

METHOD FOR FACILITATING 3TX PUSCH TRANSMISSION

TECHNICAL FIELD

[0001] The present disclosure relates to wireless communications, and more specifically to a user equipment (UE), a network entity, a processor for wireless communication, methods, and a computer readable medium for facilitating 3Tx physical uplink shared channel (PUSCH) transmission.

BACKGROUND

[0002] A wireless communication system may include one or multiple network communication devices, such as base stations, which may be otherwise known as an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. Each network communication devices, such as a base station may support wireless communications for one or multiple user communication devices, which may be otherwise known as user equipment (UE), or other suitable terminology. The wireless communications system may support wireless communications with one or multiple user communication devices by utilizing resources of the wireless communication system (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers). Additionally, the wireless communications system may support wireless communications across various radio access technologies including third generation (3G) radio access technology, fourth generation (4G) radio access technology, fifth generation (5G) radio access technology, among other suitable radio access technologies beyond 5G (e.g., sixth generation (6G)).

[0003] In Rel-15, 1-port, 2-port and 4-port PUSCH transmission are supported. In Rel-18, 8-port PUSCH transmission is supported. Current commercial mobile UEs are generally equipped with only 1 or 2 Tx antennas. To enhance uplink (UL) performance and anticipating advancements in hardware and design technology, 3Tx antennas PUSCH transmission is supported in Rel-19. Issues regarding this matter need to be studied.

SUMMARY

[0004] To support the 3Tx PUSCH transmission, some issues need to be resolved. For example, the design of 3-port codebook and transmitted precoding matrix indicator (TPMI) indication; the design of 3-port sounding reference signal (SRS) resource. Besides, SRS for antenna switching may also need to be enhanced. Embodiments of the disclosure target the relevant issues of supporting 3 Tx PUSCH transmission.

[0005] The present disclosure relates to a UE, a network entity, a processor for wireless communication, methods, and a computer readable medium to facilitate 3Tx PUSCH transmission.

[0006] In a first aspect, there is provided a UE. The UE comprises a processor; and a transceiver coupled to the processor, wherein the processor is configured to: receive, from a network entity, a configuration indicating a 3-port codebook based physical uplink shared channel (PUSCH) transmission; transmit, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and receive, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0007] In a second aspect, there is provided a network entity, comprising: a processor; and a transceiver coupled to the processor, wherein the processor is configured to: transmit, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; receive, from the UE, 3-port sounding reference signals (SRSs); and transmit, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0008] In a third aspect, there is provided a processor for wireless communication. The a processor comprise at least one memory; and a controller coupled with the at least one memory and configured to cause the controller to: receive, at a user equipment (UE) and from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; transmit, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0009] In a fourth aspect, there is provided method performed by a user equipment (UE), the method comprising: receiving, from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; transmitting, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0010] In a fifth aspect, there is provided method performed by a network entity, the method comprising: transmitting, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; receiving, from the UE, 3-port sounding reference signals (SRSs); and transmitting, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0011] In a sixth aspect, there is provided a computer readable medium having instructions stored thereon, the instructions, when executed by a processor of an apparatus, causing the apparatus to perform the method according to the fourth or the fifth aspect of the disclosure.

[0012] In some implementations of the methods, the UE and the network entity, the UE may ignore one of the first parameter and the second parameter by ignoring the second parameter based on determining that the first height range and the second height range overlap.

[0013] In some implementations of the methods, the UE and the network entity, the 3-port precoder is selected from a set of precoding matrices, and wherein each precoding matrix has three rows and one or more columns corresponding to one or more layers.

[0014] In some implementations of the methods, the UE and the network entity, for each precoding matrix, the precoding matrix includes only one non-zero element in each column.

[0015] In some implementations of the methods, the UE and the network entity, in a case that the maximum rank of the PUSCH transmission is larger than one, the TPMI field comprises three bits indicative of the 3-port precoder and the number of layers for

the PUSCH transmission; or in a case that the maximum rank of the PUSCH transmission is one, the TPMI field comprises two bits indicative of the 3-port precoder and the number of layers for the PUSCH transmission.

[0016] In some implementations of the methods, the UE and the network entity, the DCI further includes a second TPMI field indicative of a second 3-port precoder and a second number of layers for the PUSCH transmission when two SRS resource sets with usage being codebook are configured.

[0017] In some implementations of the methods, the UE and the network entity, in a case that a single frequency network (SFN) scheme or a time division multiplexing (TDM) scheme is configured for PUSCH transmission, if the maximum rank of the PUSCH transmission is larger than one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the same number of layers as indicated by the first TPMI field, or if the maximum rank of the PUSCH transmission is equal to one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission.

[0018] In some implementations of the methods, the UE and the network entity, in a case that a space division multiplexing (SDM) scheme is configured for PUSCH transmission, if the maximum rank of the PUSCH transmission is larger than one, the second TPMI field comprises three bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission; or if the maximum rank of the PUSCH transmission is one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission.

[0019] In some implementations of the methods, the UE and the network entity, a first parameter N_{ap}^{SRS} indicative of a number of antenna ports of a 3-port SRS resource is configured as 3.

[0020] In some implementations of the methods, the UE and the network entity, a second parameter $\bar{N}_{ap}^{SRS}$ in determining the cyclic shifts (CSs) of a 3-port SRS resource is 3.

[0021] In some implementations of the methods, the UE and the network entity, the UE and the network entity may perform a floor or ceiling operation to derive the CSs of

the 3-port SRS resource, in a case that a transmission comb number K_{TC} is equal to 2 and the second parameter is equal to 3.

[0022] In some implementations of the methods, the UE and the network entity, the transmission comb number K_{TC} equal to 2 and the first parameter N_{ap}^{SRS} equal to 3 cannot be configured simultaneously.

[0023] In some implementations of the methods, the UE and the network entity, the second parameter $\bar{N}_{ap}^{SRS}$ is 4 in determining the CSs of a 3-port SRS resource.

[0024] In some implementations of the methods, the UE and the network entity, the first parameter N_{ap}^{SRS} is configured as 4, and the second parameter $\bar{N}_{ap}^{SRS}$ is 4 in determining the CSs of a 3-port SRS resource.

[0025] In some implementations of the methods, the UE and the network entity, the first three CSs of a total of four derived CSs are the CSs of the 3-port SRS resource.

[0026] In some implementations of the methods, the UE and the network entity, a SRS sequence of a SRS resource is mapped to a physical resource with a coefficient indicative of the number of antenna ports equal to 3.

[0027] In some implementations of the methods, the UE and the network entity, the UE split a linear transmit power equally across 3 antenna ports for SRS transmission.

[0028] In some implementations of the methods, the UE and the network entity, the UE selects a precoder from an uplink codebook that has a number of antenna ports equal to 3.

[0029] In some implementations of the methods, the UE and the network entity, the UE transmits a SRS resource for antenna switching with supportedSRS-TxPortSwitch being one from 1T3R, 2T3R, 3T3R, 3T4R, 3T6R, and 3T8R depending on the UE's capability.

[0030] In some implementations of the methods, the UE and the network entity, for 2T3R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where a SRS resource is of two SRS ports and the other SRS resource is of a single SRS port

[0031] In some implementations of the methods, the UE and the network entity, for 2T3R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where each SRS resource is of two SRS ports.

[0032] In some implementations of the methods, the UE and the network entity, for 3T4R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where a SRS resource is of three SRS ports and the other SRS resource is of a single SRS port.

[0033] In some implementations of the methods, the UE and the network entity, for 3T4R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where each SRS resource is of three SRS ports.

[0034] In some implementations of the methods, the UE and the network entity, for 3T8R, a total number of three SRS resources in up to three SRS resource sets with usage being antenna switching are configured, where one of the three SRS resources is of two SRS ports and the other two of the three SRS resources are of three SRS ports.

[0035] In some implementations of the methods, the UE and the network entity, for 3T8R, a total number of three SRS resources in up to three SRS resource sets with usage being antenna switching are configured, where each of the three SRS resources is of three SRS ports.

[0036] In some implementations of the methods, the UE and the network entity, the UE transmits capability information indicative of support of 3-port PUSCH transmission to the network entity.

[0037] In some implementations of the methods, the UE and the network entity, the UE transmits capability information indicative of the maximum number of SRS port being 3 to the network entity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] FIG. 1 illustrates an example of a wireless communications system in which some embodiments of the present disclosure can be implemented.

[0039] FIG. 2 illustrates an example of a process flow for facilitating 3Tx PUSCH transmission in accordance with some example embodiments of the present disclosure.

[0040] FIG. 3 illustrates an example of a device that is suitable for implementing some embodiments of the present disclosure.

[0041] FIG. 4 illustrates an example of a processor that is suitable for implementing some embodiments of the present disclosure.

[0042] FIG. 5 illustrates a flowchart of a method that performed by a user equipment in accordance with aspects of the present disclosure.

[0043] FIG. 6 illustrates a flowchart of a method that performed by a network entity in accordance with aspects of the present disclosure.

[0044] Throughout the drawings, the same or similar reference numerals represent the same or similar elements.

DETAILED DESCRIPTION

[0045] Principles of the present disclosure will now be described with reference to some embodiments. It is to be understood that these embodiments are described only for the purpose of illustration and help those skilled in the art to understand and implement the present disclosure, without suggesting any limitation as to the scope of the disclosure. The disclosure described herein can be implemented in various manners other than the ones described below. In the following description and claims, unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skills in the art to which this disclosure belongs.

[0046] References in the present disclosure to “one embodiment,” “an example embodiment,” “an embodiment,” “some embodiments,” and the like indicate that the embodiment(s) described may include a particular feature, structure, or characteristic, but it is not necessary that every embodiment includes the particular feature, structure, or characteristic. Moreover, such phrases do not necessarily refer to the same embodiment(s). Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0047] It shall be understood that although the terms “first” and “second” or the like may be used herein to describe various elements, these elements should not be limited by

these terms. These terms are only used to distinguish one element from another element. For example, a first element could also be termed as a second element, and similarly, a second element could also be termed as a first element, without departing from the scope of embodiments. As used herein, the term “and/or” includes any and all combinations of one or more of the listed terms. In some examples, values, procedures, or apparatuses are referred to as “best,” “lowest,” “highest,” “minimum,” “maximum,” or the like. It will be appreciated that such descriptions are intended to indicate that a selection among many used functional alternatives can be made, and such selections need not be better, smaller, higher, or otherwise preferable to other selections.

[0048] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of embodiments. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “has,” “having,” “includes” and/or “including,” when used herein, specify the presence of stated features, elements, components and/or the like, but do not preclude the presence or addition of one or more other features, elements, components and/or combinations thereof. For example, the term “includes” and its variants are to be read as open terms that mean “includes, but is not limited to.” The term “based on” is to be read as “based at least in part on.” The term “one embodiment” and “an embodiment” are to be read as “at least one embodiment.” The term “another embodiment” is to be read as “at least one other embodiment.” The use of an expression such as “A and/or B” can mean either “only A” or “only B” or “both A and B.” Other definitions, explicit and implicit, may be included below.

[0049] Embodiments of the disclosure relates issues on 3-antenna-port PUSCH transmission. In Rel-19 multiple-input-multiple-output (MIMO) work item description (WID), it is agreed to specify non-coherent UL codebook to facilitate 3-antenna-port codebook-based transmissions, without enhancement on UL full power transmission and without enhancement on SRS resource. To support the 3-antenna-port (i.e., 3Tx) PUSCH transmission, some issues need to be resolved. For example, the design of 3-port codebook and TPMI indication; the design of 3 port SRS resource. Besides, SRS for antenna switching may also need to be enhanced.

[0050] In view of this, solutions are proposed to solve the issues mentioned above. According to embodiments of the disclosure, a user equipment (UE) may receive from a network entity (e.g. a base station, such as gNB) a configuration indicating a 3-port codebook based PUSCH transmission. Based on reception of the configuration, the UE may transmit 3-port sounding reference signals (SRSs) to the network entity, and receives a transmitted precoding matrix indicator (TPMI) indicative of a 3-port precoder and a number of layers for the PUSCHS transmission.

[0051] Aspects of the present disclosure are described in the context of a wireless communications system. FIG. 1 illustrates an example of a wireless communications system 100 in which some embodiments of the present disclosure can be implemented. The wireless communications system 100 may include one or more network entities 102 (also referred to as network equipment (NE)), one or more UEs 104, a core network 106, and a packet data network 108. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a 4G network, such as an LTE network or an LTE-Advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be a 5G network, such as an NR network. In other implementations, the wireless communications system 100 may be a combination of a 4G network and a 5G network, or other suitable radio access technology including Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G. Additionally, the wireless communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

[0052] The one or more network entities 102 may be dispersed throughout a geographic region to form the wireless communications system 100. One or more of the network entities 102 described herein may be or include or may be referred to as a network node, a base station, a network element, a radio access network (RAN), a base transceiver station, an access point, a NodeB, an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. A network entity 102 and a UE 104 may communicate via a communication link 110, which may be a wireless or wired connection. For example, a network entity 102 and a UE 104 may perform wireless communication (e.g., receive signaling, transmit signaling) over a Uu interface. In a 3GPP non-terrestrial network

(NTN), a network entity 102 in form of a satellite can directly communicate to UE 104 using NR/LTE Uu interface. The satellite may be a transparent satellite or a regenerative satellite. For NTN with a transparent satellite, a base station on earth may communicate with a UE via the satellite. For NTN with a regenerative satellite, the base station may be on board and directly communicate with the UE.

[0053] A network entity 102 may provide a geographic coverage area 112 for which the network entity 102 may support services (e.g., voice, video, packet data, messaging, broadcast, etc.) for one or more UEs 104 within the geographic coverage area 112. For example, a network entity 102 and a UE 104 may support wireless communication of signals related to services (e.g., voice, video, packet data, messaging, broadcast, etc.) according to one or multiple radio access technologies. In some implementations, a network entity 102 may be moveable, for example, a satellite associated with a non-terrestrial network. In some implementations, different geographic coverage areas 112 associated with the same or different radio access technologies may overlap, but the different geographic coverage areas 112 may be associated with different network entities 102. Information and signals described herein may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0054] The one or more UEs 104 may be dispersed throughout a geographic region of the wireless communications system 100. A UE 104 may include or may be referred to as a mobile device, a wireless device, a remote device, a remote unit, a handheld device, or a subscriber device, or some other suitable terminology. In some implementations, the UE 104 may be referred to as a unit, a station, a terminal, or a client, among other examples. Additionally, or alternatively, the UE 104 may be referred to as an Internet-of-Things (IoT) device, an Internet-of-Everything (IoE) device, or machine-type communication (MTC) device, among other examples. In some implementations, a UE 104 may be stationary in the wireless communications system 100. In some other implementations, a UE 104 may be mobile in the wireless communications system 100. In some other implementations, a UE 104 may be a UAV UE and may communicate with one or more network entities 102 while flying.

[0055] The one or more UEs 104 may be devices in different forms or having different capabilities. Some examples of UEs 104 are illustrated in FIG. 1. A UE 104 may be capable of communicating with various types of devices, such as the network entities 102, other UEs 104, or network equipment (e.g., the core network 106, the packet data network 108, a relay device, an integrated access and backhaul (IAB) node, or another network equipment), as shown in FIG. 1. Additionally, or alternatively, a UE 104 may support communication with other network entities 102 or UEs 104, which may act as relays in the wireless communications system 100.

[0056] A UE 104 may also be able to support wireless communication directly with other UEs 104 over a communication link 114. For example, a UE 104 may support wireless communication directly with another UE 104 over a device-to-device (D2D) communication link. In some implementations, such as vehicle-to-vehicle (V2V) deployments, vehicle-to-everything (V2X) deployments, or cellular-V2X deployments, the communication link 114 may be referred to as a sidelink. For example, a UE 104 may support wireless communication directly with another UE 104 over a PC5 interface.

[0057] A network entity 102 may support communications with the core network 106, or with another network entity 102, or both. For example, a network entity 102 may interface with the core network 106 through one or more backhaul links 116 (e.g., via an S1, N2, N2, or another network interface). The network entities 102 may communicate with each other over the backhaul links 116 (e.g., via an X2, Xn, or another network interface). In some implementations, the network entities 102 may communicate with each other directly (e.g., between the network entities 102). In some other implementations, the network entities 102 may communicate with each other or indirectly (e.g., via the core network 106). In some implementations, one or more network entities 102 may include subcomponents, such as an access network entity, which may be an example of an access node controller (ANC). An ANC may communicate with the one or more UEs 104 through one or more other access network transmission entities, which may be referred to as a radio heads, smart radio heads, or transmission-reception points (TRPs).

[0058] In some implementations, a network entity 102 may be configured in a disaggregated architecture, which may be configured to utilize a protocol stack physically or logically distributed among two or more network entities 102, such as an integrated

access backhaul (IAB) network, an open RAN (O-RAN) (e.g., a network configuration sponsored by the O-RAN Alliance), or a virtualized RAN (vRAN) (e.g., a cloud RAN (C-RAN)). For example, a network entity 102 may include one or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a RAN Intelligent Controller (RIC) (e.g., a Near-Real Time RIC (Near-RT RIC), a Non-Real Time RIC (Non-RT RIC)), a Service Management and Orchestration (SMO) system, or any combination thereof.

[0059] An RU may also be referred to as a radio head, a smart radio head, a remote radio head (RRH), a remote radio unit (RRU), or a transmission reception point (TRP). One or more components of the network entities 102 in a disaggregated RAN architecture may be co-located, or one or more components of the network entities 102 may be located in distributed locations (e.g., separate physical locations). In some implementations, one or more network entities 102 of a disaggregated RAN architecture may be implemented as virtual units (e.g., a virtual CU (VCU), a virtual DU (VDU), a virtual RU (VRU)).

[0060] Split of functionality between a CU, a DU, and an RU may be flexible and may support different functionalities depending upon which functions (e.g., network layer functions, protocol layer functions, baseband functions, radio frequency functions, and any combinations thereof) are performed at a CU, a DU, or an RU. For example, a functional split of a protocol stack may be employed between a CU and a DU such that the CU may support one or more layers of the protocol stack and the DU may support one or more different layers of the protocol stack. In some implementations, the CU may host upper protocol layer (e.g., a layer 3 (L3), a layer 2 (L2)) functionality and signaling (e.g., Radio Resource Control (RRC), service data adaptation protocol (SDAP), Packet Data Convergence Protocol (PDCP)). The CU may be connected to one or more DUs or RUs, and the one or more DUs or RUs may host lower protocol layers, such as a layer 1 (L1) (e.g., physical (PHY) layer) or an L2 (e.g., radio link control (RLC) layer, medium access control (MAC) layer) functionality and signaling, and may each be at least partially controlled by the CU 160.

[0061] Additionally, or alternatively, a functional split of the protocol stack may be employed between a DU and an RU such that the DU may support one or more layers of the protocol stack and the RU may support one or more different layers of the protocol stack. The DU may support one or multiple different cells (e.g., via one or more RUs). In some implementations, a functional split between a CU and a DU, or between a DU and

an RU may be within a protocol layer (e.g., some functions for a protocol layer may be performed by one of a CU, a DU, or an RU, while other functions of the protocol layer are performed by a different one of the CU, the DU, or the RU).

[0062] A CU may be functionally split further into CU control plane (CU-CP) and CU user plane (CU-UP) functions. A CU may be connected to one or more DUs via a midhaul communication link (e.g., F1, F1-c, F1-u), and a DU may be connected to one or more RUs via a fronthaul communication link (e.g., open fronthaul (FH) interface). In some implementations, a midhaul communication link or a fronthaul communication link may be implemented in accordance with an interface (e.g., a channel) between layers of a protocol stack supported by respective network entities 102 that are in communication via such communication links.

[0063] The core network 106 may support user authentication, access authorization, tracking, connectivity, and other access, routing, or mobility functions. The core network 106 may be an evolved packet core (EPC), or a 5G core (5GC), which may include a control plane entity that manages access and mobility (e.g., a mobility management entity (MME), an access and mobility management functions (AMF)) and a user plane entity that routes packets or interconnects to external networks (e.g., a serving gateway (S-GW), a Packet Data Network (PDN) gateway (P-GW), or a user plane function (UPF)). In some implementations, the control plane entity may manage non-access stratum (NAS) functions, such as mobility, authentication, and bearer management (e.g., data bearers, signal bearers, etc.) for the one or more UEs 104 served by the one or more network entities 102 associated with the core network 106.

[0064] The core network 106 may communicate with the packet data network 108 over one or more backhaul links 116 (e.g., via an S1, N2, N2, or another network interface). The packet data network 108 may include an application server 118. In some implementations, one or more UEs 104 may communicate with the application server 118. A UE 104 may establish a session (e.g., a protocol data unit (PDU) session, or the like) with the core network 106 via a network entity 102. The core network 106 may route traffic (e.g., control information, data, and the like) between the UE 104 and the application server 118 using the established session (e.g., the established PDU session). The PDU session may be an example of a logical connection between the UE 104 and the core network 106 (e.g., one or more network functions of the core network 106).

[0065] In the wireless communications system 100, the network entities 102 and the UEs 104 may use resources of the wireless communications system 100 (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers)) to perform various operations (e.g., wireless communications). In some implementations, the network entities 102 and the UEs 104 may support different resource structures. For example, the network entities 102 and the UEs 104 may support different frame structures. In some implementations, such as in 4G, the network entities 102 and the UEs 104 may support a single frame structure. In some other implementations, such as in 5G and among other suitable radio access technologies, the network entities 102 and the UEs 104 may support various frame structures (i.e., multiple frame structures). The network entities 102 and the UEs 104 may support various frame structures based on one or more numerologies.

[0066] One or more numerologies may be supported in the wireless communications system 100, and a numerology may include a subcarrier spacing and a cyclic prefix. A first numerology (e.g., $\mu=0$) may be associated with a first subcarrier spacing (e.g., 15 kHz) and a normal cyclic prefix. In some implementations, the first numerology (e.g., $\mu=0$) associated with the first subcarrier spacing (e.g., 15 kHz) may utilize one slot per subframe. A second numerology (e.g., $\mu=1$) may be associated with a second subcarrier spacing (e.g., 30 kHz) and a normal cyclic prefix. A third numerology (e.g., $\mu=2$) may be associated with a third subcarrier spacing (e.g., 60 kHz) and a normal cyclic prefix or an extended cyclic prefix. A fourth numerology (e.g., $\mu=3$) may be associated with a fourth subcarrier spacing (e.g., 120 kHz) and a normal cyclic prefix. A fifth numerology (e.g., $\mu=4$) may be associated with a fifth subcarrier spacing (e.g., 240 kHz) and a normal cyclic prefix.

[0067] A time interval of a resource (e.g., a communication resource) may be organized according to frames (also referred to as radio frames). Each frame may have a duration, for example, a 10 millisecond (ms) duration. In some implementations, each frame may include multiple subframes. For example, each frame may include 10 subframes, and each subframe may have a duration, for example, a 1 ms duration. In some implementations, each frame may have the same duration. In some implementations, each subframe of a frame may have the same duration.

[0068] Additionally or alternatively, a time interval of a resource (e.g., a communication resource) may be organized according to slots. For example, a subframe may include a number (e.g., quantity) of slots. The number of slots in each subframe may also depend on the one or more numerologies supported in the wireless communications system 100. For instance, the first, second, third, fourth, and fifth numerologies (i.e., $\mu=0$, $\mu=1$, $\mu=2$, $\mu=3$, $\mu=4$) associated with respective subcarrier spacings of 15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz may utilize a single slot per subframe, two slots per subframe, four slots per subframe, eight slots per subframe, and 16 slots per subframe, respectively. Each slot may include a number (e.g., quantity) of symbols (e.g., OFDM symbols). In some implementations, the number (e.g., quantity) of slots for a subframe may depend on a numerology. For a normal cyclic prefix, a slot may include 14 symbols. For an extended cyclic prefix (e.g., applicable for 60 kHz subcarrier spacing), a slot may include 12 symbols. The relationship between the number of symbols per slot, the number of slots per subframe, and the number of slots per frame for a normal cyclic prefix and an extended cyclic prefix may depend on a numerology. It should be understood that reference to a first numerology (e.g., $\mu=0$) associated with a first subcarrier spacing (e.g., 15 kHz) may be used interchangeably between subframes and slots.

[0069] In the wireless communications system 100, an electromagnetic (EM) spectrum may be split, based on frequency or wavelength, into various classes, frequency bands, frequency channels, etc. By way of example, the wireless communications system 100 may support one or multiple operating frequency bands, such as frequency range designations FR1 (410 MHz – 7.125 GHz), FR2 (24.25 GHz – 52.6 GHz), FR3 (7.125 GHz – 24.25 GHz), FR4 (52.6 GHz – 114.25 GHz), FR4a or FR4-1 (52.6 GHz – 71 GHz), and FR5 (114.25 GHz – 300 GHz). In some implementations, the network entities 102 and the UEs 104 may perform wireless communications over one or more of the operating frequency bands. In some implementations, FR1 may be used by the network entities 102 and the UEs 104, among other equipment or devices for cellular communications traffic (e.g., control information, data). In some implementations, FR2 may be used by the network entities 102 and the UEs 104, among other equipment or devices for short-range, high data rate capabilities.

[0070] FR1 may be associated with one or multiple numerologies (e.g., at least three numerologies). For example, FR1 may be associated with a first numerology (e.g., $\mu=0$),

which includes 15 kHz subcarrier spacing; a second numerology (e.g., $\mu=1$), which includes 30 kHz subcarrier spacing; and a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing. FR2 may be associated with one or multiple numerologies (e.g., at least 2 numerologies). For example, FR2 may be associated with a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g., $\mu=3$), which includes 120 kHz subcarrier spacing.

[0071] FIG. 2 illustrates an example of a process flow for facilitating 3Tx PUSCH transmission in accordance with some example embodiments of the present disclosure. The process flow 200 may involve a UE 201 and a network entity (e.g. a base station) 202. The process flow 200 may be applied to the wireless communications system 100 with reference to FIG. 1, for example, the UE 201 may be any of UEs 104, and the network entity 202 may be any of the network entities 102. It would be appreciated that the process flow 200 may be applied to other communication scenarios.

[0072] At 210, the network entity 202 may transmit, to the UE 201, a configuration 215 indicating a 3-port codebook based PUSCH transmission. Accordingly, at 220, the UE 201 receives the configuration 215. In this way, the UE 201 is configured to perform PUSCH transmission to the network entity 201 using 3-port transmission (3Tx) based on a codebook precoding method. In some embodiments, the UE 201 may transmit capability information indicative of support of 3-port PUSCH transmission to the network entity 202 when it accesses the communication network. The network entity may transmit the configuration 215 in response to the capability information.

[0073] At 230, the UE 210 may transmit 3-port sounding reference signals (SRSs) 235 to the network entity 202. Accordingly, at 240, the network entity 202 may receive the 3-port SRSs 235 from the UE 201. The network entity 202 may measure the received 3-port SRSs and determine a transmitted precoding matrix indicator (TPMI) based on measurements on the 3-port SRSs. The TPMI may indicate a 3-port precoder and a number of layers for the PUSCH transmission.

[0074] At 250, the network entity 202 may transmits downlink control information (DCI) 255 including a TPMI field indicative of the 3-port precoder and the number of layers for the PUSCH transmission. At 250, the network entity 202 may also transmits a configured grant (i.e., CG) configuration 255 including a TPMI field indicative of the 3-

port precoder and the number of layers for the PUSCH transmission. The PUSCH transmission may be dynamically scheduled by a DCI or periodical accordingly to RRC configuration. In some scenario, e.g. in NR, the TPMI field may be referred as a Precoding Information and Number of Layers field. Accordingly, at the 260, UE 201 may receive the DCI 255 from the network entity 202. In this way, the UE 201 obtains the 3-port precoder for the PUSCH transmission.

[0075] Details of implementations of the process flow 200 will be described in the following.

[0076] Consider the codebook design for the 3 Tx PUSCH transmission. An uplink (UL) codebook for the UE 201 may include a set of precoding matrices, each precoding matrix has three rows corresponding to the 3 antenna ports and one or more columns corresponding to one or more layers. For 3 Tx PUSCH transmission, the number of layers of the PUSCH transmission can be 1, or 2 or 3.

[0077] In some embodiments, a non-coherent UL codebook may be supported. In this case, each precoding matrix in the codebook may include only one non-zero element in each column. In other words, for each rank, there is only one non-zero element in each row in the codebook matrix. Examples of the codebook and 3-port precoders can be found in the following Table 1 to Table 3. It will be appreciated that other codebooks and precoders are also applicable to the 3Tx PUSCH transmission.

Table 1: Precoding matrix W for single-layer transmission using three antenna ports.

TPMI index	W (ordered from left to right in increasing order of TPMI index)		
0 – 2	$\frac{1}{\sqrt{3}} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{\sqrt{3}} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{\sqrt{3}} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$

Table 2: Precoding matrix W for two-layer transmission using three antenna ports.

TPMI index	W (ordered from left to right in increasing order of TPMI index)		
0 – 2	$\frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$	$\frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$	$\frac{1}{\sqrt{3}} \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$

Table 3: Precoding matrix W for three-layer transmission using three antenna ports.

TPMI index	W (ordered from left to right in increasing order of TPMI index)
0	$\frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

[0078] Consider the precoding information and number of layers (i.e., first TPMI) indication. It indicates a suitable precoder for the PUSCH transmission from the codebook defined in Table 1 to Table 3 and also indicates the actual number of layers of the PUSCH transmission.

[0079] For PUSCH transmission, if the maximum rank of the PUSCH transmission is larger than one, Table 4 may be used to indicate the precoding information and the actual number of layers; if the maximum rank of PUSCH transmission is one, Table 5 may be used to indicate the precoding information and the actual number of layers. The maximum rank may be configured by higher layer parameters maxRank. If a single frequency network (SFN) scheme is configured for the PUSCH transmission, the maximum rank is $\max\{\text{maxRank}, \text{maxRankSfn}\}$ and if a space division multiplexing (SDM) scheme is configured for the PUSCH transmission, the maximum rank is $\max\{\text{maxRank}, \text{maxRankSdm}\}$.

Table 4: Precoding information and number of layers or Second Precoding information for 3 antenna ports, if transform precoder is disabled, maxRank = 2 or 3 or $\max\{\text{maxRank}, \text{maxRankSfn}\} = 2$ or 3 or $\max\{\text{maxRank}, \text{maxRankSdm}\} = 2$ or 3 or maxRankSdm= 2, and ul-FullPowerTransmission is not configured or configured to fullpower

Bit field mapped to index	<i>codebookSubset= nonCoherent</i>
0	1 layer: TPMI=0
1	1 layer: TPMI=1
2	1 layer: TPMI=2
3	2 layer: TPMI=0
4	2 layers: TPMI=1
5	2 layers: TPMI=2
6	3 layers: TPMI=0
7	reserved

Table 5: Precoding information and number of layers or Second Precoding information, for 3 antenna ports, if transform precoder is enabled and ul-FullPowerTransmission is either not configured or configured to fullpower, or if transform precoder is disabled, $\maxRank = 1$ or $\max\{\maxRank, \maxRankSfn\} = 1$ or $\max\{\maxRank, \maxRankSdm\} = 1$ or $\maxRankSdm = 1$ or $\maxRankSfn = 1$, and ul-FullPowerTransmission is not configured or configured to fullpower

Bit field mapped to index	<i>codebookSubset= nonCoherent</i>
0	1 layer: TPMI=0
1	1 layer: TPMI=1
2	1 layer: TPMI=2
3	reserved

[0080] The TPMI field in the DCI 255 or in the CG configuration 255 may comprise 3 bits according to Table 4 for 3 antenna ports PUSCH transmission, if *txConfig = codebook*, *ul-FullPowerTransmission* is not configured or configured to *fullpower*, transform precoder is disabled, and according to the values of higher layer parameters $\maxRank = 2$ or 3 if *multipanelScheme* is not configured or $\max\{\maxRank, \maxRankSfn\} = 2$ or 3 if *multipanelScheme = sfnScheme* or $\max\{\maxRank, \maxRankSdm\} = 2$ if *multipanelScheme = sdmScheme*, and *codebookSubset*.

[0081] The TPMI field in the DCI 255 or in the CG configuration 255 may comprise 2 bits according to Table 5 for 3 antenna ports PUSCH transmission, if *txConfig = codebook*, *ul-FullPowerTransmission* is not configured or configured to *fullpower*, and according to whether transform precoder is enabled or disabled, and $\maxRank = 1$ if *multipanelScheme* is not configured or $\max\{\maxRank, \maxRankSfn\} = 1$ if *multipanelScheme = sfnScheme* or $\max\{\maxRank, \maxRankSdm\} = 1$ if *multipanelScheme = sdmScheme*, and *codebookSubset*.

[0082] In some scenarios, e.g. for multi-TRP (transmission and receiving point) transmission, the DCI 255 may further include a second TPMI field indicative of a second 3-port precoder and a second number of layers for the PUSCH transmission when two SRS resource sets with usage being codebook are configured. In some embodiments, if a SFN scheme or a TDM scheme is configured for the PUSCH transmission, the actual number of layers is same as indicated by the first TPMI. In this case, Table 6 as below and Table 5 is used for indicating the precoder for maximum rank is larger than one and maximum rank is one respectively.

Table 6: Second precoding information, for 3 antenna ports, if transform precoder is disabled, $\text{maxRank} = 2$ or 3 or $\text{maxRankSfn} = 2$, and $\text{ul-FullPowerTransmission}$ is not configured or configured to fullpower

Bit field mapped to index	<i>codebookSubset= nonCoherent</i>
0	1 layer: TPMI=0
1	1 layer: TPMI=1
2	1 layer: TPMI=2
3	reserved
0	2 layers: TPMI=0
1	2 layers: TPMI=1
2	2 layers: TPMI=2
3	Reserved
0	3 layers: TPMI=0
1-3	reserved

[0083] The second TPMI field may comprise 2 bits according to Table 6 with the same number of layers indicated by Precoding information and number of layers field for 3 antenna ports PUSCH transmission, if SRS resource set indicator field is present, $\text{txConfig} = \text{codebook}$, $\text{ul-FullPowerTransmission}$ is not configured or configured to *fullpower*, transform precoder is disabled, and according to the values of higher layer parameters $\text{maxRank}=2$ or 3 if multipanelScheme is not configured or $\text{maxRankSfn}=2$ if $\text{multipanelScheme} = \text{sfnScheme}$, and *codebookSubset*.

[0084] The second TPMI field may comprise 2 bits according to Table 5 with the same number of layers indicated by Precoding information and number of layers field for 3 antenna ports PUSCH transmission, if SRS resource set indicator field is present, $\text{txConfig} = \text{codebook}$, $\text{ul-FullPowerTransmission}$ is not configured or configured to *fullpower*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters $\text{maxRank}=1$ if multipanelScheme is not configured or $\text{maxRankSfn}=1$ if $\text{multipanelScheme} = \text{sfnScheme}$, and *codebookSubset*.

[0085] If the SDM scheme is configured for the PUSCH transmission, Table 4 and Table 5 may be used for indicating the precoder for maximum rank is larger than one and maximum rank is one respectively.

[0086] The second TPMI field may comprise 3 bits according to Table 4 for 3 antenna ports PUSCH transmission, if $txConfig = codebook$, $ul-FullPowerTransmission$ is not configured or configured to *fullpower*, transform precoder is disabled, and according to the values of higher layer parameters $maxRankSdm=2$ if $multipanelScheme = sdmScheme$, and $codebookSubset$.

[0087] The second TPMI field may comprise 2 bits according to Table 5 for 3 antenna ports PUSCH transmission, if $txConfig = codebook$, $ul-FullPowerTransmission$ is not configured or configured to *fullpower*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters $maxRankSdm=1$ if $multipanelScheme = sdmScheme$, and $codebookSubset$.

[0088] Next, consider SRS sequence generation for a 3-port SRS resource. The SRS sequence of each port of a multi-port SRS resource may be generated by a ZC sequence with different cyclic shifts (CSs). For a 4-port SRS and 8 port SRS resource, different half of the total ports may occupy different comb (i.e., resource elements, REs) and the ports within a half of the ports are orthogonal by different CSs. According to standards TS38.211, the SRS sequence is generated by:

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

The cyclic shift α_i for antenna port p_i is given as

$$\alpha_i = 2\pi \left(\frac{n_{SRS}^{cs,i}}{n_{SRS}^{cs,max}} + \frac{f_{csh}(n_f, n_{s,p}^\mu l')}{K n_{SRS}^{cs,max}} \right) \quad (1)$$

where

$$n_{SRS}^{cs,i} = \begin{cases} \left(n_{SRS}^{cs} + \frac{n_{SRS}^{cs,max}[(\bar{p}_i - 1000)/4]}{\bar{N}_{ap}^{SRS}/4} \right) \bmod n_{SRS}^{cs,max} & \text{if } \bar{N}_{ap}^{SRS} = 8 \text{ and } n_{SRS}^{cs,max} = 6 \\ \left(n_{SRS}^{cs} + \frac{n_{SRS}^{cs,max}[(\bar{p}_i - 1000)/2]}{\bar{N}_{ap}^{SRS}/2} \right) \bmod n_{SRS}^{cs,max} & \text{if } \bar{N}_{ap}^{SRS} = 4 \text{ and } n_{SRS}^{cs,max} = 6; \text{ or if } \bar{N}_{ap}^{SRS} = 8 \text{ and } n_{SRS}^{cs,max} = 12 \\ \left(n_{SRS}^{cs} + \frac{n_{SRS}^{cs,max}(\bar{p}_i - 1000)}{\bar{N}_{ap}^{SRS}} \right) \bmod n_{SRS}^{cs,max} & \text{otherwise} \end{cases} \quad (2)$$

where $n_{SRS}^{cs} \in \{0, 1, \dots, n_{SRS}^{cs,max} - 1\}$ is contained in the higher layer parameter $transmissionComb$ and $p_i = 0, 1, \dots, N_{ap}^{SRS} - 1$. N_{ap}^{SRS} is the number of antenna ports $nrofSRS\text{-}Ports$. The maximum number of cyclic shifts $n_{SRS}^{cs,max}$ is given by Table 7, and the K_{TC} is the value of comb.

The quantities $\bar{p}_i$ and $\bar{N}_{ap}^{SRS}$ are given by

- if the higher-layer parameter $nrofSRS\text{-}Ports-n8$ equals $ports8tdm$

$$\bar{p}_i = \begin{cases} 1000 + p_i \bmod 2 & \text{if } p_i - 1000 < 4 \\ 1000 + p_i \bmod 2 + 2 & \text{if } p_i - 1000 \geq 4 \end{cases}$$

$$\bar{N}_{ap}^{SRS} = 4$$

- otherwise

$$\bar{p}_i = p_i$$

$$\bar{N}_{ap}^{SRS} = N_{ap}^{SRS}$$

Table 7: Maximum number of cyclic shifts $n_{SRS}^{cs,max}$ as a function of K_{TC} .

K_{TC}	$n_{SRS}^{cs,max}$
2	8
4	12
8	6

[0089] For formula (2), the CSs of a 3-port SRS resource may be determined based on a second parameter $\bar{N}_{ap}^{SRS}$, and the value of $\bar{N}_{ap}^{SRS}$ is determined based on a first parameter N_{ap}^{SRS} indicative of a number of antenna ports of an SRS resource. The first parameter N_{ap}^{SRS} may be configured from the network, and the second parameter works as an intermediate quantity in determining the CSs of the SRS resource. Embodiments to calculate the CSs of a 3-port SRS resource are provided in the following.

[0090] In some embodiments, the CSs of a 3-port SRS resource may be determined by $\bar{N}_{ap}^{SRS} = 3$ in formula (2). In this embodiment, the number of antenna ports $n_{rofSRS-Ports}$ (i.e. N_{ap}^{SRS}) is configured as 3, and $\bar{N}_{ap}^{SRS} = 3$ for determining CSs of a 3-port SRS resource, that is $\bar{N}_{ap}^{SRS} = N_{ap}^{SRS} = 3$. The SRS ports are $\{p_i\}_{i=0}^{N_{ap}^{SRS}-1}$, and $p_i = 1000 + i$. Then for $K_{TC} = 2, 4, 8$ respectively, the CSs of a 3 port SRS resource are:

- $N_{ap}^{SRS}=3; K_{TC} = 2, n_{SRS}^{CS,i} = (n_{SRS}^{CS} + \frac{8(p_i-1000)}{3}) \bmod 8;$
- $N_{ap}^{SRS}=3; K_{TC} = 4, n_{SRS}^{CS,i} = (n_{SRS}^{CS}, n_{SRS}^{CS} + 4, n_{SRS}^{CS} + 8) \bmod 12;$
- $N_{ap}^{SRS}=3; K_{TC} = 8, n_{SRS}^{CS,i} = (n_{SRS}^{CS}, n_{SRS}^{CS} + 2, n_{SRS}^{CS} + 4) \bmod 6.$

[0091] However, for the transmission comb number $K_{TC} = 2$, based on formula (2), the $n_{SRS}^{CS,i}$ does not result in an integer. To resolve this issue, one method is to do a floor or ceiling operation of $\frac{n_{SRS}^{cs,max}(\bar{p}_i-1000)}{\bar{N}_{ap}^{SRS}}$. Alternatively, another method is 3-port SRS resource and the comb number equal to 2 cannot be configured simultaneously. That is when number of antenna ports $n_{rofSRS-Ports}$ (N_{ap}^{SRS}) is configured as 3, UE does not expect the value of comb K_{TC} is configured as 2.

[0092] When the first parameter is configured as 3, the UE may use the second parameter $\bar{N}_{ap}^{SRS} = 4$ to calculate the CSs using the formula (2). That means the CSs of a 3-port SRS resource are calculated like the CSs calculation of a 4-port SRS resource defined in TS 38.211. The only difference is the first parameter *nrofSRS-Ports* is configured as 3 since the number of SRS ports is 3 (i.e., $N_{ap}^{SRS} = 3$). Three CSs are determined in this embodiment, where the SRS ports of a 3-port SRS resource are $\{p_i\}_{i=0}^{N_{ap}^{SRS}-1}$, and $p_i = 1000 + i$.

[0093] Alternatively, the first parameter *nrofSRS-Ports* may be configured as 4. In this embodiment, UE may still use the second parameter $\bar{N}_{ap}^{SRS} = N_{ap}^{SRS} = 4$ to calculate the CSs using the formula (2). The CSs of a 3-port SRS resource are determined same as a 4-port SRS resource, that is, the number of antenna ports *nrofSRS-Ports* is configured as 4 and the CS calculation is based on $\bar{N}_{ap}^{SRS} = 4$. Different from the previous method with the first parameter *nrofSRS-Ports* equal to 3, the first parameter *nrofSRS-Ports* is configured as 4, and four CSs are determined in this embodiment. Since only three ports are used for SRS transmission, then the first three CSs of a total of the four CS of 4-port SRS are used for generating sequence for the 3-port SRS resource. That is, if 3Tx PUSCH transmission is configured and the first parameter *nrofSRS-Ports* is configured as 4, SRS ports of a 3-port SRS resource are $\{p_i\}_{i=0}^{N_{ap}^{SRS}-2}$, and $p_i = 1000 + i$. In other words, the UE shall only transmit the first three ports of a SRS resource even N_{ap}^{SRS} is configured as 4.

[0094] This embodiment is consistent with the formula (2) in TS 38.211, but several small issues need to be updated accordingly. One of the issues relates to SRS transmission power. In TS 38.211, when SRS sequence of a SRS resource is mapped to physical resource, the sequence $r^{(p_i)}(n, l')$ for each of the antenna ports of the SRS resource shall be multiplied with the amplitude scaling factor β_{SRS} in order to conform to the transmit power specified in [TS 38.213] according to

$$\begin{aligned}
 & a_{K_{TC}k' + k_0^{(p_i)}, l' + l_0}^{(p_i)} \\
 &= \begin{cases} \frac{1}{\sqrt{N_{ap}}} \beta_{SRS} r^{(p_i)}(k', l') & \text{if } k' = 0, 1, \dots, M_{sc,b}^{SRS} - 1 \text{ and } l' = 0, 1, \dots, N_{symb}^{SRS} - 1 \\ 0 & \text{otherwise} \end{cases}
 \end{aligned} \tag{3}$$

In this embodiment, the first parameter *nrofSRS-Ports* is configured as 4, i.e., $N_{ap}^{SRS}=4$ and the actual number of SRS ports is 3. Therefore, if 3Tx PUSCH transmission is configured but *nrofSRS-Ports* is configured as 4, the UE apply $N_{ap} = 3$ in formula (3). That is, the coefficient in formula (3) shall indicate the actual number of antenna ports, i.e. three ports.

[0095] Similarly, in TS 38.213, the specification saying “For SRS, a UE splits a linear value $\hat{P}_{SRS,b,f,c}(i, q_s, l)$ of the transmit power $P_{SRS,b,f,c}(i, q_s, l)$ on active UL BWP *b* of carrier *f* of serving cell *c* equally across the configured antenna ports for SRS”. If 3Tx PUSCH transmission is configured and although the configured antenna ports for SRS is configured 4, the UE shall split a linear value $\hat{P}_{SRS,b,f,c}(i, q_s, l)$ equally across 3 antenna ports for SRS.

[0096] Another issue relates to determination of a precoder of a PUSCH transmission. In TS 38.214, it is said “The transmission precoder is selected from the uplink codebook that has a number of antenna ports equal to higher layer parameter *nrofSRS-Ports* in SRS-Config, as defined in Clause 6.3.1.5 of [4, TS 38.211]”. The precoder of a PUSCH transmission is determined based on the configured number of SRS ports, *nrofSRS-Ports*. If 3Tx PUSCH transmission is configured, the precoder shall be selected from the uplink codebook defined in table 1 to table 3 that has a number of antenna ports equal to 3 other than the configured number of SRS ports, *nrofSRS-Ports*.

[0097] For better understanding, examples of calculation of CSs of 3-port SRS resource is provided. Suppose 3Tx PUSCH transmission is configured and the comb number is configured as 2. If the method with *nrofSRS-Ports* configured as 3 and $\bar{N}_{ap}^{SRS}$ equal to 4 is adopted, then $n_{SRS}^{CS,i}$ is determined as

$$\begin{aligned} n_{SRS}^{CS,i} &= \left(n_{SRS}^{CS} + \frac{n_{SRS}^{CS,max}(\bar{p}_i - 1000)}{\bar{N}_{ap}^{SRS}} \right) \bmod n_{SRS}^{CS,max} \\ &= \left(n_{SRS}^{CS} + \frac{8(\bar{p}_i - 1000)}{4} \right) \bmod 8 \end{aligned} \quad (4)$$

Where $\bar{p}_i = p_i = 1000 + i$, and $i = 0, 1, \dots, N_{ap}^{SRS} - 1$. Then the three CSs of a 3-port SRS are $(n_{SRS}^{CS}, n_{SRS}^{CS} + 2, n_{SRS}^{CS} + 4) \bmod 8$.

[0098] If the method with *nrofSRS-Ports* configured as 4 and $\bar{N}_{ap}^{SRS}$ equal to 4 is adopted, then $n_{SRS}^{CS,i}$ is same as formula (4), the four CSs are $(n_{SRS}^{CS}, n_{SRS}^{CS} + 2, n_{SRS}^{CS} + 4, n_{SRS}^{CS} + 6) \bmod 8$. But it is for 3Tx PUSCH transmission, only three CSs are required for a 3-port

SRS resource. Then for simplicity, the first three CSs values are used, that is $\bar{p}_i = p_i = 1000 + i$, and $i = 0, 1, \dots, N_{\text{ap}}^{\text{SRS}} - 2$.

[0099] Now consider SRS for antenna switching. The SRS resource(s) for antenna switching is used for acquisition DL CSI. With the introducing of 3 antenna ports for UL transmission, additional antenna switching configuration may be supported depending on UE's capability. In some embodiments, UE may transmit a SRS resource for antenna switching with supported SRS-TxPortSwitch being one from 1T3R, 2T3R, 3T3R, 3T4R, 3T6R, and 3T8R depending on the UE's capability.

[0100] For 1T3R, a total number of three SRS resources are configured in up to three SRS resource set with usage being set as 'antennaSwitching', each SRS resource in a given set consists of one SRS port, and the SRS port of SRS resources in the set is associated with a different UE antenna port. In some embodiments, the three SRS resources are configured in one SRS resource set. In some embodiments, the three SRS resources are configured in two SRS resource sets with one SRS resource set including one SRS resource and another SRS resource set including two SRS resources. In some embodiments, the three SRS resources are configured in three SRS resource sets with each SRS resource set including one SRS resource. For 3T6R, a total number of two SRS resources are configured in up to two SRS resource set with usage being set as 'antennaSwitching', each SRS resource in a given set consists of three SRS ports, and the SRS port pair of SRS resources in the set is associated with a different UE antenna port pair. For 3T3R, one SRS resources is configured in one SRS resource set with usage being set as 'antennaSwitching', each SRS resource set has one SRS resource, the number of SRS ports for each resource is equal to 3.

[0101] For 2T3R, to sounding the 3-port DL channel between gNB and the UE, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching may be configured.

[0102] In some embodiments, one SRS resource is of two SRS ports and the other SRS resource is of a single SRS port. As such, one port of the 3-port DL channel is sounded by the one-port SRS resource and the other two ports of the 3-port DL channel are sounded by the two-port SRS resource.

[0103] Zero or one 'periodic' SRS resource set may be configured. Zero or one 'semi-persistent' SRS resource sets may be configured if the UE is not indicating srs-AntennaSwitching2SP-1Periodic, or up to two 'semi-persistent' SRS resource sets and up to one 'periodic' SRS resource set may be configured if the UE is indicating srs-AntennaSwitching2SP-1Periodic. The two 'semi-persistent' SRS resource sets are not activated at the same time. Each 'periodic' or 'semi-persistent' SRS resource set has two SRS resources transmitted in different symbols with one SRS resource consisting of a single SRS port and the other SRS resource consisting of two SRS ports. The SRS port of the SRS resources in a given set are associated with a different UE antenna port.

[0104] Zero or one or two 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, two SRS resources are included and transmitted in different symbols with one SRS resource consisting of a single SRS port and the other SRS resource consisting of two SRS ports. The SRS port of the two SRS resources are associated with a different UE antenna port. In the case of two SRS resource sets, a total of two SRS resources are transmitted in different symbols of two different slots. One SRS resource set includes a single-port SRS resource and another set includes a two-port SRS resource. The SRS port of the two SRS resources are associated with a different UE antenna port.

[0105] Alternatively, for 2T3R, each SRS resource may be of two SRS ports. As such, 3-port DL channel is sounded by two two-port SRS resources and one port of the 3-port DL channel may be sounded twice. e.g., DL port 0 and port 1 are sounded by a first SRS resource; and DL port 1 and port 2 are sounded by a second SRS resource.

[0106] In this embodiment, zero or one 'periodic' SRS resource set or up to two 'semi-persistent' SRS resource sets may be configured similarly as the case where one of the two SRS resources is of one port and the other is of two ports. Each 'periodic' or 'semi-persistent' SRS resource set has two SRS resources transmitted in different symbols with each SRS resource consisting of a two SRS ports. The SRS port pair of the SRS resources in a given set are associated with a different UE antenna port pair.

[0107] Zero or one or two 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, two SRS resources are included and transmitted in different symbols with one SRS resource consisting of two SRS ports. In the case of two SRS resource sets, a total of two SRS resources are transmitted in different symbols of two

different slots with one SRS resource consisting of two SRS ports. The SRS port pair of the SRS resources in a given set are associated with a different UE antenna port pair.

[0108] For 3T4R, to sounding the 4-port DL channel between the gNB and the UE, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching may be configured. In some embodiments, one of the two SRS resources is of three SRS ports and the other SRS resource is of a single SRS port.

[0109] Zero or one 'periodic' SRS resource set or up to two 'semi-persistent' SRS resource sets may be configured as in 2T3R. Each 'periodic' or 'semi-persistent' SRS resource set has two SRS resources transmitted in different symbols with one SRS resource consisting of a single SRS port and the other SRS resource consisting of three SRS ports. The SRS port of the SRS resources in a given set are associated with a different UE antenna port.

[0110] Zero or one or two 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, two SRS resources are included and transmitted in different symbols with one SRS resource consisting of a single SRS port and the other SRS resource consisting of three SRS ports. In the case of two SRS resource sets, a total of two SRS resources are transmitted in different symbols of two different slots. One SRS resource set includes a single-port SRS resource and another set includes a three-port SRS resource. The SRS port of the two SRS resources are associated with a different UE antenna port.

[0111] For 3T4R, alternatively, each SRS resource may be of three SRS ports. As such, 4-port DL channel is sounded by two three-port SRS resources and two ports of the 4-port DL channel may be sounded twice. e.g., DL port 0, DL port 1 and port 2 are sounded by a first SRS resource; and DL port 1 to port 3 are sounded by a second SRS resource.

[0112] Zero or one 'periodic' SRS resource set or up to two 'semi-persistent' SRS resource sets may be configured as in 2T3R. Each 'periodic' or 'semi-persistent' SRS resource set has two SRS resources transmitted in different symbols with one SRS resource consisting of three SRS ports. The SRS port pair of the resource in the set is associated with a different UE antenna port pair.

[0113] Zero or one or two 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, two SRS resources are included and transmitted in different symbols with one SRS resource consisting of three SRS ports. In the case of two SRS resource sets, a total of two SRS resources are transmitted in different symbols of two different slots. One SRS resource set includes a three-port SRS resource. The SRS port pair of the two SRS resources are associated with a different UE antenna port pair.

[0114] For 3T8R, to sounding the 8-port DL channel between gNB and the UE, a total number of three SRS resources in up to three SRS resource sets with usage being antenna switching are configured. In some embodiments, one of the three SRS resources may be of two SRS ports and the other two of the three SRS resources may be of three SRS ports.

[0115] Zero or one 'periodic' SRS resource set or up to two 'semi-persistent' SRS resource sets may be configured as in 2T3R. Each 'periodic' or 'semi-persistent' SRS resource set has three SRS resources transmitted in different symbols with one SRS resource consisting of two SRS ports and the other two SRS resource consisting of three SRS ports. The SRS port pair of the SRS resources in a given set are associated with a different UE antenna port pair.

[0116] Zero or one or two or three 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, three SRS resources are included and transmitted in different symbols with one SRS resource consisting of two SRS ports and the other two SRS resources consisting of three SRS ports. In the case of two SRS resource sets, a total of three SRS resources are transmitted in different symbols of two different slots. One SRS resource set includes one SRS resource and another SRS resource set includes two SRS resources. One SRS resource is with two SRS ports and another two SRS resource are with three SRS ports. In the case of three SRS resource sets, a total of three SRS resources are transmitted in different symbols of three different slots. One SRS resource set includes one SRS resource. One SRS resource is with two SRS ports and another two SRS resource are with three SRS ports. The SRS ports of the three SRS resources are associated with a different UE antenna ports.

[0117] For 3T8R, alternatively, each of the three SRS resource may be of three ports. As such, 8-port DL channel is sounded by three three-port SRS resources and one port of the 8-port DL channel may be sounded twice. e.g., DL port 0, DL port 1 and port 2 are

sounded by a first SRS resource; and DL port 3 to port 5 are sounded by a second SRS resource; and DL port 5 to port 7 are sounded by a third SRS resource.

[0118] Zero or one 'periodic' SRS resource set or up to two 'semi-persistent' SRS resource sets may be configured as in 2T3R. Each 'periodic' or 'semi-persistent' SRS resource set has three SRS resources transmitted in different symbols with one SRS resource consisting of three SRS ports. The SRS port pair of the resource in the set is associated with a different UE antenna port pair.

[0119] Zero or one or two or three 'aperiodic' SRS resource sets may be configured. In the case of one SRS resource set, three SRS resources are included and transmitted in different symbols with one SRS resource consisting of three SRS ports. In the case of two SRS resource sets, a total of three SRS resources are transmitted in different symbols of two different slots. One SRS resource set includes one SRS resource and another SRS resource set includes two SRS resources. In the case of three SRS resource sets, a total of three SRS resources are transmitted in different symbols of three different slots. One SRS resource set includes one SRS resource. The SRS port pair of the three SRS resources are associated with a different UE antenna port pair.

[0120] The UE 201 may transmit capability information indicative of the maximum number of SRS port being 3 to the network entity 202. For a UE equipped with multiple panels (MP-UE), 2 bits UE capability may be used and each capability value corresponds to the maximum number of SRS ports of a panel, which may be 1, 2, 3, or 4. UE capability can be reported along with the beam reporting to indicate the network entity 202 whether corresponding scheduling information, e.g., precoder and number of layers, shall be changed. In some embodiments, if the UE 201 supports 3 Tx PUSCH transmission, the capability value of 3 shall be introduced for the UE equipped with multi-panels. An example of enhancement on UE capability of MP-UE is shown as below.

```
-- R1 23-1-4 UE capability value reporting
srs-PortReport-r19 SEQUENCE {
    capVal1-r19 ENUMERATED {n1, n2, n3, n4} OPTIONAL,
    capVal2-r19 ENUMERATED {n1, n2, n3, n4} OPTIONAL,
    capVal3-r19 ENUMERATED {n1, n2, n3, n4} OPTIONAL,
    capVal4-r19 ENUMERATED {n1, n2, n3, n4} OPTIONAL
}
```

[0121] Moreover, consider the phase tracking reference signal (PT-RS) issue. In some scenarios, one or two PTRS ports may be configured to a UE. The actual number of UL PT-RS port(s) may be determined based on the indicated/configured TPMI(s). If the maximum number of PTRS port is configured as 1, all the three PUSCH antenna ports

share the single PTRS port; if the maximum number of PTRS port is configured as 2. How to associate a PUSCH antenna port with a PTRS port needs to be determined.

[0122] In some embodiments, the association between a PUSCH antenna port with a PTRS port may be fixed. For example, PUSCH antenna port 1000 and 1002 in indicated TPMI(s) may share PT-RS port 0, and PUSCH antenna port 1001 in indicated TPMI(s) may share PT-RS port 1. For example, if the indicated TPMI is $\frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$, the PUSCH antenna port 1000 and 1001 share different PTRS ports, so the actual number of PTRS ports is two; if the indicated TPMI is $\frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$, the PUSCH antenna port 1000 and 1002 share a same PTRS port, so the actual number of PTRS ports is one.

[0123] In some embodiments, the association between a PUSCH antenna port with a PTRS port is UE specific. Since only two PTRS ports are supported, then two PUSCH antenna ports may share one PTRS port and one PUSCH antenna port shares another PTRS port in 3 Tx PUSCH transmission. Which two PUSCH antenna ports share a PTRS port is determined by the UE based on its hardware implementation and the UE may report this to gNB. Then gNB may indicate a proper precoder for PUSCH transmission. For example, a UE may report PUSCH antenna port 1000 and 10001 share a PTRS port 0, and PUSCH antenna port 1002 shares a PTRS port 1; another UE may report PUSCH antenna port 1000 and 10002 share a PTRS port 0, and PUSCH antenna port 1001 shares a PTRS port 1.

[0124] On the PTRS and DMRS association, if the maximum number of PTRS port is configured as 1, two bits as in Table 8 (reproduced from table 7.3.1.1.2-25 in TS 38.212) is used for indicating the PTRS port is associated with which one DMRS port. If the maximum number of PTRS port is configured as 2, one bit is enough to indicate the association as in table 9. Since in 3Tx PUSCH transmission, up to two PUSCH layers share a PTRS port and one PUSCH layer shares another PTRS port. Therefore, Table 9 may be used for indicated the PTRS-DMRS association if the number of PUSCH layers associated with a PTRS port is two; and the one DMRS port is definitely associated with the one PTRS port with no necessary of indication if the number of PUSCH layers associated with a PTRS port is one.

Table 8: PTRS-DMRS association for UL PTRS port 0

Value	DMRS port
0	1 st scheduled DMRS port
1	2 nd scheduled DMRS port
2	3 rd scheduled DMRS port
3	4 th scheduled DMRS port

Table 9: PTRS-DMRS association for UL PTRS port 0 or PTRS port 1

Value	DMRS port
0	1 st DMRS port share the PTRS port
1	2 nd DMRS port share the PTRS port

[0125] FIG. 3 illustrates an example of a device that is suitable for implementing some embodiments of the present disclosure. The device 300 may be an example of a UE 104 or network entity 102 as described herein. The device 300 may support wireless communication with one or more network entities 102, UEs 104, or any combination thereof. The device 300 may include components for bi-directional communications including components for transmitting and receiving communications, such as a processor 302, a memory 304, a transceiver 306, and, optionally, an I/O controller 308. These components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0126] The processor 302, the memory 304, the transceiver 306, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described herein. For example, the processor 302, the memory 304, the transceiver 306, or various combinations or components thereof may support a method for performing one or more of the operations described herein.

[0127] In some implementations, the processor 302, the memory 304, the transceiver 306, or various combinations or components thereof may be implemented in hardware (e.g., in communications management circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA) or other programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure. In some implementations, the processor 302 and the memory 304 coupled with

the processor 302 may be configured to perform one or more of the functions described herein (e.g., executing, by the processor 302, instructions stored in the memory 304).

[0128] For example, the processor 302 may support wireless communication at the device 300 in accordance with examples as disclosed herein. The device 300 may be an example of a UE 104. In this case, the processor 302 may be configured to operable to support means for receiving, from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; means for transmitting, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity and means for receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0129] The device 300 may be an example of a network entity 102, e.g. a network entity. In this case, the processor 302 may be configured to operable to support means for transmitting, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; means for receiving, from the UE, 3-port sounding reference signals (SRSs); and means for transmitting, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0130] The processor 302 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, a microcontroller, an ASIC, an FPGA, a programmable logic device, a discrete gate or transistor logic component, a discrete hardware component, or any combination thereof). In some implementations, the processor 302 may be configured to operate a memory array using a memory controller. In some other implementations, a memory controller may be integrated into the processor 302. The processor 302 may be configured to execute computer-readable instructions stored in a memory (e.g., the memory 304) to cause the device 300 to perform various functions of the present disclosure.

[0131] The memory 304 may include random access memory (RAM) and read-only memory (ROM). The memory 304 may store computer-readable, computer-executable code including instructions that, when executed by the processor 302 cause the device 300 to perform various functions described herein. The code may be stored in a non-

transitory computer-readable medium such as system memory or another type of memory. In some implementations, the code may not be directly executable by the processor 302 but may cause a computer (e.g., when compiled and executed) to perform functions described herein. In some implementations, the memory 304 may include, among other things, a basic I/O system (BIOS) which may control basic hardware or software operation such as the interaction with peripheral components or devices.

[0132] The I/O controller 308 may manage input and output signals for the device 300. The I/O controller 308 may also manage peripherals not integrated into the device 300. In some implementations, the I/O controller 308 may represent a physical connection or port to an external peripheral. In some implementations, the I/O controller 308 may utilize an operating system such as iOS®, ANDROID®, MS-WINDOWS®, OS/2®, UNIX®, LINUX®, or another known operating system. In some implementations, the I/O controller 308 may be implemented as part of a processor, such as the processor 302. In some implementations, a user may interact with the device 300 via the I/O controller 308 or via hardware components controlled by the I/O controller 308.

[0133] In some implementations, the device 300 may include a single antenna 310. However, in some other implementations, the device 300 may have more than one antenna 310 (i.e., multiple antennas), including multiple antenna panels or antenna arrays, which may be capable of concurrently transmitting or receiving multiple wireless transmissions. The transceiver 306 may communicate bi-directionally, via the one or more antennas 310, wired, or wireless links as described herein. For example, the transceiver 306 may represent a wireless transceiver and may communicate bi-directionally with another wireless transceiver. The transceiver 306 may also include a modem to modulate the packets, to provide the modulated packets to one or more antennas 310 for transmission, and to demodulate packets received from the one or more antennas 310. The transceiver 306 may include one or more transmit chains, one or more receive chains, or a combination thereof.

[0134] A transmit chain may be configured to generate and transmit signals (e.g., control information, data, packets). The transmit chain may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital

modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmit chain may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmit chain may also include one or more antennas 310 for transmitting the amplified signal into the air or wireless medium.

[0135] A receive chain may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receive chain may include one or more antennas 310 for receive the signal over the air or wireless medium. The receive chain may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receive chain may include at least one demodulator configured to demodulate the receive signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receive chain may include at least one decoder for decoding the processing the demodulated signal to receive the transmitted data.

[0136] FIG. 4 illustrates an example of a processor 400 is suitable for implementing some embodiments of the present disclosure. The processor 400 may be an example of a processor configured to perform various operations in accordance with examples as described herein. The processor 400 may include a controller 402 configured to perform various operations in accordance with examples as described herein. The processor 400 may optionally include at least one memory 404. Additionally, or alternatively, the processor 400 may optionally include one or more arithmetic-logic units (ALUs) 406. One or more of these components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0137] The processor 400 may be a processor chipset and include a protocol stack (e.g., a software stack) executed by the processor chipset to perform various operations (e.g., receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) in accordance with examples as described herein. The processor chipset may include one or more cores, one or more caches (e.g., memory local to or included in the processor chipset (e.g., the processor 400) or other memory (e.g., random access memory (RAM), read-only memory (ROM), dynamic RAM (DRAM), synchronous dynamic RAM (SDRAM), static RAM (SRAM),

ferroelectric RAM (FeRAM), magnetic RAM (MRAM), resistive RAM (RRAM), flash memory, phase change memory (PCM), and others).

[0138] The controller 402 may be configured to manage and coordinate various operations (e.g., signaling, receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) of the processor 400 to cause the processor 400 to support various operations in accordance with examples as described herein. For example, the controller 402 may operate as a control unit of the processor 400, generating control signals that manage the operation of various components of the processor 400. These control signals include enabling or disabling functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

[0139] The controller 402 may be configured to fetch (e.g., obtain, retrieve, receive) instructions from the memory 404 and determine subsequent instruction(s) to be executed to cause the processor 400 to support various operations in accordance with examples as described herein. The controller 402 may be configured to track memory address of instructions associated with the memory 404. The controller 402 may be configured to decode instructions to determine the operation to be performed and the operands involved. For example, the controller 402 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 400 to cause the processor 400 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 402 may be configured to manage flow of data within the processor 400. The controller 402 may be configured to control transfer of data between registers, arithmetic logic units (ALUs), and other functional units of the processor 400.

[0140] The memory 404 may include one or more caches (e.g., memory local to or included in the processor 400 or other memory, such RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc. In some implementation, the memory 404 may reside within or on a processor chipset (e.g., local to the processor 400). In some other implementations, the memory 404 may reside external to the processor chipset (e.g., remote to the processor 400).

[0141] The memory 404 may store computer-readable, computer-executable code including instructions that, when executed by the processor 400, cause the processor 400

to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. The controller 402 and/or the processor 400 may be configured to execute computer-readable instructions stored in the memory 404 to cause the processor 400 to perform various functions. For example, the processor 400 and/or the controller 402 may be coupled with or to the memory 404, the processor 400, the controller 402, and the memory 404 may be configured to perform various functions described herein. In some examples, the processor 400 may include multiple processors and the memory 404 may include multiple memories. One or more of the multiple processors may be coupled with one or more of the multiple memories, which may, individually or collectively, be configured to perform various functions herein.

[0142] The one or more ALUs 406 may be configured to support various operations in accordance with examples as described herein. In some implementation, the one or more ALUs 406 may reside within or on a processor chipset (e.g., the processor 400). In some other implementations, the one or more ALUs 406 may reside external to the processor chipset (e.g., the processor 400). One or more ALUs 406 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 406 may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 406 be configured with a variety of logical and arithmetic circuits, including adders, subtractors, shifters, and logic gates, to process and manipulate the data according to the operation. Additionally, or alternatively, the one or more ALUs 406 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 406 to handle conditional operations, comparisons, and bitwise operations.

[0143] The processor 400 may support wireless communication in accordance with examples as disclosed herein. The processor 400 may implemented at a UE 104. In this case, the processor 400 may be configured to operable to support means for receiving, from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; means for transmitting, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and means for receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0144] The processor 400 may implemented at a network entity 102, e.g. a base station. In this case, the processor 400 may be configured to operable to support means for transmitting, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission; means for receiving, from the UE, 3-port sounding reference signals (SRs); and means for transmitting, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

[0145] FIG. 5 illustrates a flowchart of a method 500 performed by a UE in accordance with aspects of the present disclosure. The operations of the method 500 may be implemented by a device or its components as described herein. For example, the operations of the method 500 may be performed by a UE 104 as described herein. In some implementations, the device may execute a set of instructions to control the function elements of the device to perform the described functions. Additionally, or alternatively, the device may perform aspects of the described functions using special-purpose hardware.

[0146] At 510, the method may include receiving, from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission. The operations of 510 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 510 may be performed by a UE 104 as described with reference to FIG. 1.

[0147] At 520, the method may include transmitting, based on reception of the configuration, 3-port sounding reference signals (SRs) to the network entity. The operations of 520 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 520 may be performed by a UE 104 as described with reference to FIG. 1.

[0148] At 530, the method may include receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission. The operations of 530 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 530 may be performed by a UE 104 as described with reference to FIG. 1.

[0149] FIG. 6 illustrates a flowchart of a method 600 performed by a network entity in accordance with aspects of the present disclosure. The operations of the method 600 may be implemented by a device or its components as described herein. For example, the operations of the method 600 may be performed by a network entity 102 as described herein. In some implementations, the device may execute a set of instructions to control the function elements of the device to perform the described functions. Additionally, or alternatively, the device may perform aspects of the described functions using special-purpose hardware.

[0150] At 610, the method may include transmitting, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission. The operations of 610 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 610 may be performed by a network entity 102 as described with reference to FIG. 1.

[0151] At 620, the method may include receiving, from the UE, 3-port sounding reference signals (SRSs). The operations of 620 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 620 may be performed by a network entity 102 as described with reference to FIG. 1.

[0152] At 630, the method may include transmitting, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission. The operations of 630 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 620 may be performed by a network entity 102 as described with reference to FIG. 1.

[0153] It should be noted that the methods described herein describes possible implementations, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible. Further, aspects from two or more of the methods may be combined.

[0154] The various illustrative blocks and components described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a DSP, an ASIC, a CPU, an FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to

perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

[0155] The functions described herein may be implemented in hardware, software executed by a processor, firmware, or any combination thereof. If implemented in software executed by a processor, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Other examples and implementations are within the scope of the disclosure and appended claims. For example, due to the nature of software, functions described herein may be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations.

[0156] Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer. By way of example, non-transitory computer-readable media may include RAM, ROM, electrically erasable programmable ROM (EEPROM), flash memory, compact disk (CD) ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other non-transitory medium that may be used to carry or store desired program code means in the form of instructions or data structures and that may be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor.

[0157] As used herein, including in the claims, an article “a” before an element is unrestricted and understood to refer to “at least one” of those elements or “one or more” of those elements. The terms “a,” “at least one,” “one or more,” and “at least one of one or more” may be interchangeable. As used herein, including in the claims, “or” as used in a list of items (e.g., a list of items prefaced by a phrase such as “at least one of” or “one

or more of” or “one or both of”) indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Also, as used herein, the phrase “based on” shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as “based on condition A” may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase “based on” shall be construed in the same manner as the phrase “based at least in part on. Further, as used herein, including in the claims, a “set” may include one or more elements.

[0158] The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

CLAIMS

1. A user equipment (UE) comprising:
a processor; and
a transceiver coupled to the processor,
wherein the processor is configured to:
receive, from a network entity, a configuration indicating a 3-port codebook based physical uplink shared channel (PUSCH) transmission;
transmit, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and
receive, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.
2. The UE of claim 1, wherein the 3-port precoder is selected from a set of precoding matrices, and wherein each precoding matrix has three rows and one or more columns corresponding to one or more layers; and each precoding matrix includes only one non-zero element in each column.
3. The UE of claim 1, wherein
in a case that the maximum rank of the PUSCH transmission is larger than one, the TPMI field comprises three bits indicative of the 3-port precoder and the number of layers for the PUSCH transmission; or
in a case that the maximum rank of the PUSCH transmission is one, the TPMI field comprises two bits indicative of the 3-port precoder and the number of layers for the PUSCH transmission.
4. The UE of claim 1, wherein the DCI further includes a second TPMI field indicative of a second 3-port precoder and a second number of layers for the PUSCH transmission when two SRS resource sets with usage being codebook are configured.
5. The UE of claim 4, wherein in a case that a single frequency network (SFN) scheme or a time division multiplexing (TDM) scheme is configured for the PUSCH transmission,

if the maximum rank of the PUSCH transmission is larger than one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the same number of layers as indicated by the first TPMI field, or

if the maximum rank of the PUSCH transmission is equal to one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission.

6. The UE of claim 4, wherein in a case that a space division multiplexing (SDM) scheme is configured for the PUSCH transmission,

if the maximum rank of the PUSCH transmission is larger than one, the second TPMI field comprises three bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission; or

if the maximum rank of the PUSCH transmission is one, the second TPMI field comprises two bits indicative of the second 3-port precoder and the second number of layers for the PUSCH transmission.

7. The UE of claim 1, wherein a first parameter N_{ap}^{SRS} indicative of a number of antenna ports of an SRS resource is configured as 3 and a second parameter $\bar{N}_{ap}^{SRS}$ in determining the cyclic shifts (CSs) of a 3-port SRS resource is 3.

8. The UE of claim 7, wherein the processor is further configured to:
in a case that a transmission comb number K_{TC} is equal to 2, perform a floor or ceiling operation to derive the CSs of the 3-port SRS resource.

9. The UE of claim 7, wherein the transmission comb number K_{TC} equal to 2 and the first parameter N_{ap}^{SRS} equal to 3 cannot be configured simultaneously.

10. The UE of claim 1, wherein a first parameter N_{ap}^{SRS} indicative of a number of antenna ports of an SRS resource is configured as 3 and the second parameter $\bar{N}_{ap}^{SRS}$ in determining the CSs of a 3-port SRS resource is 4.

11. The UE of claim 1, wherein the first parameter N_{ap}^{SRS} is configured as 4, and the second parameter $\bar{N}_{ap}^{SRS}$ in determining the CSs of a 3-port SRS resource is 4, and

wherein the first three CSs of a total of four derived CSs are the CSs of the 3-port SRS resource.

12. The UE of claim 11, wherein a SRS sequence of a SRS resource is mapped to a physical resource with a coefficient indicative of the number of antenna ports equal to 3 and the processor is further configured to:

split a linear transmit power equally across 3 antenna ports for SRS transmission; and/or

select a precoder from an uplink codebook that has a number of antenna ports equal to 3.

13. The UE of claim 1, the processor is further configured to transmit a SRS resource for antenna switching with supportedSRS-TxPortSwitch being one from 1T3R, 2T3R, 3T3R, 3T4R, 3T6R, and 3T8R depending on the UE's capability.

14. The UE of claim 13, wherein for 2T3R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where

a SRS resource is of two SRS ports and the other SRS resource is of a single SRS port; or alternatively

each SRS resource is of two SRS ports.

15. The UE of claim 13, wherein for 3T4R, a total number of two SRS resources in up to two SRS resource sets with usage being antenna switching are configured, where

a SRS resource is of three SRS ports and the other SRS resource is of a single SRS port; or alternatively

each SRS resource is of three SRS ports.

16. The UE of claim 13, wherein for 3T8R, a total number of three SRS resources in up to three SRS resource sets with usage being antenna switching are configured, where

one of the three SRS resources is of two SRS ports and the other two of the three

SRS resources are of three SRS ports; or alternatively
each of the three SRS resources is of three SRS ports.

17. The UE of claim 1, wherein the processor is configured to transmit capability information indicative of the maximum number of SRS port being 3 to the network entity.

18. A network entity, comprising:
a processor; and
a transceiver coupled to the processor,
wherein the processor is configured to:
transmit, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission;
receive, from the UE, 3-port sounding reference signals (SRSs); and
transmit, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

19. A method performed by a user equipment (UE), the method comprising:
receiving, from a network entity, a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission;
transmitting, based on reception of the configuration, 3-port sounding reference signals (SRSs) to the network entity; and
receiving, from the network entity, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a number of layers for the PUSCH transmission.

20. A method performed by a network entity, the method comprising:
transmitting, to a user equipment (UE), a configuration indicating 3-port codebook based physical uplink shared channel (PUSCH) transmission;
receiving, from the UE, 3-port sounding reference signals (SRSs); and
transmitting, to the UE, downlink control information (DCI) including a transmitted precoding matrix indicator (TPMI) field indicative of a 3-port precoder and a

number of layers for the PUSCH transmission.