duration according to some embodiments of the present invention.

Figure 15 is a schematic diagram illustrating application time of an indicated antenna port pattern for SBFD operation for activation information which does not need to be confirmed according to some embodiments of the present invention.

Figure 16 is a schematic diagram illustrating application time of an indicated antenna port pattern for SBFD operation for activation information which needs to be confirmed according to some embodiments of the present invention.

Figure 17 is a flowchart of a method of subband partition for SBFD operation according to some embodiments of the present invention.

Figure 18 is a schematic diagram illustrating an example of subband partition for SBFD operation according to some embodiments of the present invention.

Figure 19 is a schematic diagram illustrating another example of subband partition for SBFD operation according to some embodiments of the present invention.

Figure 20 is a schematic diagram illustrating still another example of subband partition for SBFD operation according to some embodiments of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Embodiments of the disclosure are described in detail with the technical matters, structural features, achieved objects, and effects with reference to the accompanying drawings as follows. Specifically, the terminologies in the embodiments of the present invention are merely for describing the purpose of the certain embodiment, but not to limit the invention.

A combination such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” or “A, B, and/or C” may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, where any combination may contain one or more members of A, B, or C.

In Rel-15/16/17, VRB-to-PRB interleaver is a way to resist frequency selective fading for PDSCH transmission. For a BWP, $N_{Bundle} = \lceil (N_{BWP}^{size} + (N_{BWP}^{size} \bmod L)) / L \rceil$, where L donates as the number of RB within a RB bundle and the values of L are 2 or 4. The number of RBs within a RB bundle should be continuous. The size of the first RB bundle (num. 0) is $L - (N_{BWP}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle} - 1$) is $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod L$ if $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle is L . The VRB bundles with num. $j \in \{0, 1, \dots, N_{Bundle}-1\}$ map to the PRB bundles according to the following manner:

- Num. $N_{Bundle}-1$ VRB bundle maps to Num. $N_{Bundle}-1$ PRB bundle.
- Num. $j \in \{0, 1, \dots, N_{Bundle}-2\}$ VRB bundle map to num. $f(j)$ PRB bundle according to the following formula.
- $f(j) = rC + c, j = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2$ for $L = 2, C = \lfloor N_{Bundle} / R \rfloor$.

Figure 1 shows an example with $L = 2$.

For SBFD operation, there are not only DL frequency resource but also UL frequency resource in SBFD duration. When VRB-to-PRB interleaver is performed, some DL RB will be located in UL frequency domain, as shown in Figure 2. In this case, the DL RB cannot be transmitted, otherwise it will disturb UL transmissions. Therefore, the VRB-to-PRB interleaver should be enhanced for SBFD operation.

In Rel-15/16/17, a UE measures Channel State Information Reference Signal (CSI-RS) and obtains Channel Status Information (CSI) including Rank Indicator (RI), Precoding Matrix Indicator (PMI), Channel Quality Indicator (CQI) and so on. Then the UE reports the CSI to a base station. The base station transmits Physical Downlink Shared CHannel (PDSCH) with precoding to the UE according to PMI in CSI. PMI is significantly related to the antenna port pattern on a base station.

Assuming that there are N antenna ports on the base station and M antennas on the UE, the CSI-RS with N ports is transmitted from the base station to the UE according to $y^{CSI-RS} = H^{CSI-RS} x^{CSI-RS} + N$, where H^{CSI-RS} is the channel matrix of CSI-RS and the size of H^{CSI-RS} is $M \times N$. The UE can speculate the channel matrix of PDSCH H^{PDSCH} according to H^{CSI-RS} . Then the UE speculates the right singular matrix of H^{PDSCH} and chooses the most closet matrix P corresponding to RI in the codebook. The size of P is $N \times RI$. Then the UE reports the index of P (PMI). Assuming that the base station adopts the reported matrix, the PDSCH with precoding transmitted from the base station to the UE according to $y^{PDSCH} = H^{PDSCH} P x^{PDSCH} + N$. It should be noted that the PDSCH with precoding transmitted by the base station is $P x^{PDSCH}$ in this formula whose size is $N \times 1$. Therefore, no matter the RI is, precoding matrix P determines that each of the N ports on the base station will transmit signal simultaneously which is part of PDSCH with precoding and the number of ports of PDSCH with precoding is the same as that of CSI-RS.

The codebook is usually defined as a set of DFT vectors with oversampling, which can be written as

$$\left\{ \begin{bmatrix} 1 \\ e^{j\frac{2\pi n}{NO}} \\ \vdots \\ e^{j\frac{2\pi n}{NO}(N-1)} \end{bmatrix}, n = 0, 1, \dots, NO - 1 \right\},$$

where N is the number of antenna ports on the base station and O is the number of oversampling between two antenna ports. The total number of DFT vectors in a set is $N*O$. The UE chooses one or more indexes of DFT vectors to report. One of DFT vectors should use $\log_2[NO]$ to indicate. Therefore, the reported indexes are related to the number of antenna ports and oversampling. The above discussion only considers one-dimension antenna port pattern. In practice, the antenna port pattern is two-dimension with dual polarizations, such that different antenna port patterns should be considered.

In DL duration in legacy TDD configuration, the base station uses all the configured antenna ports to perform PDSCH transmission. For SBFD operation at base station side, there are not only DL frequency resource but also UL frequency resource in SBFD duration. That means the base station will transmit and receive signals simultaneously in SBFD duration. The non-SBFD duration is the same as the legacy TDD configuration. Because of UL sub-bands in SBFD duration, the base station should use a part of antenna ports to receive UL signals. The base station can only use the rest antenna ports to transmit DL signals. Therefore, from non-SBFD duration to SBFD duration, the antenna port pattern is changed. This change will significantly affect PMI choice and report.

In Rel-15/16/17, a UE is configured via RRC signalling with one of two possible subband sizes for CSI reporting. A subband is defined as N_{PRB}^{SB} contiguous PRBs and depends on the total number PRBs in BWP according to Table 1 below. The first subband size is given by $N_{PRB}^{SB} - (N_{BWP}^{start} \bmod N_{PRB}^{SB})$. The last subband size given by $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod N_{PRB}^{SB}$ if $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod N_{PRB}^{SB} \neq 0$ and N_{PRB}^{SB} if $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod N_{PRB}^{SB} = 0$.

Table 1. Configurable subband sizes

BWP (PRBs)	Subband size (PRBs)
24 - 72	4, 8
73 - 144	8, 16
145 - 275	16, 32

For SBFD operation at base station side, there are not only DL frequency resources but also UL frequency resources in SBFD duration. The UL frequency resources will significantly affect the subband partition in SBFD duration. Therefore, the subband partition should be enhanced for SBFD operation.

Except for those legacy BWP allocations defined by Rel-15/16/17, a new frequency domain partition within legacy BWP would be defined to support SBFD operation in the wireless system. One set of signaling can be added, by which the UE can distinguish the transmission direction of configured frequency domain within a BWP in a SBFD duration. Therefore, here one SBFD specific frequency domain partition type may be used and informed to UE.

The set of signaling may include some frequency parameters of SBFD operation about DL, UL and guard subband. The unit of the frequency information can be RB or Hz. The frequency parameters about DL band can be the start frequency of DL subband (N_{subDL1}^{start} or N_{subDL2}^{start}) and the frequency size of DL subband (N_{subDL1}^{size} or N_{subDL2}^{size}). The frequency parameters about UL band can be the start frequency of UL subband (N_{subUL}^{start}) and the frequency size of UL subband (N_{subUL}^{size}). The frequency parameters about guard band can be the frequency size of guard subband (N_{guard}^{size}). These SBFD parameters have relationship with BWP parameters, as shown in Figure 3. For example, $N_{BWP}^{start} = N_{subDL1}^{start}$, $N_{BWP}^{size} = N_{subDL1}^{size} + N_{subDL2}^{size} + N_{subUL}^{size} + 2N_{guard}^{size}$. Therefore, UE can deduce the rest parameters about frequency resource partition of SBFD operation according to the informed parameters.

The present invention is related to a wireless communication system. Specifically, the idea mainly focuses on the enhancements about VRB-to-PRB interleaver, (CSI related) antenna port pattern and (CSI) subband partition for

subband full duplex (SBFD) operation. With this disclosure, the SBFD operation can benefit from less frequency selective fading and more accurate CSI feedback.

The present invention can be summarized as follows, but is not limited thereto:

1. To enhance VRB-to-PRB interleaver in SBFD duration, the following embodiments are proposed.

In an embodiment, the VRBs in the first and second DL frequency domain are respectively arranged to the VRB bundles. The VRB bundles in the first and second DL frequency domain respectively perform legacy interleaver, then map to the PRB bundles.

In another embodiment, the VRBs in the first and second DL frequency domain are respectively arranged to the VRB bundles. The VRB bundles in the first and second DL frequency domain, which are nearest to the UL/guard frequency domain directly map to the PRB bundles in the first DL and second DL frequency domain. The rest VRB bundles in the first and second DL frequency domain jointly connect to perform legacy interleaver, then map to the PRB bundles.

In still another embodiment, the VRBs in the first and second DL frequency domain are respectively arranged to the VRB bundles. Firstly, estimate the number of VRBs in the VRB bundles in the first and second frequency domain. If the number of VRBs is less than a configured value, the VRB bundles directly map to the PRB bundle. If the number of VRBs is equal to the configured value, the VRB bundles perform legacy interleaver, then map to the PRB bundles.

In yet another embodiment, the VRBs in the first and second DL frequency domain are jointly arranged to the VRB bundles. Firstly, estimate whether one of VRBs in the VRB bundles is in the UL/guard frequency domain and estimate whether all VRBs in the VRB bundles are in the DL frequency domain. The VRB bundle, which has one of VRBs in the UL/guard frequency domain, directly map to the PRB bundles. The VRB bundle, which has all VRBs in the DL frequency domain, perform legacy interleaver, then map to the PRB bundles.

2. To enhance antenna port configuration for SBFD operation, the following embodiments are proposed.

In an embodiment, base station sends the SBFD specific antenna port configuration (e.g. an antenna port pattern) to UE via RRC signaling. UE receives the reference signal and performs measurement in SBFD duration according to the configuration. UE feedbacks the measurement results according to the configuration.

In another embodiment, base station sends the SBFD specific antenna port configuration (e.g. a list of antenna port pattern) to UE via RRC signaling, and then sends the activation information to UE via MAC CE or DCI. UE receives the reference signal and performs measurement in SBFD duration according to the activation information. UE feedbacks the measurement results according to the activation information.

3. To enhance subband partition of CSI report for SBFD operation, the following embodiments are proposed.

In an embodiment, the sizes of the first and second DL frequency domain respectively determine the subband sizes in the first and second DL frequency domain.

In another embodiment, the sum of the sizes of the first and second DL frequency domain determine the subband size in the first and second DL frequency domain.

In still another embodiment, the size of BWP determines the subband size in the first and second DL frequency domain.

Figure 4 illustrates that, in some embodiments, one or more user equipments (UEs) 10, a first transmission/reception point (TRP) or base station 20 and a second TRP or base station 30 for wireless communication in a communication network system according to an embodiment of the present invention are provided. The communication network system includes the one or more UEs 10, the first TRP (or base station) 20 and the second TRP (or base station) 30. The one or more UEs 10 may include a memory 12, a transceiver 13, and a processor 11

coupled to the memory 12 and the transceiver 13. The first TRP 20 may include a memory 22, a transceiver 23, and a processor 21 coupled to the memory 22 and the transceiver 23. The second TRP 30 may include a memory 32, a transceiver 33, and a processor 31 coupled to the memory 32 and the transceiver 33. The processor 11 or 21 or 31 may be configured to implement proposed functions, procedures and/or methods described in this description. Layers of radio interface protocol may be implemented in the processor 11 or 21 or 31. The memory 12 or 22 or 32 is operatively coupled with the processor 11 or 21 or 31 and stores a variety of information to operate the processor 11 or 21 or 31. The transceiver 13 or 23 or 33 is operatively coupled with the processor 11 or 21 or 31, and the transceiver 13 or 23 or 33 transmits and/or receives a radio signal. The first TRP 20 (and the second TRP 30) and a next generation core network (5GCN) may also communicate with each other either wirelessly or in a wired way. When the communication network system complies with the New Radio (NR) standard of the 3rd Generation Partnership Project (3GPP), the next generation core network is a backend serving network system and may include an Access and Mobility Management Function (AMF), User Plane Function (UPF), and a Session Management Function (SMF). In one aspect, the user equipment can include almost any consumer electronic device or appliance that can connect to a radio access network and a core network for the releases of 3GPP and further, such as, but not limited to NR networks.

The processor 11 or 21 or 31 may include application-specific integrated circuit (ASIC), other chipset, logic circuit and/or data processing device. The memory 12 or 22 or 32 may include read-only memory (ROM), random access memory (RAM), flash memory, memory card, storage medium and/or other storage device. The transceiver 13 or 23 or 33 may include baseband circuitry to process radio frequency signals. When the embodiments are implemented in software, the techniques described herein can be implemented with modules (e.g., procedures, functions, and so on) that perform the functions described herein. The modules can be stored in the memory 12 or 22 or 32 and executed by the processor 11 or 21 or 31. The memory 12 or 22 or 32 can be implemented within the processor 11 or 21 or 31 or external to the processor 11 or 21 or 31 in which case those can be communicatively coupled to the processor 11 or 21 or 31 via various means as is known in the art. The user plane radio protocol architecture within the TRP (or gNB) and UE is shown in Figure 5, which includes optional Service Data Adaptation Protocol (SDAP), Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), Medium Access Control (MAC). In RAN functional split, a gNB further includes a centralized unit (CU) and a plurality of distributed unit (DUs) as shown in Figure 6. The protocol stack of CU includes an RRC layer, an optional SDAP layer, and a PDCP layer, while the protocol stack of DU includes an RLC layer, a MAC layer, and a PHY layer. The F1 interface between the CU and DU is established between the PDCP layer and the RLC layer.

Figure 7 is a flowchart of a method 100 of enhancing VRB-to-PRB interleaver in SBFD duration according to some embodiments of the present invention. Referring to Figure 7 in conjunction with Figure 4, the method 100 can be performed by a TRP or a base station. In the method 100, simultaneous downlink (DL) and uplink (UL) transmission occurs in the SBFD duration at the TRP or base station side. The method 100 includes the followings. In Step 110, the TRP or base station performs VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a Bandwidth Part (BWP) in a SBFD duration. The BWP may include a first DL frequency domain and a second DL frequency domain in the SBFD duration for the DL transmission, and an UL frequency domain for the UL transmission. The first DL frequency domain and the second DL frequency domain separated apart from each other by the UL frequency domain. The BWP may further include a first guard frequency domain located between the first DL frequency domain and the UL frequency domain, and a second guard frequency domain located between the second DL frequency domain and the UL frequency domain. The VRB-to-PRB interleaver may be performed in the first DL frequency domain and the second DL frequency domain respectively or may be

performed by combining the first DL frequency domain and the second DL frequency domain. Furthermore, the VRBs in the first DL frequency domain and the second DL frequency domain may be respectively arranged to the VRB bundles or may be jointly arranged to the VRB bundles.

At user equipment (UE) side, the UE performs a corresponding method, in which the UE receives downlink (DL) signals on PRBs of PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration, wherein resource blocks (RBs) are interleaved and VRB bundles are mapped to the PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration.

With the above-described methods, the VRB-to-PRB interleaver is enhanced for SBFD operation, which can benefit from less frequency selective fading.

In some embodiments, in a case that the VRB-to-PRB interleaver is performed in the first DL frequency domain, the number of RB bundles in the first DL frequency domain and in the second DL frequency domain is calculated, the number of RBs in each RB bundle is calculated, and the VRB bundles in the first DL frequency domain and second DL frequency domain respectively perform interleaver and then map to the PRB bundles.

In some embodiments, in a case that the VRB-to-PRB interleaver is performed by combining the first DL frequency domain and the second DL frequency domain, the number of RB bundles in the first DL frequency domain and in the second DL frequency domain is calculated, the number of RBs in each RB bundle is calculated, the VRB bundle in the first DL frequency domain which is nearest to an uplink (UL) frequency domain or a first guard frequency domain directly map to the PRB bundles in the first DL frequency domain, the VRB bundle in the second DL frequency domain which is nearest to the UL frequency domain or a second guard frequency domain directly map to the PRB bundles in the second DL frequency domain, and the rest VRB bundles in the first DL frequency domain and the second DL frequency domain jointly connect to perform interleaver and then map to the PRB bundles.

Alternatively, in a case that the VRB-to-PRB interleaver is performed by combining the first DL frequency domain and the second DL frequency domain, the number of VRBs in the VRB bundle in the first DL frequency domain which is nearest to an UL frequency domain or a first guard frequency domain and the number of VRBs in the VRB bundle in the second DL frequency domain which is nearest to the UL frequency domain or a second guard frequency domain are determined; if the number of VRBs in the VRB bundle in the first DL frequency domain or the second DL frequency domain which is nearest to the UL frequency domain or the first guard frequency domain or the second guard frequency domain is less than a configured value, the VRB bundles directly map to the PRB bundles in the first DL frequency domain and the second DL frequency domain; and if the number of VRBs is equal to the configured value, the VRB bundles perform interleaver and then map to the PRB bundles.

In some embodiments, in a case that the VRB-to-PRB interleaver is performed by combining the first DL frequency domain and the second DL frequency domain and the VRBs in the first DL frequency domain and the second DL frequency domain are jointly arranged to the VRB bundles, the VRB-to-PRB interleaver is performed in the BWP including the first DL frequency domain, the second DL frequency domain and the UL frequency domain. The number of RB bundles in the BWP is calculated based on the size of the BWP. The number of RBs in each RB bundle is calculated. Whether one of VRBs in the VRB bundle is in the UL frequency domain is determined and whether all VRBs in the VRB bundle are in the first DL frequency domain or the second DL frequency domain is determined, and the VRB bundle, which has one of VRBs in the UL frequency domain, directly maps to the PRB bundle, and the VRB bundle, which has all VRBs in the first DL frequency domain or the second DL frequency domain, performs interleaver and then maps to the PRB bundle.

Further details on enhancing VRB-to-PRB interleaver in SBFD duration are provided below.

In a first possible implementation, it is proposed to respectively perform VRB-to-PRB interleaver in different DL frequency domain in SBFD duration. For the first DL frequency domain, $N_{Bundle1} = \lceil (N_{subDL1}^{size} + (N_{subDL1}^{size} \bmod L)) / L \rceil$, where L donates as the number of RB within a RB bundle configured in higher parameters and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the first DL frequency domain is $L - (N_{subDL1}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle1} - 1$) in the first DL frequency domain is $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod L$ if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the first DL frequency domain is L . The VRB bundles with num. $j \in \{0, 1, \dots, N_{Bundle1} - 1\}$ map to the PRB bundles according to the following manner:

- Num. $N_{Bundle1} - 1$ VRB bundle maps to Num. $N_{Bundle1} - 1$ PRB bundle in the first DL frequency domain.
- Num. $j \in \{0, 1, \dots, N_{Bundle1} - 2\}$ VRB bundle map to num. $f(j)$ PRB bundle in the first DL frequency domain according to the following formula.
- $f(j) = rC + c$, $j = cR + r$, $r = 0, 1, \dots, R - 1$, $c = 0, 1, \dots, C - 1$, $R = 2$, $C = \lfloor N_{Bundle1} / R \rfloor$.

For the second DL frequency domain, $N_{Bundle2} = \lceil (N_{subDL2}^{size} + (N_{subDL2}^{size} \bmod L)) / L \rceil$, where L donates as the number of RB within a RB bundle and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the second DL frequency domain is $L - (N_{subDL2}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle2} - 1$) in the second DL frequency domain is $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod L$ if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the second DL frequency domain is L . The VRB bundles with num. $j \in \{0, 1, \dots, N_{Bundle2} - 1\}$ map to the PRB bundles according to the following manner.

- Num. $N_{Bundle2} - 1$ VRB bundle maps to Num. $N_{Bundle2} - 1$ PRB bundle in the second DL frequency domain.
- Num. $j \in \{0, 1, \dots, N_{Bundle2} - 2\}$ VRB bundle map to num. $f(j)$ PRB bundle in the second DL frequency domain according to the following formula.
- $f(j) = rC + c$, $j = cR + r$, $r = 0, 1, \dots, R - 1$, $c = 0, 1, \dots, C - 1$, $R = 2$, $C = \lfloor N_{Bundle2} / R \rfloor$.

For the UL frequency domain, num. $j \in \{N_{subUL}^{start}, N_{subUL}^{start} + 1, \dots, N_{subUL}^{size} - 1\}$ VRBs map to num. $k \in \{N_{subUL}^{start}, N_{subUL}^{start} + 1, \dots, N_{subUL}^{size} - 1\}$ PRBs one-by-one. For the guard frequency domain, if any, the similar one-by-one mapping manner is performed. The mapping procedure in the UL frequency domain and the guard frequency domain is not indispensable when performing VRB-to-PRB interleaver.

Figure 8 shows an example of the result of VRB-to-PRB interleaver described above. In this example, guard bands are neglected.

In a second possible implementation, it is proposed to perform VRB-to-PRB interleaver across different DL frequency domain in SBFD duration. For the first DL frequency domain, $N_{Bundle1} = \lceil (N_{subDL1}^{size} + (N_{subDL1}^{size} \bmod L)) / L \rceil$, where L donates as the number of RB within a RB bundle configured in higher parameters and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the first DL frequency domain is $L - (N_{subDL1}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle1} - 1$) in the first DL frequency domain is $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod L$ if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the first DL frequency domain is L . For the second DL frequency domain, $N_{Bundle2} = \lceil (N_{subDL2}^{size} + (N_{subDL2}^{size} \bmod L)) / L \rceil$, where L donates as the number of RB within a RB bundle and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the second DL frequency domain is $L - (N_{subDL2}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle2} - 1$) in the second DL frequency domain is $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod L$ if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the second DL frequency domain

is L . The total number of VRB bundles across two DL frequency domains is $N_{\text{Bundle1}} + N_{\text{Bundle2}}$. The VRB bundles with num. $j \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1\}$ map to the PRB bundles according to the following manner:

- Num. $N_{\text{Bundle1}} - 1$ VRB bundle maps to num. $N_{\text{Bundle1}} - 1$ PRB bundle across two DL frequency domains.
- Num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} PRB bundle across two DL frequency domains.
- Num. $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$ VRB bundle maps to Num. $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$ PRB bundle across two DL frequency domains.
- Num. $j \in \{0, 1, \dots, N_{\text{Bundle1}} - 2, N_{\text{Bundle1}} + 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2\}$ VRB bundle renumber to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 4\}$, or num. $j \in \{0, 1, \dots, N_{\text{Bundle1}} - 2, N_{\text{Bundle1}} + 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2\}$ VRB bundle map to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 4\}$ first medium RB bundle.
- Num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 4\}$ VRB bundle or first medium RB bundle map to num. $f(j')$ second medium RB bundle according to the following formula.
- $f(j') = rC + c$, $j' = cR + r$, $r = 0, 1, \dots, R - 1$, $c = 0, 1, \dots, C - 1$, $R = 2$, $C = \lfloor (N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2) / R \rfloor$.
- Num. $f(j') \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 4\}$ second medium RB bundle map to num. $j'' \in \{0, 1, \dots, N_{\text{Bundle1}} - 2, N_{\text{Bundle1}} + 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2\}$ PRB bundle across two DL frequency domains.

Num. 0 VRB bundle across two DL frequency domain is the first VRB bundle in the first DL frequency domain. Num. $N_{\text{Bundle1}} - 1$ VRB bundle across two DL frequency domain is the last VRB bundle in the first DL frequency domain and is the nearest to the UL/guard frequency domain. Num. N_{Bundle1} VRB bundle across two DL frequency domain is the first VRB bundle in the second DL frequency domain and is the nearest to the UL/guard frequency domain. Num. $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$ VRB bundle is the last VRB bundle in the second DL frequency domain.

For the UL frequency domain, num. $j \in \{N_{\text{subUL}}^{\text{start}}, N_{\text{subUL}}^{\text{start}} + 1, \dots, N_{\text{subUL}}^{\text{size}} - 1\}$ VRBs map to num. $k \in \{N_{\text{subUL}}^{\text{start}}, N_{\text{subUL}}^{\text{start}} + 1, \dots, N_{\text{subUL}}^{\text{size}} - 1\}$ PRBs one-by-one. For the guard frequency domain, if any, the similar one-by-one mapping manner is performed. The mapping procedure in the UL frequency domain and the guard frequency domain is not indispensable when performing VRB-to-PRB interleaver.

Figure 9 shows an example of the result of VRB-to-PRB interleaver described above. In this example, guard bands are neglected.

In a third possible implementation, it is proposed to perform VRB-to-PRB interleaver across different DL frequency domain in SBFD duration. For the first DL frequency domain, $N_{\text{Bundle1}} = \lfloor (N_{\text{subDL1}}^{\text{size}} + (N_{\text{subDL1}}^{\text{size}} \bmod L)) / L \rfloor$, where L donates as the number of RB within a RB bundle configured in higher parameters and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the first DL frequency domain is $L - (N_{\text{subDL1}}^{\text{start}} \bmod L)$. The size of the last RB bundle (num. $N_{\text{Bundle1}} - 1$) in the first DL frequency domain is $(N_{\text{subDL1}}^{\text{start}} + N_{\text{subDL1}}^{\text{size}}) \bmod L$ if $(N_{\text{subDL1}}^{\text{start}} + N_{\text{subDL1}}^{\text{size}}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the first DL frequency domain is L . For the second DL frequency domain, $N_{\text{Bundle2}} = \lfloor (N_{\text{subDL2}}^{\text{size}} + (N_{\text{subDL2}}^{\text{size}} \bmod L)) / L \rfloor$, where L donates as the number of RB within a RB bundle and the values of L are 2 or 4. The size of the first RB bundle (num. 0) in the second DL frequency domain is $L - (N_{\text{subDL2}}^{\text{start}} \bmod L)$. The size of the last RB bundle (num. $N_{\text{Bundle2}} - 1$) in the second DL frequency domain is $(N_{\text{subDL2}}^{\text{start}} + N_{\text{subDL2}}^{\text{size}}) \bmod L$ if $(N_{\text{subDL2}}^{\text{start}} + N_{\text{subDL2}}^{\text{size}}) \bmod L > 0$, otherwise is L . The size of the rest RB bundle in the second DL frequency domain is L . The total number of VRB bundles across two DL frequency domains is $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$. The VRB bundles with num. $j \in \{0, 1, \dots, N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1\}$ map to the PRB bundles according to the following manner:

- Num. $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$ VRB bundle maps to Num. $N_{\text{Bundle1}} + N_{\text{Bundle2}} - 1$ PRB bundle across two DL frequency domains.

- If the number of RB within num. $N_{\text{Bundle1}}-1$ VRB bundle is less than L , num. $N_{\text{Bundle1}}-1$ VRB bundle maps to num. $N_{\text{Bundle1}}-1$ PRB bundle across two DL frequency domains. If the number of RB within num. $N_{\text{Bundle1}}-1$ VRB bundle is equal to L , num. $N_{\text{Bundle1}}-1$ VRB bundle maps to num. $N_{\text{Bundle1}}-1$ first RB bundle across two DL frequency domains.
- If the number of RB within num. N_{Bundle1} VRB bundle is less than L , num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} PRB bundle across two DL frequency domains. If the number of RB within num. N_{Bundle1} VRB bundle is equal to L , num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} first RB bundle across two DL frequency domains.
- If the number of RB within num. $N_{\text{Bundle1}}-1$ and num. N_{Bundle1} VRB bundle is equal to L ,
 - ◆ num. $N_{\text{Bundle1}}-1$ VRB bundle maps to num. $N_{\text{Bundle1}}-1$ first RB bundle across two DL frequency domains,
 - ◆ num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} first RB bundle across two DL frequency domains,
 - ◆ num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle renumber to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$, or num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle map to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ first medium RB bundle.
 - ◆ Num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle or first medium RB bundle map to num. $f(j')$ second medium RB bundle according to the following formula.
 - ◆ $f(j') = rC + c, j' = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2, C = \lfloor (N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2)/R \rfloor$.
 - ◆ Num. $f(j') \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ second medium RB bundle map to num. $j'' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ PRB bundle across two DL frequency domains.
- If the number of RB within num. $N_{\text{Bundle1}}-1$ is equal to L and the number of RB within num. N_{Bundle1} VRB bundle is less than L ,
 - ◆ num. $N_{\text{Bundle1}}-1$ VRB bundle maps to num. $N_{\text{Bundle1}}-1$ first RB bundle across two DL frequency domains,
 - ◆ num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} PRB bundle across two DL frequency domains,
 - ◆ num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}-1, N_{\text{Bundle1}}+1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle renumber to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$, or num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}-1, N_{\text{Bundle1}}+1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle map to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$ first medium RB bundle.
 - ◆ Num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$ VRB bundle or first medium RB bundle map to num. $f(j')$ second medium RB bundle according to the following formula.
 - ◆ $f(j') = rC + c, j' = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2, C = \lfloor (N_{\text{Bundle1}} + N_{\text{Bundle2}} - 2)/R \rfloor$.
 - ◆ Num. $f(j') \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$ second medium RB bundle map to num. $j'' \in \{0, 1, \dots, N_{\text{Bundle1}}-1, N_{\text{Bundle1}}+1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ PRB bundle across two DL frequency domains.
- If the number of RB within num. $N_{\text{Bundle1}}-1$ is less than L and the number of RB within num. N_{Bundle1} VRB bundle is equal to L ,
 - ◆ num. $N_{\text{Bundle1}}-1$ VRB bundle maps to num. $N_{\text{Bundle1}}-1$ PRB bundle across two DL frequency domains,
 - ◆ num. N_{Bundle1} VRB bundle maps to num. N_{Bundle1} first RB bundle across two DL frequency domains,
 - ◆ num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}-2, N_{\text{Bundle1}}, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle renumber to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$, or num. $j \in \{0, 1, \dots, N_{\text{Bundle1}}-2, N_{\text{Bundle1}}, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-2\}$ VRB bundle map to num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$ first medium RB bundle.
 - ◆ Num. $j' \in \{0, 1, \dots, N_{\text{Bundle1}}+N_{\text{Bundle2}}-3\}$ VRB bundle or first medium RB bundle map to num. $f(j')$ second medium RB bundle according to the following formula.

- ◆ $f(j') = rC + c, j' = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2, C = \lfloor (N_{Bundle1} + N_{Bundle2} - 2)/R \rfloor$.
- ◆ Num. $f(j') \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 3\}$ second medium RB bundle map to num. $j'' \in \{0, 1, \dots, N_{Bundle1} - 2, N_{Bundle1} + N_{Bundle2} - 2\}$ PRB bundle across two DL frequency domains.
- If the number of RB within num. $N_{Bundle1} - 1$ and num. $N_{Bundle1}$ VRB bundle is less than L ,
 - ◆ num. $N_{Bundle1} - 1$ VRB bundle maps to num. $N_{Bundle1} - 1$ PRB bundle across two DL frequency domains,
 - ◆ num. $N_{Bundle1}$ VRB bundle maps to num. $N_{Bundle1}$ PRB bundle across two DL frequency domains,
 - ◆ Num. $j \in \{0, 1, \dots, N_{Bundle1} - 2, N_{Bundle1} + 1, \dots, N_{Bundle1} + N_{Bundle2} - 2\}$ VRB bundle renumber to num. $j' \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 4\}$, or num. $j \in \{0, 1, \dots, N_{Bundle1} - 2, N_{Bundle1} + 1, \dots, N_{Bundle1} + N_{Bundle2} - 2\}$ VRB bundle map to num. $j' \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 4\}$ first medium RB bundle.
 - ◆ Num. $j' \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 4\}$ VRB bundle or first medium RB bundle map to num. $f(j')$ second medium RB bundle according to the following formula.
 - ◆ $f(j') = rC + c, j' = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2, C = \lfloor (N_{Bundle1} + N_{Bundle2} - 2)/R \rfloor$.
 - ◆ Num. $f(j') \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 4\}$ second medium RB bundle map to num. $j'' \in \{0, 1, \dots, N_{Bundle1} - 2, N_{Bundle1} + 1, \dots, N_{Bundle1} + N_{Bundle2} - 2\}$ PRB bundle across two DL frequency domains.

Num. 0 VRB bundle across two DL frequency domain is the first VRB bundle in the first DL frequency domain. Num. $N_{Bundle1} - 1$ VRB bundle across two DL frequency domain is the last VRB bundle in the first DL frequency domain and is the nearest to the UL/guard frequency domain. Num. $N_{Bundle1}$ VRB bundle across two DL frequency domain is the first VRB bundle in the second DL frequency domain and is the nearest to the UL/guard frequency domain. Num. $N_{Bundle1} + N_{Bundle2} - 1$ VRB bundle is the last VRB bundle in the second DL frequency domain.

For the UL frequency domain, num. $j \in \{N_{subUL}^{start}, N_{subUL}^{start} + 1, \dots, N_{subUL}^{size} - 1\}$ VRBs map to num. $k \in \{N_{subUL}^{start}, N_{subUL}^{start} + 1, \dots, N_{subUL}^{size} - 1\}$ PRBs one-by-one. For the guard frequency domain, if any, the similar one-by-one mapping manner is performed. The mapping procedure in the UL frequency domain and the guard frequency domain is not indispensable when performing VRB-to-PRB interleaver.

In a fourth possible implementation, it is proposed to perform VRB-to-PRB interleaver across different DL frequency domain in SBF duration. For the BWP, $N_{Bundle} = \lfloor (N_{BWP}^{size} + (N_{BWP}^{size} \bmod L)) / L \rfloor$, where L donates as the number of RB within a RB bundle configured in higher parameters and the values of L are 2 or 4. The size of the first RB bundle (num. 0) is $L - (N_{BWP}^{start} \bmod L)$. The size of the last RB bundle (num. $N_{Bundle} - 1$) is $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod L$ if $(N_{BWP}^{start} + N_{BWP}^{size}) \bmod L > 0$, otherwise is L . If all VRBs within a VRB bundle are in the DL frequency domain, this kind of VRB bundles are called as DL VRB bundles. The number of these VRB bundles in the first DL frequency domain and in the second DL frequency domain is $N_{Bundle1}$ and $N_{Bundle2}$, respectively. The size of the rest RB bundle is L . If one of VRBs within a VRB bundle is in the UL frequency domain, the guard frequency domain, or both, this kind of VRB bundles are called as UL VRB bundles. The number of this kind of VRB bundles is denoted as $N_{Bundle3}$. So $N_{Bundle1} + N_{Bundle2} + N_{Bundle3} = N_{Bundle}$. The VRB bundles with num. $j \in \{0, 1, \dots, N_{Bundle} - 1\}$ map to the PRB bundles according to the following manner:

- Num. $j \in \{0, 1, \dots, N_{Bundle1} - 1\}$ DL VRB bundle maps to num. $j' \in \{0, 1, \dots, N_{Bundle1} - 1\}$ first medium RB bundle and num. $j \in \{N_{Bundle1} + N_{Bundle3} - 1, \dots, N_{Bundle1} + N_{Bundle3} + N_{Bundle2} - 1\}$ DL VRB bundle map to num. $j' \in \{N_{Bundle1}, \dots, N_{Bundle1} + N_{Bundle2} - 1\}$ first medium RB bundle.
- Num. $N_{Bundle1} + N_{Bundle2} - 1$ first medium RB bundle maps to num. $N_{Bundle1} + N_{Bundle2} - 1$ second medium bundle.
- Num. $j'' \in \{0, 1, \dots, N_{Bundle1} + N_{Bundle2} - 2\}$ first medium RB bundle map to num. $f(j'')$ the second medium

RB bundle according to the following formula.

- $f(j'') = rC + c, j'' = cR + r, r = 0, 1, \dots, R-1, c = 0, 1, \dots, C-1, R = 2, C = \lfloor N_{Bundle1} + N_{Bundle2} / R \rfloor$.
- Num. $f(j'') \in \{0, 1, \dots, N_{Bundle1}-1\}$ second medium RB bundle map to num. $k \in \{0, 1, \dots, N_{Bundle1}-1\}$ PRB bundle in the BWP.
- Num. $f(j'') \in \{N_{Bundle1}, \dots, N_{Bundle1} + N_{Bundle2} - 1\}$ second medium RB bundle map to num. $k \in \{N_{Bundle1} + N_{Bundle3} - 1, \dots, N_{Bundle1} + N_{Bundle3} + N_{Bundle2} - 1\}$ PRB bundle in the BWP.
- Num. $j \in \{N_{Bundle1}, \dots, N_{Bundle1} + N_{Bundle3} - 1\}$ UL VRB bundle map to num. $j' \in \{N_{Bundle1}, \dots, N_{Bundle1} + N_{Bundle3} - 1\}$ PRB bundle in the BWP. Here UL VRB bundle is a virtual concept which is convenient to partition RB bundle.

The mapping procedure in the UL frequency domain and the guard frequency domain is not indispensable when performing VRB-to-PRB interleaver.

Figure 10 shows an example of the result of VRB-to-PRB interleaver described above. In this example, guard bands are neglected.

Figure 11 is a flowchart of a method 200 of receiving measurement report for SBFD operation according to some embodiments of the present invention. Referring to Figure 11 in conjunction with Figure 4, the method 200 can be performed by a TRP or a base station. The method 200 includes the followings. In Step 210, the TRP or base station informs to a user equipment (UE) with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively. The SBFD or non-SBFD specific antenna port pattern may be configured via Radio Resource Control (RRC) signaling.

At user equipment (UE) side, the UE performs a corresponding method, in which the UE is informed with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively.

With the above-described methods, measurement report for SBFD operation can be realized, and SBFD operation can benefit from more accurate CSI feedback.

In some embodiments, zero padding bits are added in a Precoding Matrix Indicator (PMI) field in a measurement result associated with the SBFD operation. The number of zero padding bits equals to the number of PMI associated with non-SBFD operation minus the number of PMI associated with the SBFD operation.

In some embodiments, in a case that the SBFD specific antenna port configuration comprises a list of antenna port pattern, the method further comprises sending an activation information to the UE to activate one antenna port pattern in the list of antenna port pattern. The activation information may be sent via Media Access Control (MAC) Control Element (CE) or Downlink Control Information (DCI). For the activation information which does not need to be confirmed, if time point of the activation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately. For the activation information which does not need to be confirmed, if time point of the activation information plus a time offset is located in a SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

In some embodiments, in a case that the SBFD specific antenna port configuration comprises a list of antenna port patterns, the method further comprises sending an activation information to the UE to activate one antenna port pattern in the list of antenna port pattern; and receiving a confirmation information from the UE to confirm activation of the one antenna port pattern in the list of antenna port pattern. For the activation information which needs to be confirmed, if time point of the confirmation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately. For the activation information which needs to be

confirmed, if time point of the confirmation information plus a time offset is located in a SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

Further details on enhancing antenna port configuration for SBFD operation are provided below.

In a first possible implementation, except for those legacy antenna port patterns defined by Rel-15/16/17, a new antenna port pattern would be defined to support SBFD operation at base station side in the wireless system. One mark will be added to the antenna port pattern, by which the UE can distinguish the usage of the configuration of antenna port pattern for non-SBFD operation or SBFD operation etc. Therefore, here one SBFD specific antenna port pattern type is used and indicated to UE side. The type can be denoted as string, index or name. The detailed implementation is as shown in Table 2.

Table 2. Direct SBFD specific antenna port pattern configuration.

Indication method	Detail description
String	String is used to distinguish the antenna port pattern type, for example, "Non-SBFD based" which means the configuration is for non-SBFD operation; "SBFD based" which means the configuration is for SBFD operation.
ID	ID is used to distinguish the antenna port pattern type, for example , 0: the configuration is for non-SBFD operation; 1: the configuration is for SBFD operation.
Antenna port pattern name	Antenna port pattern name is used to distinguish the antenna port pattern type, for example , nrofAntennaPorts/n1-n2: the configuration is for non-SBFD operation; SBFD nrofAntennaPorts/n1-n2: the configuration is for SBFD operation.

In addition to those methodologies mentioned above, with direct indication to inform UE of the usage of the configuration, also the implicit indication method should be considered, as shown in the following.

nrOfAntennaPorts

SEQUENCE {

.....

n1-n2

CHOICE {

two-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (8)),

two-two-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (64)),

four-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (16)),

three-two-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (96)),

six-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (24)),

four-two-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (128)),

eight-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (32)),

four-three-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (192)),

six-two-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (192)),

twelve-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (48)),

four-four-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (256)),

eight-two-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (256)),

sixteen-one-TypeI-SinglePanel-Restriction

BIT STRING (SIZE (64))

},

n1-n2-SBFD

CHOICE {

two-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (8)),
two-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (64)),
four-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (16)),
three-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (96)),
six-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (24)),
four-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (128)),
eight-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (32)),
four-three-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),
six-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),
twelve-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (48)),
},	
.....	
},	

The configuration order is used to distinguish the usage of antenna port pattern. Take the case of single panel with Type I codebook as an example, the same for another case. The first antenna port pattern configuration 'n1-n2' is for non-SBFD operation. The second configuration 'n1-n2-SBFD' is for SBFD operation.

Figure 12 shows an example of non-SBFD and SBFD based antenna port pattern. For non-SBFD duration (DL), 'four-two-TypeI-SinglePanel-Restriction' is configured in 'n1-n2', so base station uses all antenna ports to transmit DL signals in non-SBFD duration (DL) (e.g. the first PDSCH). For SBFD duration, 'four-one-TypeI-SinglePanel-Restriction' is configured in 'n1-n2-SBFD', so base station uses the antenna ports at one row (e.g. the upper row) to transmit DL signals in SBFD duration (e.g. the second PDSCH) and uses the antenna ports at the other row (e.g. the lower row) to receive UL signals.

To support SBFD operation, a CSI report configuration can include two types of CSI-RS resources, respectively associated with non-SBFD operation and SBFD operation. The number of CSI-RS resources is not limited. One type of CSI-RS resources associated with non-SBFD operation means the CSI-RS resources in non-SBFD duration (DL). The other type of CSI-RS resources associated with SBFD operation means the CSI-RS resources in SBFD duration. Therefore, base station will use different antenna port patterns to transmit CSI-RS resources in different duration. Different antenna port pattern results in different number of bits of PMI. Different number of bits of PMI results in different size of a report about a CSI measurement result associated with a CSI-RS resource. Therefore, there are two types of CSI measurement result, respectively associated with non-SBFD operation and SBFD operation, in a CSI report configuration. UE will choose a CSI measurement result to report in a CSI report configuration. In this case, base station cannot know which CSI measurement result is reported by UE such that base station should perform blind detection because of two types of report sizes. Therefore, alignment between two types of report sizes can be adopted to avoid blind detection. By the way, base station can distinguish the type of CSI measurement results according CRI in the report, if base station decodes the report correctly.

Because the number of antenna ports for CSI measurement in SBFD duration is equal to or less than that in non-SBFD duration, the number of bits of PMI in CSI measurement results associated with SBFD operation is equal to or less than that associated with non-SBFD operation. Therefore, zero padding bits can add after PMI field in CSI measurement results associated with SBFD operation to align with PMI field in CSI measurement results associated with non-SBFD operation. The number of zero padding bits equals to the number of PMI associated with non-SBFD operation minus the number of PMI associated with SBFD operation.

Figure 13 shows an example of procedure of CSI measurement and report for non-SBFD and SBFD operation. For non-SBFD operation, $N_1 = 4$, $N_2 = 2$, $O_1 = 4$ and $O_2 = 4$. The number of bits of information X_1 in PMI associated with non-SBFD operation denote as $(\lceil \log_2 N_1 O_1 \rceil, \lceil \log_2 N_2 O_2 \rceil) = (4, 3)$, if *codebookMode* = 1. For SBFD operation, $N_1 = 4$, $N_2 = 1$, $O_1 = 4$ and $O_2 = 1$. The number of bits of information X_1 in PMI associated with SBFD operation denote as $(\lceil \log_2 N_1 O_1 \rceil, \lceil \log_2 N_2 O_2 \rceil) = (4, 0)$, if *codebookMode* = 1. The number of bits of other information in PMI associated with non-SBFD and SBFD operation is the same. Therefore, PMI associated with SBFD operation is 3 bit less than that with non-SBFD operation. 3 zero padding bits add after PMI filed associated with SBFD operation.

In a second possible implementation, it is proposed that the list of SBFD-specific antenna port patterns is configured via RRC signalling and the indication of a SBFD-specific antenna port pattern is used via MAC CE.

Considering different DL or UL traffic in different SBFD duration, the number of antenna ports in different SBFD duration for DL or UL transmission may be different. Different number of antenna ports leads to different antenna port pattern. Therefore, several alternative antenna port patterns for SBFD operation are configured to UE, then the activation information is transmitted to UE dynamically about which antenna port pattern is used for SBFD operation. The configuration of antenna port patterns for SBFD operation can be a list in RRC signalling, as shown in the following.

nrOfAntennaPorts	SEQUENCE {
.....	
n1-n2	CHOICE {
two-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (8)),
two-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (64)),
four-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (16)),
three-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (96)),
six-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (24)),
four-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (128)),
eight-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (32)),
four-three-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),
six-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),
twelve-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (48)),
four-four-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (256)),
eight-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (256)),
sixteen-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (64))
},	
n1-n2-SBFD	List {
two-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (8)),
two-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (64)),
four-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (16)),
three-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (96)),
six-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (24)),
four-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (128)),
eight-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (32)),
four-three-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),

six-two-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (192)),
twelve-one-TypeI-SinglePanel-Restriction	BIT STRING (SIZE (48)),
},	
.....	
},	

The dynamic activation information about which antenna port pattern is used for SBFD can be carried by PDSCH (MAC CE) or by PDCCH (DCI). The dynamic activation information can be a bitmap or an ID. Figure 14 shows an example of different antenna port patterns in different SBFD duration. As shown in Figure 14, if the first activation information is the ID with '0010', 'four-one-TypeI-SinglePanel-Restriction' is activated, so base station uses the antenna ports at one row (e.g. the upper row) to transmit DL signals in SBFD duration (e.g. the first PDSCH) and uses the antenna ports at the other row (e.g. the lower row) to receive UL signals; and if the activation information is the ID with '0001', 'two-two-TypeI-SinglePanel-Restriction' is activated, so base station uses the two antenna ports at one row (e.g. the upper row) and the two antenna ports at other row (e.g. the lower row) to transmit DL signals in SBFD duration (e.g. the second PDSCH) and uses the four antenna ports at the two rows (e.g. the upper row and the lower row) to receive UL signals.

Due to time of antenna switching, time offset and application time of antenna port pattern for SBFD operation should be defined. For activation information which does not need to be confirmed (e.g. DCI), if the time point of the activation information time plus time offset is not located in a SBFD duration, the indicated antenna port pattern for SBFD operation can be applied immediately, as shown in Figure 15(a). In this case, the application time is the time point of the activation information time plus time offset. If the time of the activation information time plus time offset is located in a SBFD duration, the indicated antenna port pattern for SBFD operation can be applied after this SBFD duration finishes, as shown in Figure 15(b). In this case, the application is the first time unit after the SBFD duration finishes. After the activation information time and before the application information time, the antenna port pattern indicated by the previous last activation information is used for SBFD operation.

For activation information which needs to be confirmed (e.g. MAC CE, DCI), if the time point of the confirmation information time plus time offset is not located in a SBFD duration, the indicated antenna port pattern for SBFD operation can be applied immediately, as shown in Figure 16(a). In this case, the application time is the time point of the confirmation information time plus time offset. If the time of the confirmation information time plus time offset is located in a SBFD duration, the indicated antenna port pattern for SBFD operation can be applied after this SBFD duration finishes, as shown in Figure 16(b). In this case, the application is the first time unit after the SBFD duration finishes. After the activation information time and before the application information time, the antenna port pattern indicated by the previous last activation information is used for SBFD operation.

Figure 17 is a flowchart of a method 300 of subband partition for SBFD operation according to some embodiments of the present invention. Referring to Figure 17 in conjunction with Figure 4, the method 300 can be performed by a TRP or a base station. In the method 300, simultaneous downlink (DL) and uplink (UL) transmission occurs in the SBFD duration at the TRP or base station side, and a first DL frequency domain and a second DL frequency domain in the SBFD duration for the DL transmission are separated by an UL frequency domain for the UL transmission. The method 300 includes the followings. In Step 310, the TRP or base station determines subbands in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules.

At user equipment (UE) side, the UE performs a corresponding method, in which the UE determines subbands in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules.

With the above-described methods, subband partition is enhanced for SBFD operation.

In some embodiments, subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on the sizes of the first DL frequency domain and the second DL frequency domain, respectively.

In some embodiments, subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on a sum of the sizes of the first DL frequency domain and the second DL frequency domain.

In some embodiments, subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on the size of BWP.

Further details on enhancing subband partition of CSI report for SBFD operation are provided below.

In a first possible implementation, it is proposed to divide a BWP into subbands respectively in different DL frequency domain in SBFD duration. As illustrated in Figure 18, the first subband size in SBFD duration (N_{subDL1}^{SB}) is determined by the size of the first DL frequency domain (N_{subDL1}^{size}) according to configuration and Table 1. The first subband in the first DL frequency domain in SBFD duration is given by $N_{subDL1}^{SB} - (N_{subDL1}^{start} \bmod N_{subDL1}^{SB})$. The last subband size is given by $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL1}^{SB}$ if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL1}^{SB} \neq 0$ and N_{subDL1}^{SB} if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL1}^{SB} = 0$. The amount of subbands in the first DL frequency domain is $Q_{subDL1}^{SB} = \lceil (N_{subDL1}^{size} + (N_{subDL1}^{size} \bmod N_{subDL1}^{SB})) / N_{subDL1}^{SB} \rceil$. The first subband size (N_{subDL2}^{SB}) in the second DL frequency domain in SBFD duration is determined by the size of the second DL frequency domain (N_{subDL2}^{size}). The last subband size is given by $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL2}^{SB}$ if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL2}^{SB} \neq 0$ and N_{subDL2}^{SB} if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL2}^{SB} = 0$. The amount of subbands in the second DL frequency domain is $Q_{subDL2}^{SB} = \lceil (N_{subDL2}^{size} + (N_{subDL2}^{size} \bmod N_{subDL2}^{SB})) / N_{subDL2}^{SB} \rceil$.

In a second possible implementation, it is proposed to divide a BWP into subbands across different DL frequency domain in SBFD duration. As illustrated in Figure 19, the subband size in SBFD duration (N_{subDL}^{SB}) is determined by the sum of the sizes of the first DL frequency domain and the second frequency domain ($N_{subDL1}^{size} + N_{subDL2}^{size}$) according to configuration and Table 1. The first subband in the first DL frequency domain in SBFD duration is given by $N_{subDL1}^{SB} - (N_{subDL1}^{start} \bmod N_{subDL}^{SB})$. The last subband size given by $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL}^{SB}$ if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL}^{SB} \neq 0$ and N_{subDL}^{SB} if $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{subDL}^{SB} = 0$. The amount of subbands in the first DL frequency domain is $Q_{subDL1}^{SB} = \lceil (N_{subDL1}^{size} + (N_{subDL1}^{size} \bmod N_{subDL}^{SB})) / N_{subDL}^{SB} \rceil$. The first subband in the second DL frequency domain in SBFD duration is given by $N_{subDL2}^{SB} - (N_{subDL2}^{start} \bmod N_{subDL}^{SB})$. The last subband size given by $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL}^{SB}$ if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL}^{SB} \neq 0$ and N_{subDL}^{SB} if $(N_{subDL2}^{start} + N_{subDL2}^{size}) \bmod N_{subDL}^{SB} = 0$. The amount of subbands in the second DL frequency domain is $Q_{subDL2}^{SB} = \lceil (N_{subDL2}^{size} + (N_{subDL2}^{size} \bmod N_{subDL}^{SB})) / N_{subDL}^{SB} \rceil$.

In a third possible implementation, it is proposed to divide a BWP into subbands across different DL frequency domain in SBFD duration. As illustrated in Figure 20, the subband size in non-SBFD duration (N_{PRB}^{SB}) is determined by the BWP size (N_{BWP}^{size}) according to configuration and Table 1. The amount of subbands in non-SBFD duration is $Q^{SB} = \lceil (N_{BWP}^{size} + (N_{BWP}^{size} \bmod N_{PRB}^{SB})) / N_{PRB}^{SB} \rceil$. In SBFD duration, the same subband size is adopted as in non-SBFD operation. However, the first subband and the last subband in the first frequency domain and in the second frequency domain should be redefined. The first subband in the first DL frequency domain in SBFD duration is given by $N_{PRB}^{SB} - (N_{subDL1}^{start} \bmod N_{PRB}^{SB})$. The last subband size given by $(N_{subDL1}^{start} + N_{subDL1}^{size}) \bmod N_{PRB}^{SB}$ if $(N_{subDL1}^{start} +$

$N_{subDL1}^{Size}) \bmod N_{PRB}^{SB} \neq 0$ and N_{PRB}^{SB} if $(N_{subDL1}^{Start} + N_{subDL1}^{Size}) \bmod N_{PRB}^{SB} \neq 0$. The amount of subbands in the first DL frequency domain in SBFD duration is $Q_{subDL1}^{SB} = \lceil (N_{subDL1}^{size} + (N_{subDL1}^{size} \bmod N_{PRB}^{SB})) / N_{PRB}^{SB} \rceil$. The first subband in the second DL frequency domain in SBFD duration is given by $N_{PRB}^{SB} - (N_{subDL2}^{start} \bmod N_{PRB}^{SB})$. The last subband size given by $(N_{subDL2}^{Start} + N_{subDL2}^{Size}) \bmod N_{PRB}^{SB}$ if $(N_{subDL2}^{Start} + N_{subDL2}^{Size}) \bmod N_{PRB}^{SB} \neq 0$ and N_{PRB}^{SB} if $(N_{subDL1}^{Start} + N_{subDL1}^{Size}) \bmod N_{PRB}^{SB} \neq 0$. The amount of subbands in the second DL frequency domain in SBFD duration is $Q_{subDL2}^{SB} = \lceil (N_{subDL2}^{size} + (N_{subDL2}^{size} \bmod N_{PRB}^{SB})) / N_{PRB}^{SB} \rceil$.

Commercial interests for some embodiments are as follows. 1. Solving issues in the prior art. 2. Enhancing VRB-to-PRB interleaver for SBFD operation. 3. Realizing measurement report for SBFD operation. 4. Enhancing subband partition for SBFD operation. 5. Benefit from less frequency selective fading. 6. Benefit from more accurate CSI feedback. Some embodiments of the present invention are used by 5G-NR chipset vendors, V2X communication system development vendors, automakers including cars, trains, trucks, buses, bicycles, moto-bikes, helmets, and etc., drones (unmanned aerial vehicles), smartphone makers, communication devices for public safety use, AR/VR device maker for example gaming, conference/seminar, education purposes. Some embodiments of the present invention are a combination of “techniques/processes” that can be adopted in 3GPP specification to create an end product. Some embodiments of the present invention could be adopted in the 5G NR unlicensed band communications. Some embodiments of the present invention propose technical mechanisms.

The embodiment of the present invention further provides The embodiment of the present invention further provides a transmission-reception point (TRP) comprising a processor and a transmitter. The processor is configured to call and run program instructions stored in a memory, to execute corresponding processes implemented in each of the methods of the embodiment of the present invention. For brevity, details will not be described herein again.

The embodiment of the present invention further provides The embodiment of the present invention further provides a user equipment (UE) comprising a processor and a transmitter. The processor is configured to call and run program instructions stored in a memory, to execute corresponding processes implemented in each of the methods of the embodiment of the present invention. For brevity, details will not be described herein again.

The embodiment of the present invention further provides a computer readable storage medium for storing a computer program. The computer readable storage medium enables a computer to execute corresponding processes implemented by the UE/base station (BS)/TRP in each of the methods of the embodiment of the present invention. For brevity, details will not be described herein again.

The embodiment of the present invention further provides a computer program product including computer program instructions. The computer program product enables a computer to execute corresponding processes implemented by the UE/BS/TRP in each of the methods of the embodiment of the present invention. For brevity, details will not be described herein again.

The embodiment of the present invention further provides a computer program. The computer program enables a computer to execute corresponding processes implemented by the UE/BS/TRP in each of the methods of the embodiment of the present invention. For brevity, details will not be described herein again.

The non-transitory computer readable medium may include at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory. In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system using, for example,

removable storage drive. A control module (in this example, software instructions or executable computer program code), when executed by the processor in the computer system, causes a processor to perform the functions of the invention as described herein.

Furthermore, the inventive concept can be applied to any circuit for performing signal processing functionality within a network element. It is further envisaged that, for example, a semiconductor manufacturer may employ the inventive concept in a design of a stand-alone device, such as a microcontroller of a digital signal processor (DSP), or application-specific integrated circuit (ASIC) and/or any other sub-system element.

A person of ordinary skill in the art may be aware that, in combination with the examples described in the embodiments disclosed in this specification, units and algorithm steps may be implemented by electronic hardware or a combination of computer software and electronic hardware. Whether the functions are performed by hardware or software depends on particular applications and design constraint conditions of the technical solutions. A person skilled in the art may use different approaches to implement the described functions for each particular application, but it should not be considered that the implementation goes beyond the scope of the present invention.

While the present invention has been described in connection with what is considered the most practical and preferred embodiments, it is understood that the present invention is not limited to the disclosed embodiments but is intended to cover various arrangements made without departing from the scope of the broadest interpretation of the appended claims.

CLAIMS

1. A method of virtual resource blocks to physical resource blocks (VRB-to-PRB) interleaver in sub-band full duplex (SBFD) duration, the method comprising:

performing VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a Bandwidth Part (BWP) in a SBFD duration.

2. The method of claim 1, wherein the BWP comprises a first downlink (DL) frequency domain and a second DL frequency domain separated apart from each other.

3. The method of claim 2, wherein the VRB-to-PRB interleaver is performed in the first DL frequency domain and the second DL frequency domain, respectively.

4. The method of claim 3, wherein the number of RB bundles in the first DL frequency domain and in the second DL frequency domain is calculated based on the size of the first DL frequency domain and the second frequency domain, respectively.

5. The method of claim 4, wherein the number of RBs in each RB bundle is calculated.

6. The method of claim 5, wherein the VRB bundles in the first DL frequency domain and second DL frequency domain respectively perform interleaver and then map to the PRB bundles.

7. The method of claim 2, wherein the VRB-to-PRB interleaver is performed by combining the first DL frequency domain and the second DL frequency domain.

8. The method of claim 7, wherein the number of RB bundles in the first DL frequency domain and in the second DL frequency domain is calculated based on the size of the first DL frequency domain and the second frequency domain, respectively.

9. The method of claim 8, wherein the number of RBs in each RB bundle is calculated.

10. The method of claim 9, wherein the VRB bundle in the first DL frequency domain which is nearest to an uplink (UL) frequency domain or a first guard frequency domain of the BWP directly map to the PRB bundles in the first DL frequency domain, the VRB bundle in the second DL frequency domain which is nearest to the UL frequency domain or a second guard frequency domain directly map to the PRB bundles in the second DL frequency domain, and the rest VRB bundles in the first DL frequency domain and the second DL frequency domain jointly connect to perform interleaver and then map to the PRB bundles.

11. The method of claim 9, wherein the number of VRBs in the VRB bundle in the first DL frequency domain which is nearest to an UL frequency domain or a first guard frequency domain of the BWP and the number of VRBs in the VRB bundle in the second DL frequency domain which is nearest to the UL frequency domain or a second guard frequency domain are determined;

12. The method of claim 11, wherein if the number of VRBs in the VRB bundle in the first DL frequency domain or the second DL frequency domain which is nearest to the UL frequency domain or the first guard frequency domain or the second guard frequency domain is less than a configured value, the VRB bundles directly map to the PRB bundles in the first DL frequency domain and the second DL frequency domain; and if the number of VRBs is equal to the configured value, the VRB bundles perform interleaver and then map to the PRB bundles.

13. The method of claim 2, wherein the number of RB bundles in the BWP is calculated based on the size of the BWP.

14. The method of claim 13, the number of RBs in each RB bundle is calculated.

15. The method of claim 14, wherein the BWP further comprises a UL frequency domain, whether one of VRBs in the VRB bundle is in the UL frequency domain is determined and whether all VRBs in the VRB bundle are in the

first DL frequency domain or the second DL frequency domain is determined, and the VRB bundle, which has one of VRBs in the UL frequency domain, directly maps to the PRB bundle, and the VRB bundle, which has all VRBs in the first DL frequency domain or the second DL frequency domain, performs interleaver and then maps to the PRB bundle.

16. The method of claim 2, wherein the BWP further comprises a UL frequency domain, and for the UL frequency domain, the VRBs map to the PRBs one by one.

17. The method of claim 2, wherein the BWP further comprises a guard frequency domain and a UL frequency domain, the guard frequency domain is arranged between the UL frequency domain and the first DL frequency domain or between the UL frequency domain and the second DL frequency domain, and for the guard frequency domain, the VRBs map to the PRBs one by one.

18. A method of virtual resource blocks to physical resource blocks (VRB-to-PRB) interleaver in sub-band full duplex (SBFD) duration, the method comprising:

receiving downlink (DL) signals on PRBs of PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration, wherein resource blocks (RBs) are interleaved and VRB bundles are mapped to the PRB bundles in the first DL frequency domain and the second DL frequency domain in the SBFD duration.

19. A transmission-reception point (TRP), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of any of claims 1 to 17.

20. A user equipment (UE), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of claim 18.

21. A method of receiving measurement report for sub-band full duplex (SBFD) operation, the method comprising:

informing to a user equipment (UE) with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively.

22. The method of claim 21, wherein the type of antenna port pattern, which is SBFD specific or non-SBFD specific, is informed by a string, an index or a name.

23. The method of claim 21, wherein the type of antenna port pattern, which is SBFD specific or non-SBFD specific, is informed by an implicit indication.

24. The method of claim 21, wherein zero padding bits are added in a Precoding Matrix Indicator (PMI) field in a measurement result associated with the SBFD operation.

25. The method of claim 24, wherein the number of zero padding bits equals to the number of PMI associated with non-SBFD operation minus the number of PMI associated with the SBFD operation.

26. The method of claim 21, wherein the SBFD or non-SBFD specific antenna port pattern is configured via Radio Resource Control (RRC) signaling.

27. The method of claim 21, wherein the SBFD specific antenna port pattern is included in a list of antenna port pattern.

28. The method of claim 27, wherein the list of antenna port pattern are configured via Radio Resource Control (RRC) signaling.

29. The method of claim 28, further comprising:

sending an activation information to the UE to activate one antenna port pattern in the list of antenna port pattern.

30. The method of claim 29, wherein the activation information is sent via Media Access Control (MAC) Control Element (CE) or Downlink Control Information (DCI).

31. The method of claim 29, wherein if time point of the activation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately.

32. The method of claim 29, wherein if time point of the activation information plus a time offset is located in a SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

33. The method of claim 29, further comprising:

receiving a confirmation information from the UE to confirm activation of the one antenna port pattern in the list of antenna port pattern.

34. The method of claim 33, wherein for the activation information which needs to be confirmed, if time point of the confirmation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately.

35. The method of claim 33, wherein for the activation information which needs to be confirmed, if time point of the confirmation information plus a time offset is located in a SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

36. A transmission-reception point (TRP), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of any of claims 21 to 35.

37. A method of measurement reporting for sub-band full duplex (SBFD) operation, the method comprising:

being informed with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for downlink (DL) transmission in SBFD or non-SBFD duration, respectively.

38. The method of claim 37, wherein the type of antenna port pattern, which is SBFD specific or non-SBFD specific, is informed by a string, an index or a name.

39. The method of claim 37, wherein the type of antenna port pattern, which is SBFD specific or non-SBFD specific, is informed by an implicit indication.

40. The method of claim 37, wherein zero padding bits are added in a Precoding Matrix Indicator (PMI) field in a measurement result associated with the SBFD operation.

41. The method of claim 40, wherein the number of zero padding bits equals to the number of PMI associated with non-SBFD operation minus the number of PMI associated with the SBFD operation.

42. The method of claim 37, wherein the SBFD or non-SBFD specific antenna port pattern is configured via Radio Resource Control (RRC) signaling.

43. The method of claim 37, wherein the SBFD specific antenna port pattern is included in a list of antenna port pattern.

44. The method of claim 43, wherein the list of antenna port pattern are configured via Radio Resource Control (RRC) signaling.

45. The method of claim 44, further comprising:

receiving an activation information to activate one antenna port pattern in the list of antenna port pattern.

46. The method of claim 45, wherein the activation information is sent via Media Access Control (MAC) Control Element (CE) or Downlink Control Information (DCI).

47. The method of claim 45, wherein if time point of the activation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately.

48. The method of claim 45, wherein if time point of the activation information plus a time offset is located in a

SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

49. The method of claim 45, further comprising:

transmitting a confirmation information to confirm activation of the one antenna port pattern in the list of antenna port pattern.

50. The method of claim 49, wherein for the activation information which needs to be confirmed, if time point of the confirmation information plus a time offset is out of the SBFD duration, the activated antenna port pattern for the SBFD operation is applied immediately.

51. The method of claim 49, wherein for the activation information which needs to be confirmed, if time point of the confirmation information plus a time offset is located in a SBFD duration, the activated antenna port pattern for the SBFD operation is applied after the located SBFD duration finished.

52. A user equipment (UE), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of claims 37 to 51.

53. A method of subband partition for sub-band full duplex (SBFD) operation the method comprising:

determining subbands in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules.

54. The method of claim 53, wherein subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on the sizes of the first DL frequency domain and the second DL frequency domain, respectively.

55. The method of claim 53, wherein subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on a sum of the sizes of the first DL frequency domain and the second DL frequency domain.

56. The method of claim 53, wherein subband sizes in the first DL frequency domain and the second DL frequency domain in the SBFD duration are determined based on the size of BWP.

57. A transmission-reception point (TRP), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of any of claims 53 to 56.

58. A user equipment (UE), comprising a processor and a transmitter, wherein the processor is configured to call and run program instructions stored in a memory, to execute the method of claims 53 to 56.

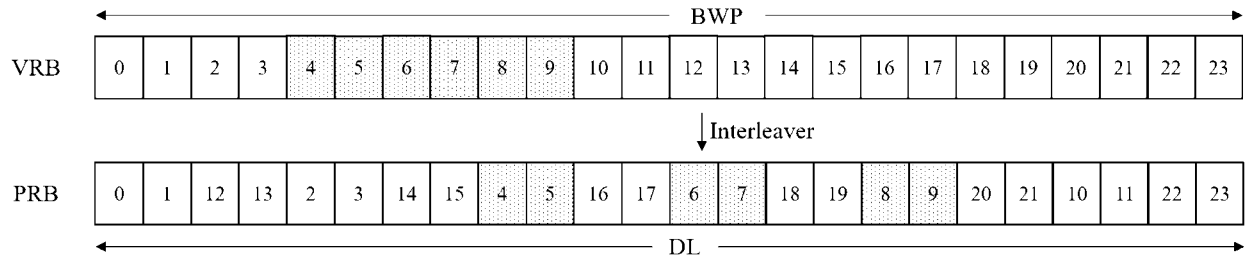


Figure 1

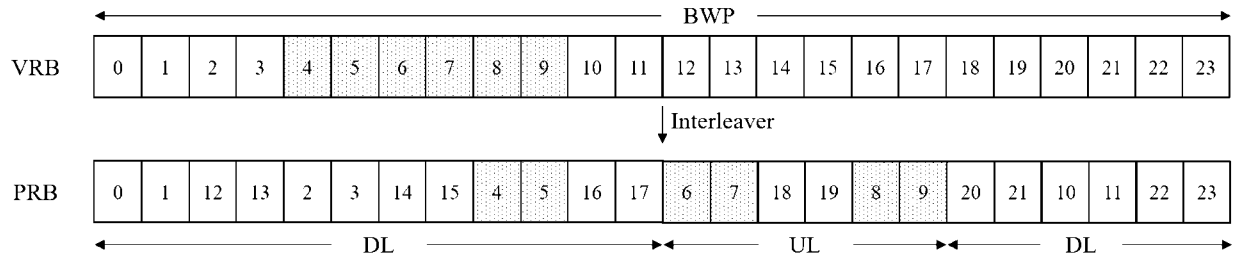


Figure 2

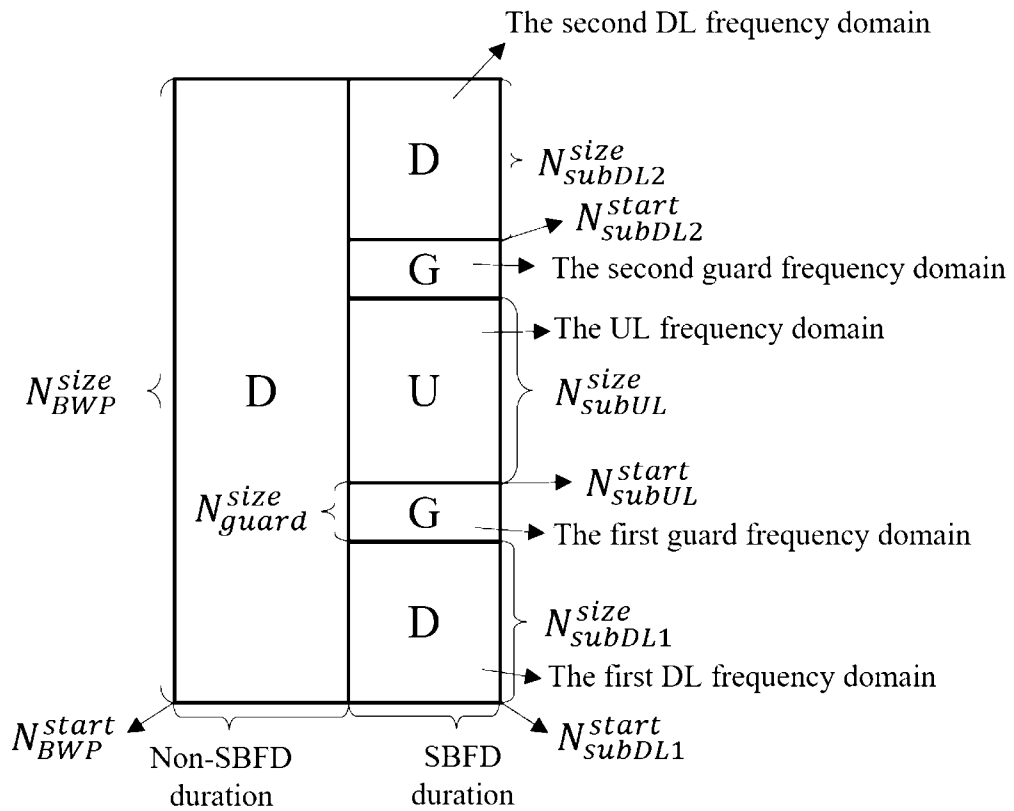


Figure 3

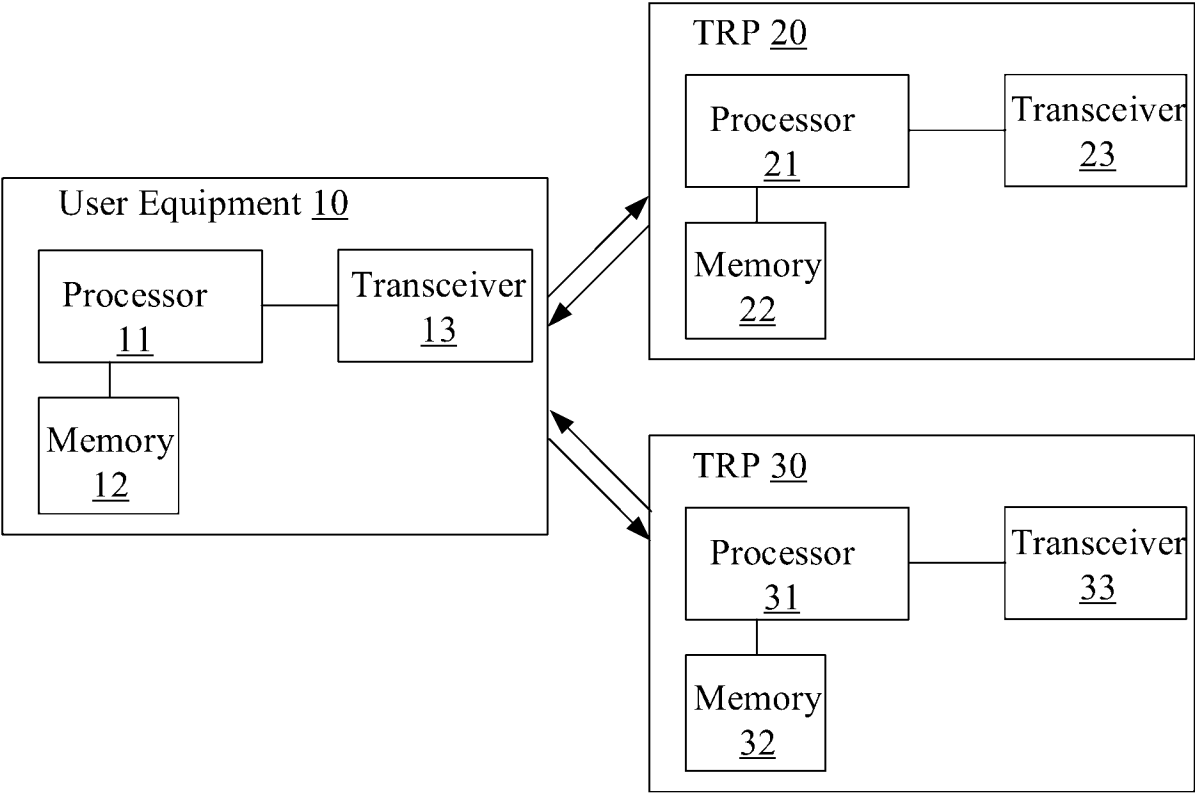


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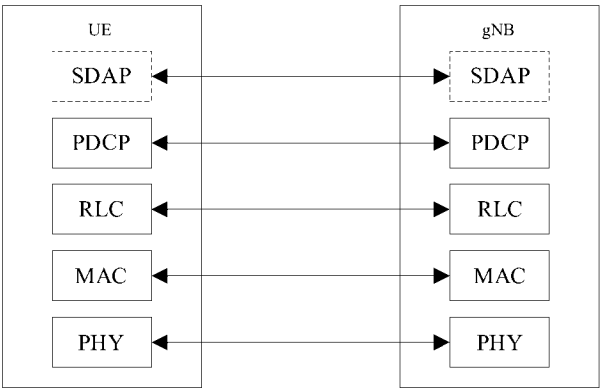


Figure 5

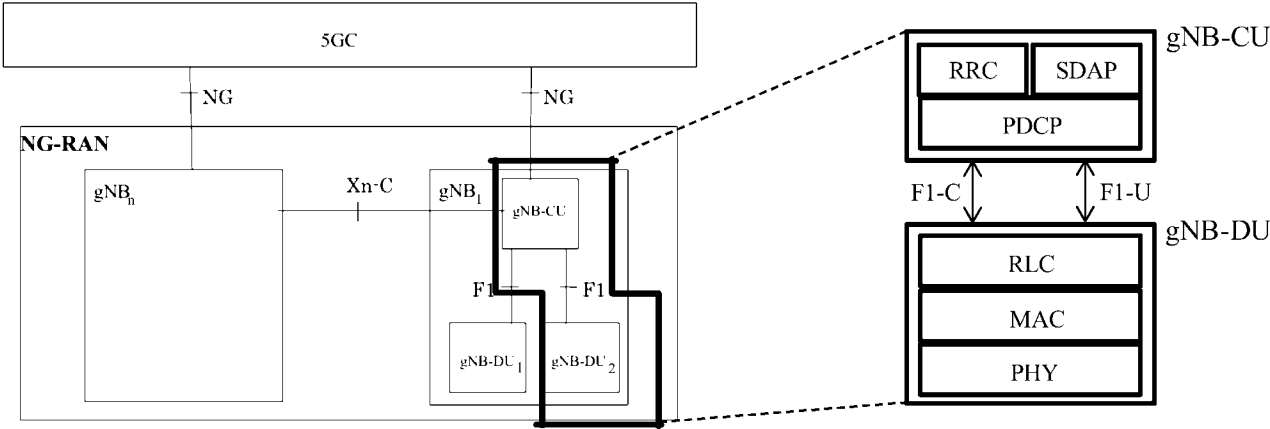


Figure 6

100

performing VRB-to-PRB interleaver to interleave resource blocks (RBs) and map VRB bundles to PRB bundles in a Bandwidth Part (BWP) in a SBFD duration S110

Figure 7

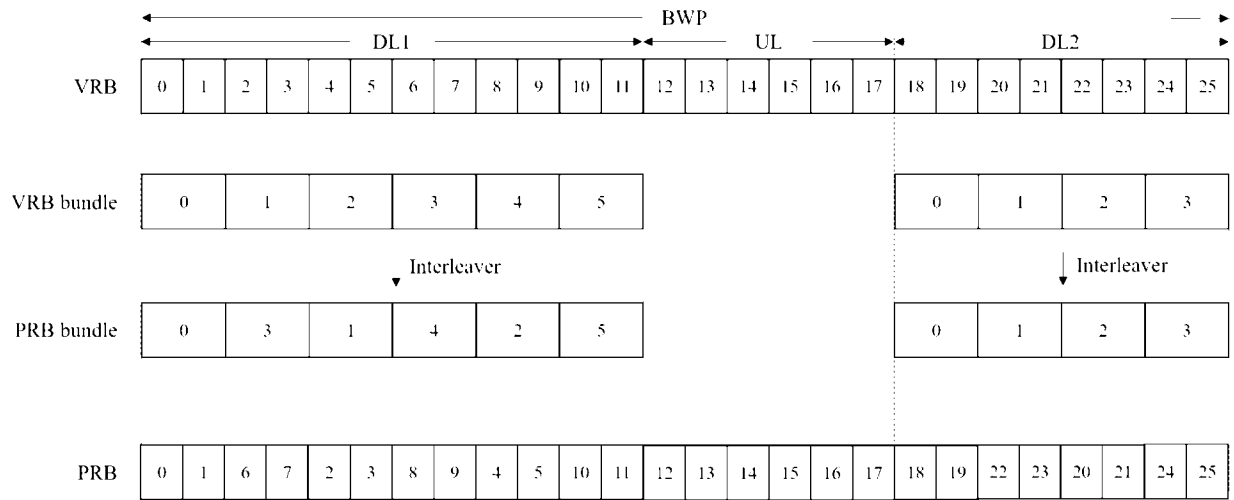


Figure 8

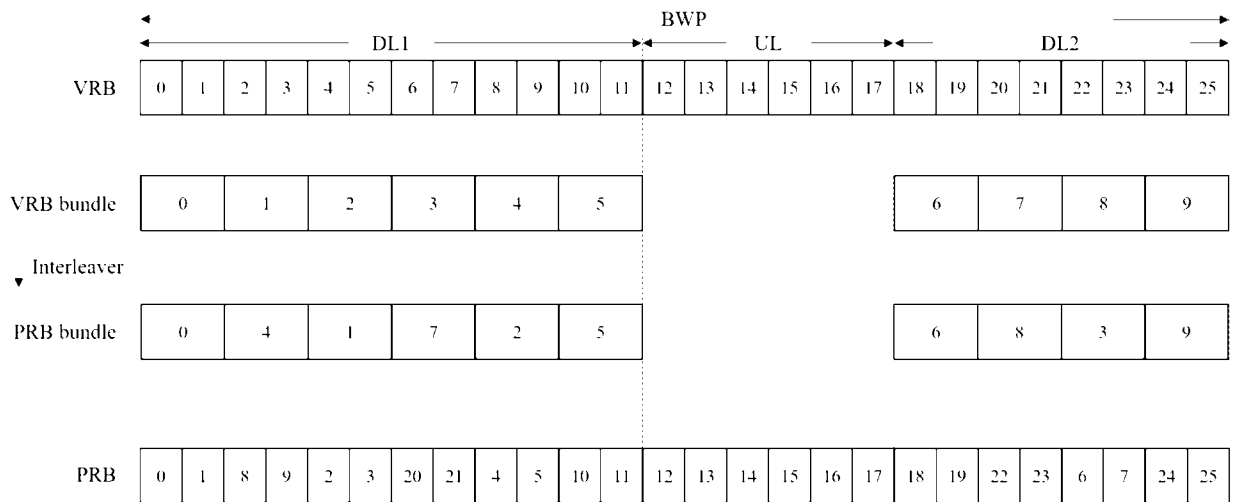


Figure 9



Figure 10

200

informing to a UE with a SBFD or non-SBFD specific antenna port pattern, wherein the SBFD or non-SBFD specific antenna port pattern indicates antenna port distribution for DL transmission in SBFD or non-SBFD duration, respectively

S210

Figure 11

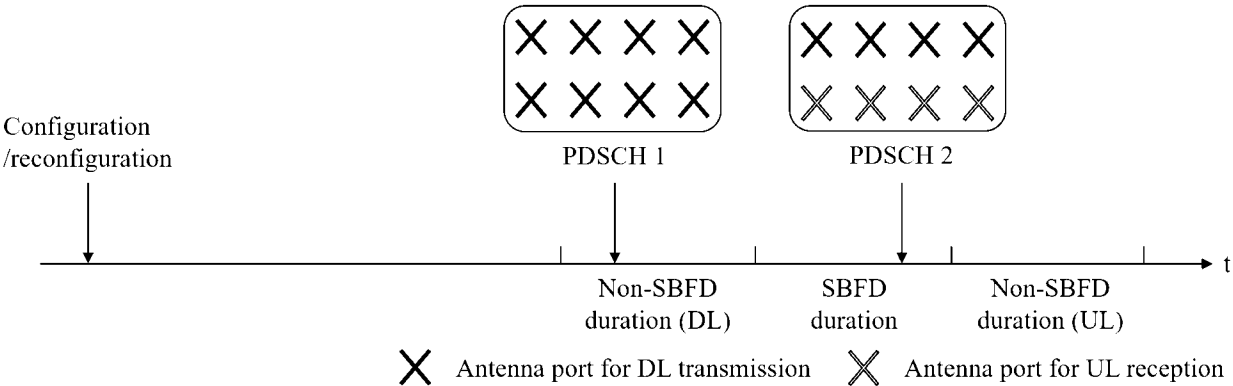


Figure 12

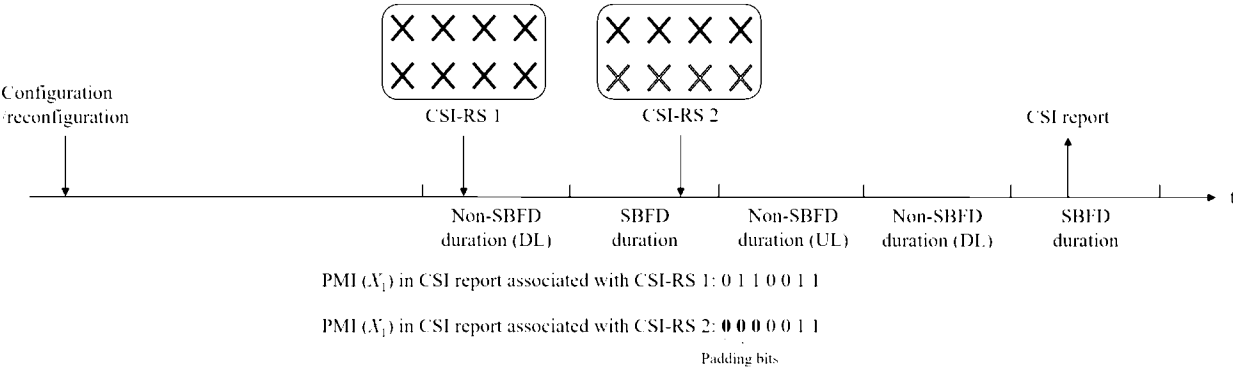


Figure 13

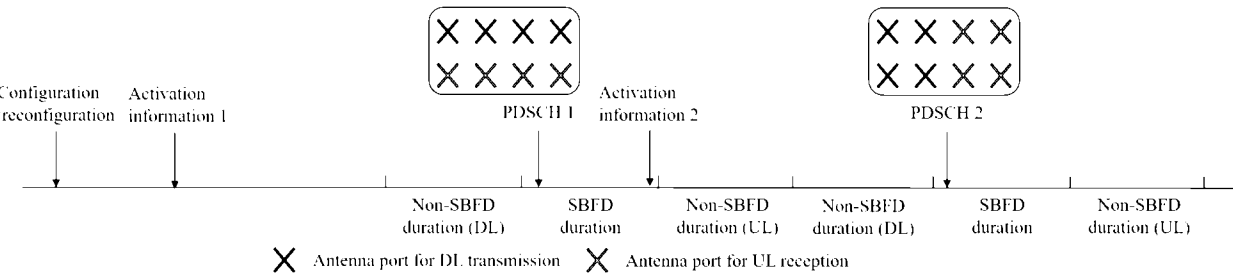


Figure 14

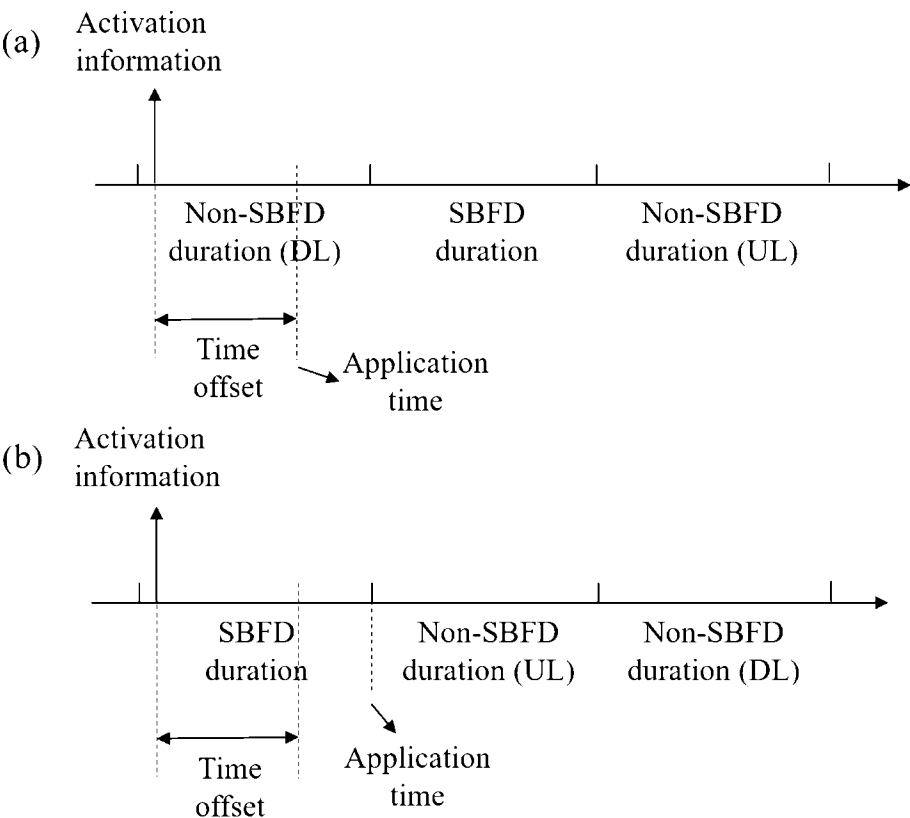


Figure 15

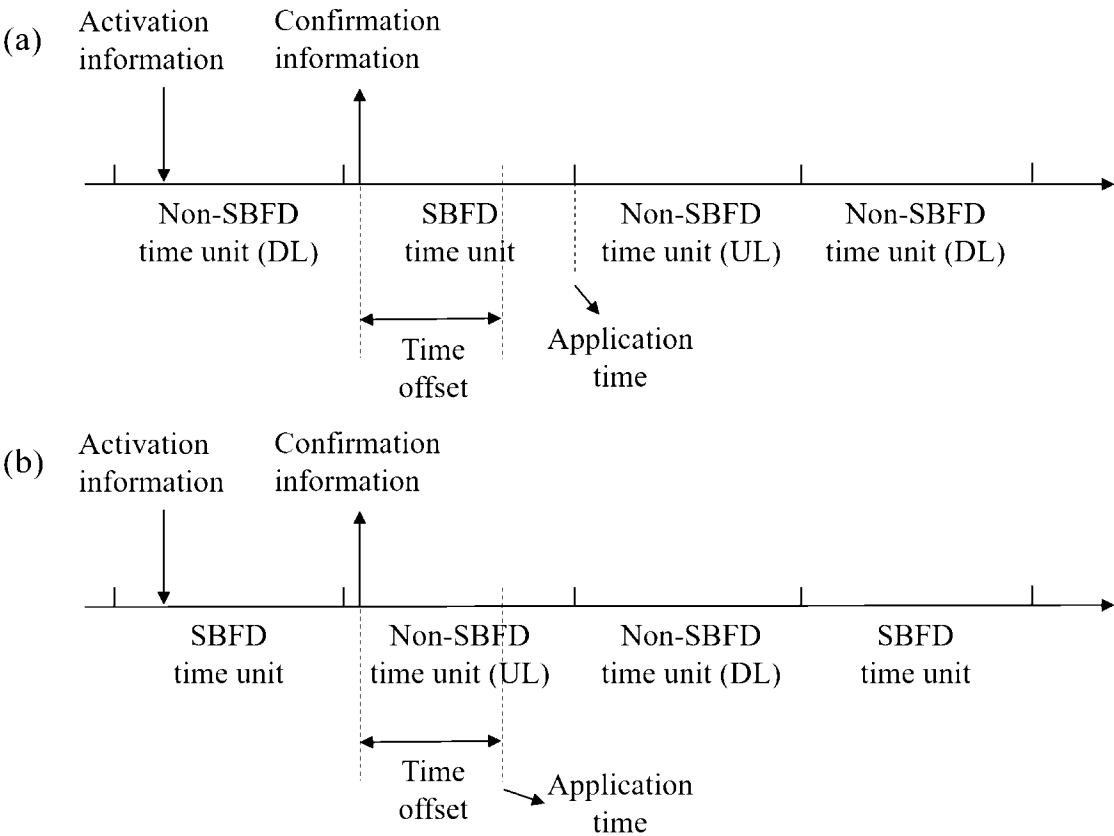


Figure 16

300

determining subbands in a first DL frequency domain and a second DL frequency domain in SBFD duration based on preset rules

S310

Figure 17

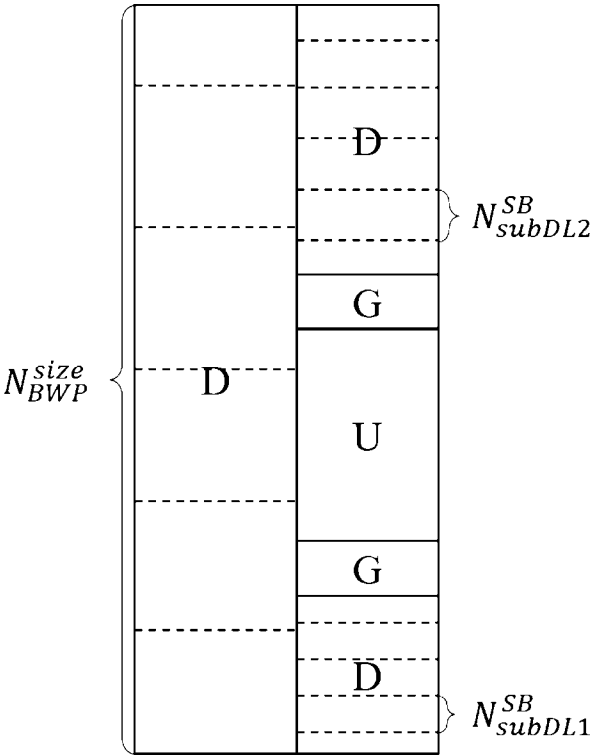


Figure 18

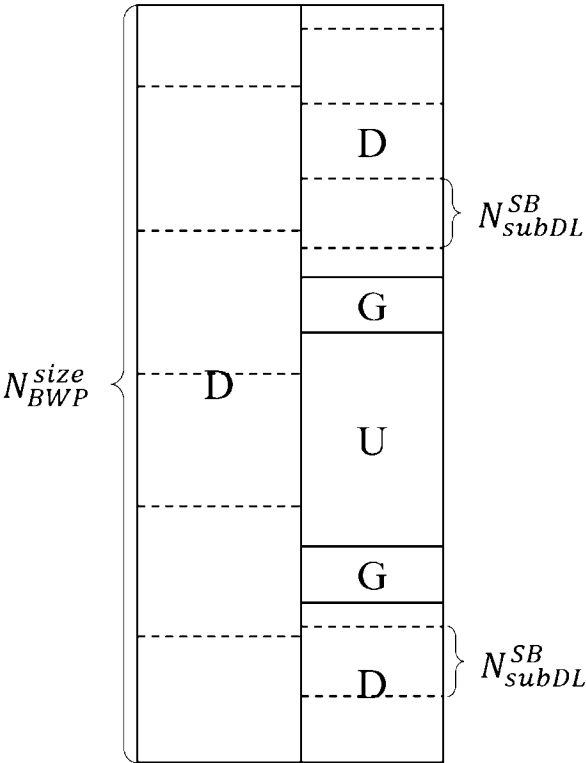


Figure 19

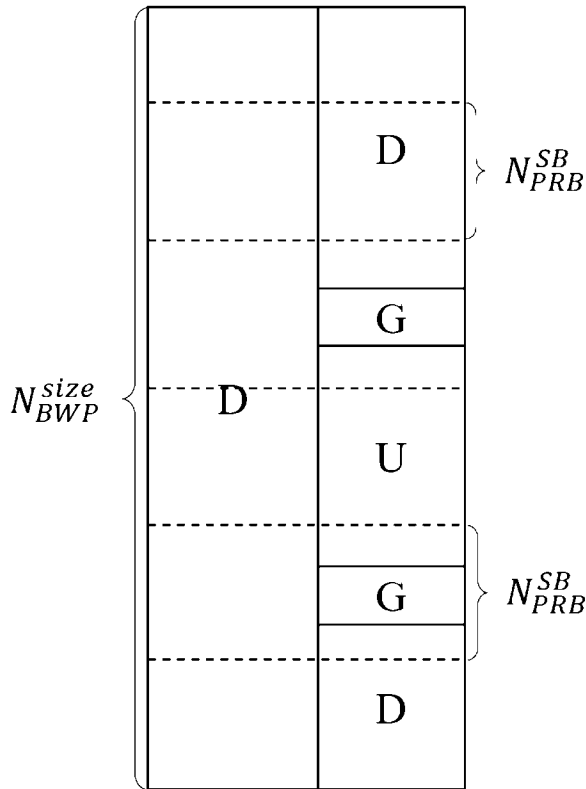


Figure 20

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/112747

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/0453(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: 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)

CNTXT, ENTXT, DWPI: 5G, NR, sub-band full duplex, SBFD, resource block, virtual, physical, interleave, map, downlink, Bandwidth Part, BWP, bundle, size, antenna, port, pattern, rule

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 115516804 A (QUALCOMM INC.) 23 December 2022 (2022-12-23) description, paragraphs 0009-0255, and figures 1-15	1-20
X	WO 2022056480 A1 (QUALCOMM INC.) 17 March 2022 (2022-03-17) description, paragraphs 0023-0253, and figures 1-18	21-52
X	US 2021360664 A1 (QUALCOMM INC.) 18 November 2021 (2021-11-18) description, paragraphs 0044-0303, and figures 1-18	53-58
A	CN 115053586 A (QUALCOMM INC.) 13 September 2022 (2022-09-13) the whole document	1-58
A	CN 114600390 A (QUALCOMM INC.) 07 June 2022 (2022-06-07) the whole document	1-58
A	WO 2023287184 A2 (LG ELECTRONICS INC.) 19 January 2023 (2023-01-19) the whole document	1-58



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“D” document cited by the applicant in the international application

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“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

07 April 2024

Date of mailing of the international search report

12 April 2024

Name and mailing address of the ISA/CN

**CHINA NATIONAL INTELLECTUAL PROPERTY
ADMINISTRATION**
6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088, China

Authorized officer

WANG,GuoGang

Telephone No. (+86) 010-53961755

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2023/112747

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