

(51) International Patent Classification:

H04W 72/1268 (2023.01) H04B 7/0404 (2017.01)

H04W 72/21 (2023.01) H04L 5/00 (2006.01)

(21) International Application Number:

PCT/US2024/036692

(22) International Filing Date:

03 July 2024 (03.07.2024)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/525,106 05 July 2023 (05.07.2023) US

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

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST,

(54) Title: METHODS AND APPARATUSES FOR UCI MULTIPLEXING IN MULTI-PUSCH TRANSMISSION

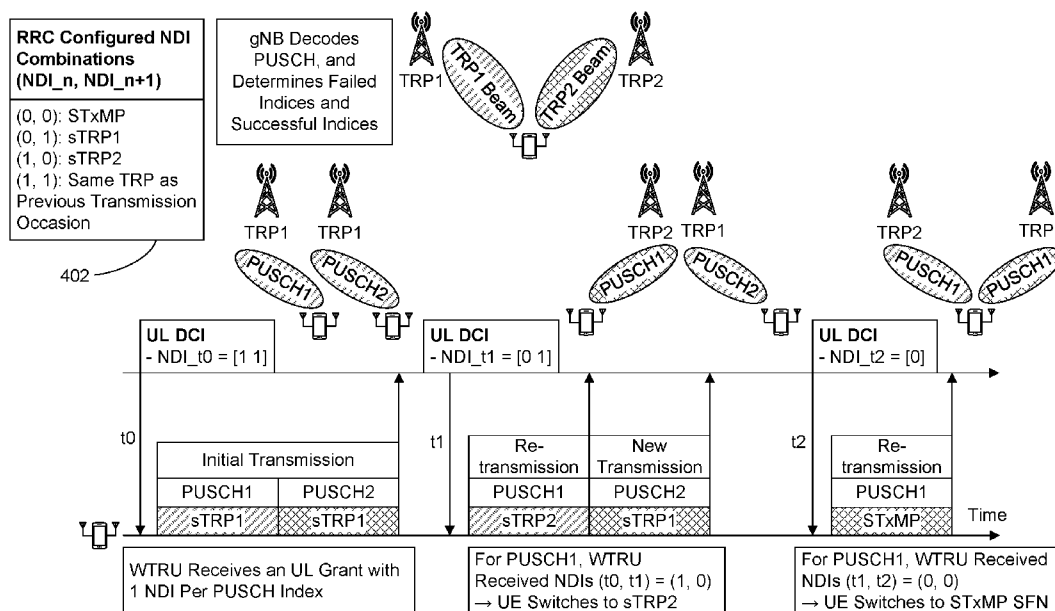


FIG. 4

(57) **Abstract:** In a multi-physical uplink shared channel (PUSCH) transmission with simultaneous transmission over multiple panels (STxMP), a wireless transmit/receive unit (WTRU) may determine the PUSCH index and panel where uplink control information (UCI) is multiplexed.

SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

METHODS AND APPARATUSES FOR UCI MULTIPLEXING IN MULTI-PUSCH TRANSMISSION**CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of U.S. Provisional Patent Application Number 63/525,106, filed July 5, 2023, which is hereby incorporated herein by reference in its entirety.

BACKGROUND

[0002] In some cellular/wireless standards (e.g., 3GPP), continued evolution of 5G New Radio (NR) may continue to optimize management and enhance performance for wireless communications. To enhance reliability and throughput, some enhancements for uplink transmission are considered. For example, additional or improved features and procedures regarding simultaneous transmission may be desired.

SUMMARY

[0003] Embodiments disclosed herein generally relate to communication networks, wireless and/or wired. One or more examples disclosed herein are related to methods, apparatuses, and procedures for simultaneous transmission over multiple panels (STxMP) multi-physical uplink shared channel (PUSCH) transmission in wireless communications (e.g., in a 5G NR network).

[0004] An example wireless transmit/receive unit (WTRU) for performing multi-PUSCH retransmission may comprise a transceiver and a processor. The processor may be configured to receive, via the transceiver, an uplink grant. The uplink grant may comprise an indication of scheduling information for a multi-physical uplink shared channel (PUSCH) transmission and a set of new data indicator (NDI) values for the multi-PUSCH transmission. The processor may be configured to determine, based on the set of NDI values, a respective uplink transmission mode for each PUSCH transmission of the multi-PUSCH transmission. The processor may be configured to transmit, via the transceiver, a first PUSCH transmission of the multi-PUSCH transmission using a first uplink transmission mode, based on the set of NDI values comprising an indication that the first PUSCH transmission is a retransmission. The processor may be configured to transmit, via the transceiver, a second PUSCH transmission of the multi-PUSCH transmission using a second uplink transmission mode, based on the set of NDI values comprising an indication the second PUSCH transmission is a transmission of new data. The first uplink transmission mode may comprise a single-panel mode, and the second uplink transmission mode may comprise a simultaneous transmission over multi-panel (STxMP) mode. The processor may be configured to determine a transmission mode based on a sequence of NDI toggle states. The processor may be configured to determine the respective uplink transmission mode based on the NDI values received in the

uplink grant and at least one previous NDI value. The processor may be configured to determine the respective uplink transmission mode based on the set of NDI values and at least one of a modulation and coding scheme (MCS) index, a number of codewords, a number PUSCHs, a PUSCH index, a redundancy version (RV) index, or a reference signal received power (RSRP) of a link between the WTRU and a transmission/reception point (TRP). Each NDI value of the set of NDI values may comprise a bit indicative of a new transmission or a retransmission, wherein a toggled on state of the bit indicates a new transmission and a toggled off state of the bit indicates a retransmission.

[0005] An example method for performing multi-PUSCH retransmission may be performed by a WTRU. The method may comprise receiving an uplink grant, the uplink grant comprising an indication of scheduling information for a multi- physical uplink shared channel (PUSCH) transmission and a set of new data indicator (NDI) values for the multi-PUSCH transmission. The method may comprise determining, based on the set of NDI values, a respective uplink transmission mode for each PUSCH transmission of the multi-PUSCH transmission. The method may comprise transmitting a first PUSCH transmission of the multi-PUSCH transmission using a first uplink transmission mode, based on the set of NDI values comprising an indication that the first PUSCH transmission is a retransmission. The method may comprise transmitting a second PUSCH transmission of the multi-PUSCH transmission using a second uplink transmission mode, based on the set of NDI values comprising an indication the second PUSCH transmission is a transmission of new data. The first uplink transmission mode may comprise a single-panel mode, and the second uplink transmission mode may comprise a simultaneous transmission over multi-panel (STxMP) mode. The method may comprise determining a transmission mode based on a sequence of NDI toggle states. The method may comprise determining the respective uplink transmission mode based on the NDI values received in the uplink grant and at least one previous NDI value. The method may comprise determining the respective uplink transmission mode based on the set of NDI values and at least one of a modulation and coding scheme (MCS) index, a number of codewords, a number PUSCHs, a PUSCH index, a redundancy version (RV) index, or a reference signal received power (RSRP) of a link between the WTRU and a transmission/reception point (TRP). Each NDI value of the set of NDI values may comprise a bit indicative of a new transmission or a retransmission, wherein a toggled on state of the bit indicates a new transmission and a toggled off state of the bit indicates a retransmission.

[0006] At least one example non-transitory computer-readable storage medium may comprise executable instructions for configuring at least one processor to perform multi-PUSCH retransmission. The executable instructions may configure at least one processor to receive an uplink grant, the uplink grant comprising an indication of scheduling information for a multi- physical uplink shared channel (PUSCH) transmission and a set of new data indicator (NDI) values for the multi-PUSCH transmission. The executable instructions may configure at least one processor to determine, based on the set of NDI

values, a respective uplink transmission mode for each PUSCH transmission of the multi-PUSCH transmission. The executable instructions may configure at least one processor to transmit a first PUSCH transmission of the multi-PUSCH transmission using a first uplink transmission mode, based on the set of NDI values comprising an indication that the first PUSCH transmission is a retransmission. The executable instructions may configure at least one processor to transmit a second PUSCH transmission of the multi-PUSCH transmission using a second uplink transmission mode, based on the set of NDI values comprising an indication the second PUSCH transmission is a transmission of new data. The first uplink transmission mode may comprise a single-panel mode, and the second uplink transmission mode may comprise a simultaneous transmission over multi-panel (STxMP) mode. The executable instructions may configure at least one processor to determine a transmission mode based on a sequence of NDI toggle states. The executable instructions may configure at least one processor to determine the respective uplink transmission mode based on the NDI values received in the uplink grant and at least one previous NDI value. The executable instructions may configure at least one processor to determine the respective uplink transmission mode based on the set of NDI values and at least one of a modulation and coding scheme (MCS) index, a number of codewords, a number PUSCHs, a PUSCH index, a redundancy version (RV) index, or a reference signal received power (RSRP) of a link between the WTRU and a transmission/reception point (TRP). Each NDI value of the set of NDI values may comprise a bit indicative of a new transmission or a retransmission, wherein a toggled on state of the bit indicates a new transmission and a toggled off state of the bit indicates a retransmission.

[0007] An example WTRU for performing fallback and mode selection for multi-PUSCH transmission may comprise a transceiver and a processor. The processor may be configured to receive, via the transceiver, a grant for simultaneous transmission over multiple panels (STxMP) of the WTRU using multiple time slots. Where the WTRU is scheduled for STxMP, the processor may be configured to determine to transmit using a single panel of the multiple panels of the WTRU during one or more time slots of the multiple time slots. The processor may be configured to transmit, via the transceiver, a time-based pattern of panel activity comprising an indication of one or more on/off periods per panel of the multiple panels of the WTRU. The time-based pattern may be transmitted via a medium access control (MAC) control element (CE). The time-based pattern may be transmitted via a channel state information (CSI) report. The time-based pattern of panel activity may be based on an availability of each panel of the multiple panels of the WTRU. The time-based pattern of panel activity may comprise at least one of a panel index, a sequence of slot indices, or panel activation status. The time-based pattern of panel activity may be transmitted based on occurrence of an event comprising at least one of a channel state information (CSI) report trigger, a beam failure, or a change in connection state. The time-based pattern of panel activity may be periodically transmitted.

[0008] An example method for performing fallback and mode selection for multi-PUSCH transmission may be performed by a WTRU. The method may comprise receiving a grant for simultaneous transmission over multiple panels (STxMP) of the WTRU using multiple time slots. Where the WTRU is scheduled for STxMP, the method may comprise determining to transmit using a single panel of the multiple panels of the WTRU during one or more time slots of the multiple time slots. The method may comprise transmitting a time-based pattern of panel activity comprising an indication of one or more on/off periods per panel. The method may comprise transmitting the time-based pattern via a medium access control (MAC) – control element (CE). The method may comprise transmitting the time-based pattern via a channel state information (CSI) report. The time-based pattern of panel activity may be based on an availability of each panel of the multiple panels of the WTRU. The time-based pattern of panel activity may comprise at least one of a panel index, a sequence of slot indices, or panel activation status. The method may comprise transmitting the time-based pattern of panel activity based on occurrence of an event comprising at least one of a channel state information (CSI) report trigger, a beam failure, or a change in connection state. The method may comprise periodically transmitting the time-based pattern of panel activity.

[0009] At least one example non-transitory computer-readable storage medium may comprise executable instructions for configuring at least one processor to perform fallback and mode selection for multi-PUSCH transmission. The executable instructions may configure at least one processor to receive a grant for simultaneous transmission over multiple panels (STxMP) of the WTRU using multiple time slots. Where the WTRU is scheduled for STxMP, the executable instructions may configure at least one processor to determine to transmit using a single panel of the multiple panels of the WTRU during one or more time slots of the multiple time slots. The executable instructions may configure at least one processor to transmit a time-based pattern of panel activity comprising an indication of one or more on/off periods per panel. The time-based pattern may be transmitted via a medium access control (MAC) – control element (CE). The time-based pattern may be transmitted via a channel state information (CSI) report. The time-based pattern of panel activity may be based on an availability of each panel of the multiple panels of the WTRU. The time-based pattern of panel activity may comprise at least one of a panel index, a sequence of slot indices, or panel activation status. Transmission of the time-based pattern of panel activity may be based on occurrence of an event, wherein the time-based pattern of panel activity is periodically transmitted, or a combination thereof.

[0010] An example WTRU for performing enhanced multi-PUSCH transmission may comprise a transceiver and a processor. The processor may be configured to receive, via the transceiver, an uplink grant comprising an indication of scheduling for retransmissions of a multi-physical uplink shared channel (PUSCH) associated with one or more codewords and one or more new data indicator (NDI) fields. The processor may be configured to determine a mapping of retransmitted PUSCH indices of the multi-PUSCH

and the one or more codewords as a function of a preconfigured mapping rule. The processor may be configured to transmit, via the transceiver, the one or more codewords based on the determined mapping. The preconfigured mapping may be based on a number of untoggled NDIs in the received uplink grant. The processor may be configured to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission starting with a first PUSCH index having at least one NDI untoggled. The processor may be configured to stack retransmissions first followed by new transmissions to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission. The preconfigured mapping may be based on a number of toggled NDIs in the received uplink grant. The processor may be configured to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission starting with a first PUSCH index having at least one NDI toggled. The processor may be configured to stack retransmissions first followed by new transmissions to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission.

[0011] An example method for enhanced multi-PUSCH transmission may be performed by a WTRU. The method may comprise receiving an uplink grant comprising an indication of scheduling for retransmissions of a multi-physical uplink shared channel (PUSCH) associated with one or more codewords and one or more new data indicator (NDI) fields. The method may comprise determining a mapping of retransmitted PUSCH indices of the multi-PUSCH and the one or more codewords as a function of a preconfigured mapping rule. The method may comprise transmitting the one or more codewords based on the determined mapping. The mapping may be based on a number of untoggled NDIs in the received uplink grant. The method may comprise stacking retransmissions first followed by new transmissions to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission. Sequentially mapping may comprise stacking retransmissions first followed by new transmissions. The mapping may be based on a number of toggled NDIs in the received uplink grant. The method may comprise stacking retransmissions first followed by new transmissions to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission. Sequentially mapping may comprise stacking retransmissions first followed by new transmissions.

[0012] At least one example non-transitory computer-readable storage medium may comprise executable instructions for configuring at least one processor to perform enhanced multi-PUSCH transmission. The executable instructions may configure at least one processor to receive an uplink grant comprising an indication of scheduling for retransmissions of a multi-physical uplink shared channel (PUSCH) associated with one or more codewords and one or more new data indicator (NDI) fields. The executable instructions may configure at least one processor to determine a mapping of retransmitted

PUSCH indices and the one or more codewords as a function of a preconfigured mapping rule. The executable instructions may configure at least one processor to transmit the one or more codewords based on the determined mapping. The mapping may be based on a number of untoggled NDIs in the received uplink grant. The executable instructions may configure at least one processor to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission starting with a first PUSCH index having at least one NDI untoggled. Sequentially mapping may comprise stacking retransmissions first followed by new transmissions. Mapping may be based on a number of toggled NDIs in the received uplink grant. The executable instructions may configure at least one processor to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission starting with a first PUSCH index having at least one NDI toggled, wherein the sequentially mapping comprising stacking retransmissions first followed by new transmissions.

[0013] An example WTRU for performing multi-PUSCH transmission with hybrid STxMP mappings may comprise a transceiver and a processor. The processor may be configured to receive, via the transceiver, an uplink grant indicating scheduling for simultaneous transmission over multiple panels (STxMP) of the WTRU with multi-physical uplink shared channel (PUSCH) transmission. The processor may be configured to determine a multi-PUSCH STxMP mode of operation based on a mode switching indication. The processor may be configured to transmit, via the transceiver, a PUSCH transmission using the determined multi-PUSCH STxMP mode of operation. The mode switching indication may comprise an indication of a switch among a first mode, a second mode, and a single-panel transmission. The first mode may comprise STxMP with a same PUSCH index on each panel of the WTRU. The second mode may comprise STxMP with a different PUSCH index on each panel of the WTRU. The processor may be configured to determine a number of PUSCHs for a first mode, a number of PUSCHs for a second mode, and a number of PUSCHs for a STxMP mode, based on the mode switching indication. The mode switching indication may comprise a table comprising different configuration patterns. The processor may be configured to determine a mapping associated with PUSCH indices as a function of a determined mode of operation for each PUSCH index.

[0014] An example method for performing multi-PUSCH transmission with hybrid STxMP mappings may be performed by a WTRU. The method may comprise receiving an uplink grant indicating scheduling for simultaneous transmission over multiple panels (STxMP) of the WTRU with multi-physical uplink shared channel (PUSCH) transmission. The method may comprise determining a multi-PUSCH STxMP mode of operation based on a mode switching indication. The method may comprise transmitting a PUSCH transmission using the determined multi-PUSCH STxMP mode of operation. The mode switching indication may comprise an indication of a switch among a first mode, a second mode, and a single-panel transmission. The first mode may comprise STxMP with a same PUSCH index on each panel of the

WTRU. The second mode may comprise STxMP with a different PUSCH index on each panel of the WTRU. The method may comprise determining a number of PUSCHs for a first mode, a number of PUSCHs for a second mode, and a number of PUSCHs for a STxMP mode, based on the mode switching indication. The mode switching indication may comprise a table comprising different configuration patterns. The method may comprise determining a mapping associated with PUSCH indices as a function of a determined mode of operation for each PUSCH index.

[0015] At least one example non-transitory computer-readable storage medium may comprise executable instructions for configuring at least one processor to perform multi-PUSCH transmission with hybrid STxMP mappings. The executable instructions may configure at least one processor to receive an uplink grant indicating scheduling for simultaneous transmission over multiple panels (STxMP) of the WTRU with multi-physical uplink shared channel (PUSCH) transmission. The executable instructions may configure at least one processor to determine a multi-PUSCH STxMP mode of operation based on a mode switching indication. The executable instructions may configure at least one processor to transmit a PUSCH transmission using the determined multi-PUSCH STxMP mode of operation. The mode switching indication may comprise an indication of a switch among a first mode, a second mode, and a single-panel transmission. The first mode may comprise STxMP with a same PUSCH index on each panel of the WTRU. The second mode may comprise STxMP with a different PUSCH index on each panel of the WTRU. The executable instructions may configure at least one processor to determine a number of PUSCHs for a first mode, a number of PUSCHs for a second mode, and a number of PUSCHs for a STxMP mode, based on the mode switching indication. The executable instructions may configure at least one processor to determine a mapping associated with PUSCH indices as a function of a determined mode of operation for each PUSCH index.

[0016] An example WTRU for performing uplink control information (UCI) multiplexing in a multi-PUSCH transmission may comprise a transceiver and a processor. The processor may be configured to receive, via the transceiver, an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels. The processor may be configured to determine, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI). The processor may be configured to transmit, via the transceiver, a PUSCH transmission multiplexed with the UCI. The WTRU may be scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index. The processor may be configured to determine on which panel to multiplex the UCI. The processor may be configured to determine the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a highest reference signal received power (RSRP) value. The processor may be configured to determine the at least

one PUSCH index on which to multiplex the UCI based on a UCI payload size. The processor may be configured to determine the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index. PUSCH indices may be assigned respective identifiers (IDs), and the processor may be configured to determine the at least one PUSCH index on which to multiplex the UCI based the PUSCH IDs of the multi-PUSCH simultaneous transmission.

[0017] An example method for performing uplink control information (UCI) multiplexing in a multi-PUSCH transmission may be performed by a WTRU. The method may comprise receiving an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels. The method may comprise determining, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI). The method may comprise transmitting a PUSCH transmission multiplexed with the UCI. The WTRU may be scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index. The method may comprise determining on which panel to multiplex the UCI. The method may comprise determining the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a highest reference signal received power (RSRP) value. The method may comprise determining the at least one PUSCH index on which to multiplex the UCI based on a UCI payload size. The method may comprise determining the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index. PUSCH indices may be assigned respective identifiers (IDs), and the method may comprise determining the at least one PUSCH index on which to multiplex the UCI based on the PUSCH IDs of the multi-PUSCH simultaneous transmission.

[0018] At least one example non-transitory computer-readable storage medium may comprise executable instructions for configuring at least one processor to perform uplink control information (UCI) multiplexing in a multi-PUSCH transmission. The executable instructions may configure at least one processor to receive an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels. The executable instructions may configure at least one processor to determine, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI). The executable instructions may configure at least one processor to transmit a PUSCH transmission multiplexed with the UCI. The WTRU may be scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index. The executable instructions may configure at least one processor to determine on which panel to multiplex the UCI. The executable instructions may configure at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a

highest reference signal received power (RSRP) value. The executable instructions may configure at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a UCI payload size. The executable instructions may configure at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] A more detailed understanding may be had from the detailed description below, wherein:

[0020] FIG. 1A is a system diagram illustrating an example communications system;

[0021] FIG. 1B is a system diagram illustrating an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A;

[0022] FIG. 1C is a system diagram illustrating an example radio access network (RAN) and an example core network (CN) that may be used within the communications system illustrated in FIG. 1A;

[0023] FIG. 1D is a system diagram illustrating a further example RAN and a further example CN that may be used within the communications system illustrated in FIG. 1A;

[0024] FIG. 2 is a diagram illustrating an example of a multi-PUSCH transmission scheme with single panel;

[0025] FIG. 3 is a diagram illustrating an example of an STxMP PUSCH operation;

[0026] FIG. 4 is a diagram illustrating an example of new data indicator (NDI) mode switching for multi-PUSCH retransmissions;

[0027] FIG. 5 is a diagram illustrating an example of retransmission of PUSCH codewords (CWs) multiplexing;

[0028] FIG. 6 is a diagram illustrating an example of codeword (CW) multiplexing with different number of retransmitted CWs;

[0029] FIG. 7 is a diagram illustrating an example of STxMP per PUSCH (Mode 1) transmission;

[0030] FIG. 8 is a diagram illustrating an example of STxMP across PUSCHs (Mode 2) transmission; and

[0031] FIG. 9 is a diagram illustrating an example of STxMP multi-PUSCH hybrid mode of operation.

DETAILED DESCRIPTION

[0032] In the following detailed description, numerous specific details are set forth to provide a thorough understanding of embodiments and/or examples disclosed herein. However, it will be understood that such embodiments and examples may be practiced without some or all of the specific details set forth herein. In other instances, well-known methods, procedures, components and circuits have not been described in detail, so as not to obscure the following description. Further, embodiments and examples not specifically described herein may be practiced in lieu of, or in combination with, the embodiments and other examples described, disclosed or otherwise provided explicitly, implicitly and/or inherently (collectively "provided") herein. Although various embodiments are described and/or claimed herein in which an apparatus, system, device, etc. and/or any element thereof carries out an operation, process, algorithm, function, etc. and/or any portion thereof, it is to be understood that any embodiments described and/or claimed herein assume that any apparatus, system, device, etc. and/or any element thereof is configured to carry out any operation, process, algorithm, function, etc. and/or any portion thereof.

[0033] The methods, procedures, apparatuses and systems provided herein are well-suited for communications involving both wired and wireless networks. An overview of various types of wireless devices and infrastructure is provided with respect to FIGs. 1A-1D, where various elements of the network may utilize, perform, be arranged in accordance with and/or be adapted and/or configured for the methods, apparatuses and systems provided herein.

[0034] FIG. 1A is a system diagram illustrating an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), zero-tail (ZT) unique-word (UW) discrete Fourier transform (DFT) spread OFDM (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0035] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104/113, a core network (CN) 106/115, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device

configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d, any of which may be referred to as a "station" and/or a "STA", may be configured to transmit and/or receive wireless signals and may include (or be) a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a subscription-based unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, a hotspot or Mi-Fi device, an Internet of Things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical device and applications (e.g., remote surgery), an industrial device and applications (e.g., a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. Any of the WTRUs 102a, 102b, 102c and 102d may be interchangeably referred to as a UE. Further, any description herein that is described with reference to a UE may be equally applicable to a WTRU (or *vice versa*). For example, a WTRU may be configured to perform any of the processes or procedures described herein as being performed by a UE (or *vice versa*).

[0036] The communications systems 100 may also include a base station 114a and/or a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d, e.g., to facilitate access to one or more communication networks, such as the CN 106/115, the Internet 110, and/or the networks 112. By way of example, the base stations 114a, 114b may be any of a base transceiver station (BTS), a Node-B (NB), an eNode-B (eNB), a Home Node-B (HNB), a Home eNode-B (HeNB), a gNode-B (gNB), a NR Node-B (NR NB), a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0037] The base station 114a may be part of the RAN 104/113, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals on one or more carrier frequencies, which may be referred to as a cell (not shown). These frequencies may be in licensed spectrum, unlicensed spectrum, or a combination of licensed and unlicensed spectrum. A cell may provide coverage for a wireless service to a specific geographical area that may be relatively fixed or that may change over time. The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in an embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In an embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and may utilize multiple transceivers for each or any sector of the cell. For example, beamforming may be used to transmit and/or receive signals in desired spatial directions.

[0038] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 116, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, centimeter wave, micrometer wave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 116 may be established using any suitable radio access technology (RAT).

[0039] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104/113 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 116 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink Packet Access (HSDPA) and/or High-Speed Uplink Packet Access (HSUPA).

[0040] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface 116 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A) and/or LTE-Advanced Pro (LTE-A Pro).

[0041] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as NR Radio Access, which may establish the air interface 116 using New Radio (NR).

[0042] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement multiple radio access technologies. For example, the base station 114a and the WTRUs 102a, 102b, 102c may implement LTE radio access and NR radio access together, for instance using dual connectivity (DC) principles. Thus, the air interface utilized by WTRUs 102a, 102b, 102c may be characterized by multiple types of radio access technologies and/or transmissions sent to/from multiple types of base stations (e.g., an eNB and a gNB).

[0043] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (Wi-Fi)), IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

[0044] The base station 114b in FIG. 1A may be a wireless router, Home Node-B, Home eNode-B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, an industrial facility, an air corridor (e.g., for use by drones), a roadway, and the like. In an embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In an embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In an embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, LTE-A Pro, NR, etc.) to establish any of a small cell, picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the CN 106/115.

[0045] The RAN 104/113 may be in communication with the CN 106/115, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. The data may have varying quality of service (QoS) requirements, such as differing throughput requirements, latency requirements, error tolerance requirements, reliability requirements, data throughput requirements, mobility requirements, and the like. The CN 106/115 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104/113 and/or the CN 106/115 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104/113 or a different RAT. For example, in addition to being connected to the RAN 104/113, which may be utilizing an NR radio technology, the CN 106/115 may also be in communication with another RAN (not shown) employing any of a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or Wi-Fi radio technology.

[0046] The CN 106/115 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and/or the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired and/or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104/114 or a different RAT.

[0047] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities (e.g., the WTRUs 102a, 102b, 102c, 102d may include multiple transceivers for communicating with different wireless networks over different wireless links). For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0048] FIG. 1B is a system diagram illustrating an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130, removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and/or other elements/peripherals 138, among others. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0049] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together, e.g., in an electronic package or chip.

[0050] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station 114a) over the air interface 116. For example, in an embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In an embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In an embodiment, the transmit/receive element 122 may be configured to transmit and/or receive both RF and light signals. It will be appreciated that the transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0051] Although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. For example, the WTRU 102 may employ MIMO technology. Thus, in an embodiment, the WTRU 102 may include two or more transmit/receive

elements 122 (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface 116.

[0052] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as NR and IEEE 802.11, for example.

[0053] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0054] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), etc.), solar cells, fuel cells, and the like.

[0055] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset 136, the WTRU 102 may receive location information over the air interface 116 from a base station (e.g., base stations 114a, 114b) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0056] The processor 118 may further be coupled to other elements/peripherals 138, which may include one or more software and/or hardware modules/units that provide additional features, functionality and/or wired or wireless connectivity. For example, the elements/peripherals 138 may include an accelerometer,

an e-compass, a satellite transceiver, a digital camera (e.g., for photographs and/or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, a virtual reality and/or augmented reality (VR/AR) device, an activity tracker, and the like. The elements/peripherals 138 may include one or more sensors, the sensors may be one or more of a gyroscope, an accelerometer, a hall effect sensor, a magnetometer, an orientation sensor, a proximity sensor, a temperature sensor, a time sensor; a geolocation sensor; an altimeter, a light sensor, a touch sensor, a magnetometer, a barometer, a gesture sensor, a biometric sensor, and/or a humidity sensor.

[0057] The WTRU 102 may include a full duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for both the uplink (e.g., for transmission) and downlink (e.g., for reception) may be concurrent and/or simultaneous. The full duplex radio may include an interference management unit to reduce and or substantially eliminate self-interference via either hardware (e.g., a choke) or signal processing via a processor (e.g., a separate processor (not shown) or via processor 118). In an embodiment, the WTRU 102 may include a half-duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for either the uplink (e.g., for transmission) or the downlink (e.g., for reception)).

[0058] FIG. 1C is a system diagram illustrating the RAN 104 and the CN 106 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 116. The RAN 104 may also be in communication with the CN 106.

[0059] The RAN 104 may include eNode-Bs 160a, 160b, 160c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 160a, 160b, 160c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In an embodiment, the eNode-Bs 160a, 160b, 160c may implement MIMO technology. Thus, the eNode-B 160a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0060] Each of the eNode-Bs 160a, 160b, and 160c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink (UL) and/or downlink (DL), and the like. As shown in FIG. 1C, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0061] The CN 106 shown in FIG. 1C may include a mobility management entity (MME) 162, a serving gateway (SGW) 164, and a packet data network (PDN) gateway (PGW) 166. While each of the foregoing

elements are depicted as part of the CN 106, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the CN operator.

[0062] The MME 162 may be connected to each of the eNode-Bs 160a, 160b, and 160c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 162 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The MME 162 may provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM and/or WCDMA.

[0063] The SGW 164 may be connected to each of the eNode-Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The SGW 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The SGW 164 may perform other functions, such as anchoring user planes during inter-eNode-B handovers, triggering paging when DL data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0064] The SGW 164 may be connected to the PGW 166, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0065] The CN 106 may facilitate communications with other networks. For example, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the CN 106 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 106 and the PSTN 108. In addition, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers.

[0066] Although the WTRU is described in FIGs. 1A-1D as a wireless terminal, it is contemplated that in certain representative embodiments that such a terminal may use (e.g., temporarily or permanently) wired communication interfaces with the communication network.

[0067] In representative embodiments, the other network 112 may be a WLAN.

[0068] A WLAN in infrastructure basic service set (BSS) mode may have an access point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may have an access or an interface to a distribution system (DS) or another type of wired/wireless network that carries traffic into and/or out of the BSS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be

delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to respective destinations. Traffic between STAs within the BSS may be sent through the AP, for example, where the source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. The traffic between STAs within a BSS may be considered and/or referred to as peer-to-peer traffic. The peer-to-peer traffic may be sent between (e.g., directly between) the source and destination STAs with a direct link setup (DLS). In certain representative embodiments, the DLS may use an 802.11e DLS or an 802.11z tunneled DLS (TDLS). A WLAN using an Independent BSS (IBSS) mode may not have an AP, and the STAs (e.g., all of the STAs) within or using the IBSS may communicate directly with each other. The IBSS mode of communication may sometimes be referred to herein as an "ad-hoc" mode of communication.

[0069] When using the 802.11ac infrastructure mode of operation or a similar mode of operations, the AP may transmit a beacon on a fixed channel, such as a primary channel. The primary channel may be a fixed width (e.g., 20 MHz wide bandwidth) or a dynamically set width via signaling. The primary channel may be the operating channel of the BSS and may be used by the STAs to establish a connection with the AP. In certain representative embodiments, Carrier sense multiple access with collision avoidance (CSMA/CA) may be implemented, for example in 802.11 systems. For CSMA/CA, the STAs (e.g., every STA), including the AP, may sense the primary channel. If the primary channel is sensed/detected and/or determined to be busy by a particular STA, the particular STA may back off. One STA (e.g., only one station) may transmit at any given time in a given BSS.

[0070] High throughput (HT) STAs may use a 40 MHz wide channel for communication, for example, via a combination of the primary 20 MHz channel with an adjacent or nonadjacent 20 MHz channel to form a 40 MHz wide channel.

[0071] Very high throughput (VHT) STAs may support 20 MHz, 40 MHz, 80 MHz, and/or 160 MHz wide channels. The 40 MHz, and/or 80 MHz, channels may be formed by combining contiguous 20 MHz channels. A 160 MHz channel may be formed by combining 8 contiguous 20 MHz channels, or by combining two non-contiguous 80 MHz channels, which may be referred to as an 80+80 configuration. For the 80+80 configuration, the data, after channel encoding, may be passed through a segment parser that may divide the data into two streams. Inverse fast fourier transform (IFFT) processing, and time domain processing, may be done on each stream separately. The streams may be mapped on to the two 80 MHz channels, and the data may be transmitted by a transmitting STA. At the receiver of the receiving STA, the above-described operation for the 80+80 configuration may be reversed, and the combined data may be sent to a medium access control (MAC) layer, entity, etc.

[0072] Sub 1 GHz modes of operation are supported by 802.11af and 802.11ah. The channel operating bandwidths, and carriers, are reduced in 802.11af and 802.11ah relative to those used in 802.11n, and 802.11ac. 802.11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV white space (TVWS) spectrum, and 802.11ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.11ah may support meter type control/machine-type communications (MTC), such as MTC devices in a macro coverage area. MTC devices may have certain capabilities, for example, limited capabilities including support for (e.g., only support for) certain and/or limited bandwidths. The MTC devices may include a battery with a battery life above a threshold (e.g., to maintain a very long battery life).

[0073] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11n, 802.11ac, 802.11af, and 802.11ah, include a channel which may be designated as the primary channel. The primary channel may have a bandwidth equal to the largest common operating bandwidth supported by all STAs in the BSS. The bandwidth of the primary channel may be set and/or limited by a STA, from among all STAs in operating in a BSS, which supports the smallest bandwidth operating mode. In the example of 802.11ah, the primary channel may be 1 MHz wide for STAs (e.g., MTC type devices) that support (e.g., only support) a 1 MHz mode, even if the AP, and other STAs in the BSS support 2 MHz, 4 MHz, 8 MHz, 16 MHz, and/or other channel bandwidth operating modes. Carrier sensing and/or network allocation vector (NAV) settings may depend on the status of the primary channel. If the primary channel is busy, for example, due to a STA (which supports only a 1 MHz operating mode), transmitting to the AP, the entire available frequency bands may be considered busy even though a majority of the frequency bands remains idle and may be available.

[0074] In the United States, the available frequency bands, which may be used by 802.11ah, are from 902 MHz to 928 MHz. In Korea, the available frequency bands are from 917.5 MHz to 923.5 MHz. In Japan, the available frequency bands are from 916.5 MHz to 927.5 MHz. The total bandwidth available for 802.11ah is 6 MHz to 26 MHz depending on the country code.

[0075] FIG. 1D is a system diagram illustrating the RAN 113 and the CN 115 according to an embodiment. As noted above, the RAN 113 may employ an NR radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 113 may also be in communication with the CN 115.

[0076] The RAN 113 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 113 may include any number of gNBs while remaining consistent with an embodiment. The gNBs 180a, 180b, 180c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In an embodiment, the gNBs 180a, 180b, 180c may implement MIMO

technology. For example, gNBs 180a, 180b may utilize beamforming to transmit signals to and/or receive signals from the WTRUs 102a, 102b, 102c. Thus, the gNB 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. In an embodiment, the gNBs 180a, 180b, 180c may implement carrier aggregation technology. For example, the gNB 180a may transmit multiple component carriers to the WTRU 102a (not shown). A subset of these component carriers may be on unlicensed spectrum while the remaining component carriers may be on licensed spectrum. In an embodiment, the gNBs 180a, 180b, 180c may implement Coordinated Multi-Point (CoMP) technology. For example, WTRU 102a may receive coordinated transmissions from gNB 180a and gNB 180b (and/or gNB 180c).

[0077] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using transmissions associated with a scalable numerology. For example, OFDM symbol spacing and/or OFDM subcarrier spacing may vary for different transmissions, different cells, and/or different portions of the wireless transmission spectrum. The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using subframe or transmission time intervals (TTIs) of various or scalable lengths (e.g., including a varying number of OFDM symbols and/or lasting varying lengths of absolute time).

[0078] The gNBs 180a, 180b, 180c may be configured to communicate with the WTRUs 102a, 102b, 102c in a standalone configuration and/or a non-standalone configuration. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c without also accessing other RANs (e.g., such as eNode-Bs 160a, 160b, 160c). In the standalone configuration, WTRUs 102a, 102b, 102c may utilize one or more of gNBs 180a, 180b, 180c as a mobility anchor point. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using signals in an unlicensed band. In a non-standalone configuration WTRUs 102a, 102b, 102c may communicate with/connect to gNBs 180a, 180b, 180c while also communicating with/connecting to another RAN such as eNode-Bs 160a, 160b, 160c. For example, WTRUs 102a, 102b, 102c may implement DC principles to communicate with one or more gNBs 180a, 180b, 180c and one or more eNode-Bs 160a, 160b, 160c substantially simultaneously. In the non-standalone configuration, eNode-Bs 160a, 160b, 160c may serve as a mobility anchor for WTRUs 102a, 102b, 102c and gNBs 180a, 180b, 180c may provide additional coverage and/or throughput for servicing WTRUs 102a, 102b, 102c.

[0079] Each of the gNBs 180a, 180b, 180c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the UL (uplink) and/or DL (downlink), support of network slicing, dual connectivity, interworking between NR and E-UTRA, routing of user plane data towards user plane functions (UPFs) 184a, 184b, routing of control

plane information towards access and mobility management functions (AMFs) 182a, 182b, and the like. As shown in FIG. 1D, the gNBs 180a, 180b, 180c may communicate with one another over an Xn interface.

[0080] The CN 115 shown in FIG. 1D may include at least one AMF 182a, 182b, at least one UPF 184a, 184b, at least one session management function (SMF) 183a, 183b, and at least one Data Network (DN) 185a, 185b. While each of the foregoing elements are depicted as part of the CN 115, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0081] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N2 interface and may serve as a control node. For example, the AMF 182a, 182b may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, support for network slicing (e.g., handling of different protocol data unit (PDU) sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of NAS signaling, mobility management, and the like. Network slicing may be used by the AMF 182a, 182b, e.g., to customize CN support for WTRUs 102a, 102b, 102c based on the types of services being utilized WTRUs 102a, 102b, 102c. For example, different network slices may be established for different use cases such as services relying on ultra-reliable and low latency communications (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for MTC access, and/or the like. The AMF 182 may provide a control plane function for switching between the RAN 113 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-3GPP access technologies such as Wi-Fi.

[0082] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 115 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 115 via an N4 interface. The SMF 183a, 183b may select and control the UPF 184a, 184b and configure the routing of traffic through the UPF 184a, 184b. The SMF 183a, 183b may perform other functions, such as managing and allocating WTRU IP address, managing PDU sessions, controlling policy enforcement and QoS, providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0083] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, e.g., to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The UPF 184a, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0084] The CN 115 may facilitate communications with other networks. For example, the CN 115 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 115 and the PSTN 108. In addition, the CN 115 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers. In an embodiment, the WTRUs 102a, 102b, 102c may be connected to a local Data Network (DN) 185a, 185b through the UPF 184a, 184b via the N3 interface to the UPF 184a, 184b and an N6 interface between the UPF 184a, 184b and the DN 185a, 185b.

[0085] In view of FIGs. 1A-1D, and the corresponding description of FIGs. 1A-1D, one or more, or all, of the functions described herein with regard to any of: WTRUs 102a-d, base stations 114a-b, eNode-Bs 160a-c, MME 162, SGW 164, PGW 166, gNBs 180a-c, AMFs 182a-b, UPFs 184a-b, SMFs 183a-b, DNs 185a-b, and/or any other element(s)/device(s) described herein, may be performed by one or more emulation elements/devices (not shown). The emulation devices may be one or more devices configured to emulate one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0086] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all, functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network. The emulation device may be directly coupled to another device for purposes of testing and/or may perform testing using over-the-air wireless communications.

[0087] The one or more emulation devices may perform the one or more, including all, functions while not being implemented/deployed as part of a wired and/or wireless communication network. For example, the emulation devices may be utilized in a testing scenario in a testing laboratory and/or a non-deployed (e.g., testing) wired and/or wireless communication network in order to implement testing of one or more components. The one or more emulation devices may be test equipment. Direct RF coupling and/or wireless communications via RF circuitry (e.g., which may include one or more antennas) may be used by the emulation devices to transmit and/or receive data.

[0088] Regarding multi-PUSCH transmissions a WTRU may be scheduled using a single downlink control information (DCI) with up to 8 PUSCH(s) in time-division multiplexed (TDMed) slots. For example, referring to FIG. 2, a PUSCHconfig may contain a multi-PUSCH time domain resource allocation (TDRA)

table (*pusch-TimeDomainAllocationListForMultiPUSCH*), where one row may be configured with up to eight Start and Length Indicator Values (SLIVs) (one per PUSCH) where the SLIV (start and length indicator value) may determine the starting symbol, and number of symbols allocated per PUSCH. Each PUSCH (e.g., PUSCH1, PUSCH2, PUSCH8 as depicted in FIG. 2) may correspond to one transport block (TB). In an example configuration, a PUSCH may be associated with a single CW. One K2 value may determine the time offset from the DCI to the first PUSCH; the remaining PUSCHs may be contiguously allocated following the SLIV and K2 of the first PUSCH. Uplink (UL) DCI may comprise an indicator that points to one of the TDRA rows. The UL DCI 202 may comprise, a New Data Indicator (NDI). An NDI may comprise a bit indicative of a new transmission or a retransmission, wherein a toggled on state of the bit indicates a new transmission and a toggled off state of the bit indicates a retransmission. For example, an NDI may comprise 1 bit per PUSCH (e.g., up to 8) to indicate if it is a new transmission (toggled on), or if it is a retransmission (toggled off). The UL DCI may comprise a Redundancy Version (RV), which may comprise 1 bit per PUSCH (e.g., up to 8) to indicate the redundancy value. The UL DCI may comprise a Modulation and Coding Scheme (MCS), which may comprise 1 field to indicate the modulation and coding for all indices. The UL DCI may comprise one frequency domain resource assignment (FDRA), and SRI(sounding reference signal) / TPMI (transmit precoding matric indicator), which may apply to all PUSCH indices. The UL DCI may comprise one hybrid automatic repeat request (HARQ) process identifier (ID) for the first PUSCH; wherein the WTRU may determine the HARQ process ID for the other indices by incrementing by one for each successive PUSCH.

[0089] FIG. 3 is a diagram illustrating an example of an STxMP PUSCH operation. Simultaneous transmission on multi-panel (STxMP) PUSCH may be used. For example, referring to FIG. 3, a WTRU equipped with two panels simultaneously transmits in the same time slot using both panels. An example single DCI (or sDCI) case may consider only complete overlap in time and frequency of both panel transmissions (e.g., no partial overlap). PUSCHconfig may contain a TDRA table, and there may be a single CW PUSCH where different layers are transmitted over different panels. The uplink DCI may contain: one FDRA and TDRA that applies to both panels; two SRIs/TPMIs which indicate the precoder and layers per panel (e.g., total number of layers across panels is limited to 4 for example) (Layer combinations: {1+1, 1+2, 2+1, 2+2}); Radio Resource Control (RRC) configured STxMP mode of operation (Spatial Division Multiplexing (SDM) for different data (e.g., block 302 or FIG. 3), or Single Frequency Network (SFN) for repetitions) (e.g., block 304 of FIG. 3); and dynamic switching between single panel and STxMP mode of operation using SRS (sounding reference signal) resource set indicator: "00" indicates single panel to transmission/reception point 1 (TRP1), "01" indicates single panel to TRP2, "10" indicates STxMP, and "11" is reserved.

[0090] As described herein, single DCI (or sDCI) PUSCH may support simultaneous transmission on multi-panel (STxMP) WTRUs towards multiple TRPs with a single CW. As further described herein, a WTRU may be configured to operate with STxMP when two CWs and/or multi-PUSCH are enabled.

[0091] In multi-PUSCH retransmission with STxMP, a WTRU may transmit multi-PUSCH in an initial transmission, and the network (e.g., a gNB) may receive one of the PUSCHs in error. The network (e.g., the gNB) may schedule the WTRU with sTRP multi-PUSCH transmission(s). The WTRU behavior for retransmission of erroneous PUSCH indices is discussed herein.

[0092] In an example, the WTRU behavior may include determining the mode of operation per PUSCH index in a multi-PUSCH retransmission. In this example, the WTRU may be configured to perform one or more of the following operations or procedures.

[0093] The WTRU may receive an UL grant including scheduling for a multi-PUSCH transmission with an NDI/RV indicating retransmissions for at least one PUSCH index.

[0094] The WTRU may determine the UL transmission mode of operation (single panel or STxMP) for the retransmitted PUSCH indices where one or more of the following may apply. The WTRU may determine the transmission mode per PUSCH index as a function of the New Data Indicator (NDI) value where a toggled NDI field (i.e., new data) indicates single panel mode, and an untoggled NDI value (i.e., retransmission) indicates STxMP (e.g., STxMP SFN).

[0095] A WTRU may determine a respective UL transmission mode based on NDI values received in an UL grant and at least one previous NDI value. The WTRU may determine the transmission mode per PUSCH index as a function of the previous and current NDI values (e.g., toggled+toggled, toggled+untoggled, untoggled+untoggled) associated with each PUSCH index. When sTRP/single panel is used, the WTRU may determine the TRP for transmission based on one or more of the NDI values.

[0096] The WTRU may determine per PUSCH index to transmit with STxMP mode as a function of a combination of NDI and other parameter where a WTRU may consider one (or more) of the following parameters (examples in details for each parameter): MCS being above a threshold; number of layers/CWs being above a threshold (e.g., only if single CW is used); number of PUSCHs or PUSCH index being above a threshold; Redundancy Version (RV) index; number of toggled NDIs being above a threshold; and/or reference signal received power (RSRP) of WTRU-TRP link.

[0097] A WTRU may determine to reset the sequence of toggled state after a preconfigured time threshold since the last reception of a toggled NDI. The WTRU may transmit a PUSCH with each PUSCH index based on the determined UL transmission mode for each PUSCH index. In an example, a WTRU transmits a PUSCH with a first PUSCH index with a single panel, and a PUSCH with a second PUSCH

index in STxMP. In an example, in sTRP mode, a WTRU may explicitly or implicitly determine the TRP index (e.g., a default index, the strongest one, re-transmission on the strongest one). In an example, when retransmission is indicated in sTRP mode, the WTRU may retransmit on the same TRP as the initial transmission. In an example, the WTRU may use the status of an NDI or combination of NDIs to determine the TRP for a sTRP retransmission.

[0098] Regarding fallback from Multi-PUSCH STxMP to Single-panel Transmission and WTRU-assisted Mode Selection, a WTRU may be scheduled to transmit in STxMP, however, the WTRU may not be able to use one or more panels on the scheduled slots. As such, methods and procedures may be desired to address single panel fallback when a WTRU cannot transmit in STxMP on scheduled slots.

[0099] As described herein, a WTRU may be configured to perform one or more of the following operations or procedures. In some examples, SFN or SDM behaviors performed by the WTRU may be different.

[0100] A WTRU may receive a grant to transmit in STxMP over multiple slots, where the WTRU may not be able to use one or more panels on one or more slots from the grant. The WTRU may determine to transmit using a single panel on slots where the WTRU is scheduled for STxMP, and may perform one or more of the following operations.

[0101] In an example (e.g., fallback), a WTRU may determine to fallback to sTRP based on one or more of the following: MPE (maximum permissible exposure) with STxMP scheduled exceeds a threshold; RSRP for a panel or RSRP difference between indicated panels is below a threshold for STxMP; power domain (e.g., PCmax) issue such as exceeding a max SAR (total radiated power) threshold; and/or Inactive panel is scheduled for STxMP. For example, as described below, the WTRU may receive a grant for STxMP using multiple time slots. The WTRU may determine, however, to transmit using a single panel of the multiple panels of the WTRU during at least one of the time slots. The WTRU may transmit a time-based pattern of panel activity comprising one or more on/off periods per panel of the multiple panels of the WTRU.

[0102] If the WTRU determines to fallback, the WTRU may perform one or more of the following. The WTRU may transmit on one of the panels, where a panel is selected by the WTRU based on a priority rule (e.g., panel index, PUSCH index, signal quality, default configuration, and/or layer/CW index fallback). The WTRU may determine the cause of fallback, and the WTRU may trigger the transmission of a feedback, such as for example, a MAC-control element (CE) or uplink control information (UCI), to indicate the fallback cause, and the panel index and/or PUSCH index where fallback occurred. The WTRU may transmit on the determined panel, and includes information about the fallback panel (e.g., info for next slot available, whether the WTRU transmitted, or a gNB failure).

[0103] The time-based pattern may be transmitted via a MAC-CE. The time-based pattern may be transmitted via a channel state information (CSI) report. In an example Semi-static WTRU-aided configuration, the WTRU may transmit a time-based pattern of panel activity to the gNB (e.g., MAC-CE or CSI report) which indicates the on/off periods per panel. The WTRU may indicate the panel indices (e.g., SRS resource sets), and the active symbols/slots where the WTRU may transmit in single panel, and where the WTRU may transmit in STxMP. The time-based pattern of panel activity may be based on an availability of each panel of the multiple panels of the WTRU. The WTRU may determine that it may be scheduled in STxMP when its indicated pattern indicates that both panels are simultaneously active. The time-based pattern of panel activity may comprise at least one of a panel index, a sequence of slot indices, or panel activation status. In an example, if the WTRU is scheduled for PUSCH transmission, the WTRU may determine the mode of operation (e.g., single panel or STxMP) as a function of 1) the symbol/slot index, 2) panel indices, and/or 3) the pattern of panel activity. The WTRU may transmit (e.g., PUSCH transmission) using the determined mode of operation.

[0104] Regarding NDI for Multi-PUSCH with two CWs, a WTRU may retransmit each failed CW in a separate slot/symbol as a function of the SLIV. Using different slots/symbols may add latency to the retransmissions. As such, enhanced methods of using NDI for two CWs and multi-PUSCH transmission are described herein.

[0105] A WTRU may be configured to perform one or more of the following operations or procedures. A WTRU may receive an UL grant including scheduling for retransmissions of a multi-PUSCH with one or more CWs and one or more NDI fields. The WTRU may receive (e.g., in an UL grant) NDI fields and determine the mapping of retransmitted PUSCH indices and codewords (CWs) as a function of a preconfigured mapping rule, where the rule may be one or more of the following. Further, the WTRU may transmit the one or more CWs based on the determined mapping.

[0106] A WTRU may apply the rule as a function of the number of untoggled NDIs in the scheduling grant. The preconfigured mapping may be based the state of NDIs in the received UL grant. The preconfigured mapping may be based on a number of untoggled NDIs in the received UL grant. The preconfigured mapping may be based on a number of toggled NDIs in the received UL grant. A WTRU may sequentially map the PUSCH indices and CWs from the initial transmission onto the CWs of the retransmission starting with the first PUSCH index that has at least one NDI untoggled. The WTRU may stack retransmissions first followed by new transmissions to sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission. Thus, the WTRU may sequentially map the PUSCH indices and CWs from the initial transmission onto the CWs of the retransmission starting with the first PUSCH index that has at least one NDI untoggled, then in ascending

PUSCH index, and then in ascending CW index (e.g., stacking retransmissions first, then new transmissions). For example, if the number of untoggled NDIs is greater than or equal to 2, start with the first PUSCH index with at least one untoggled NDI, map the first two retransmissions in ascending PUSCH index order, and ascending CW order (based on the PUSCH index and CW index of the initial transmission), then continue with the next PUSCH index with at least one untoggled NDI and map the next two (one if only one left) retransmissions, and repeat until all retransmissions have been mapped. The WTRU may sequentially map the PUSCH indices and codewords from an initial transmission onto the codewords of the retransmission starting with a first PUSCH index having at least one NDI toggled. The WTRU may map the CWs with the toggled NDIs to the unused PUSCH indices in a similar fashion (e.g., ascending PUSCH index order, and ascending CW order).

[0107] The WTRU may retransmit the CWs of the initial multi-PUSCH transmission (e.g., the CWs with the NDIs untoggled) based on the determined mapping. The WTRU may transmit new CWs (e.g., the CWs with the NDIs toggled) based on the determined mapping.

[0108] Regarding multi-PUSCH with hybrid STxMP mappings, a WTRU may be configured to transmit multi-PUSCH with different STxMP mappings. The WTRU may determine to transmit multi-PUSCH with STxMP, and map (or determine the mappings) the PUSCHs to respective panels.

[0109] A WTRU may be configured to perform one or more of the following operations or procedures. The WTRU may receive an UL scheduling grant for STxMP with multi-PUSCH. The WTRU may receive an UL grant indicating scheduling for STxMP of the WTRU with multi-PUSCH. The WTRU may determine a multi-PUSCH STxMP mode of operation based on a mode switching indication. WTRU may determine the time-pattern of multi-PUSCH STxMP modes of operation based on a received mode switching indication, where the WTRU switches between Mode 1 (STxMP with the same PUSCH index on both panels), Mode 2 (STxMP with different PUSCH indices on the panels), and single panel transmission. The WTRU may transmit a PUSCH transmission using the multi-PUSCH STxMP mode of operation.

[0110] A WTRU may receive an RRC/MAC-CE configuration indicating which mode to use and/or parameters/thresholds associated with each of one or more of the modes. The mode to use may be a function of the number of PUSCHs, n (e.g., in a slot), compared to a threshold. For example, if $n < n_1$ PUSCH, a WTRU transmits in STxMP mode 1 (e.g., in the slot). If $n_1 < n < n_2$ PUSCH, a WTRU transmits in STxMP mode 2 (e.g., in the slot). If $n > n_2$, a WTRU transmits in single panel PUSCH (e.g., in the slot). A mode switching indication may comprise switching among a first mode, a second mode, and a single-panel mode. For example, the first mode may comprise STxMP with the same PUSCH index on each panel of the WTRU and the second mode may comprise STxMP with a different PUSCH index on each panel of the WTRU. The mode to use for a multi-PUSCH transmission may be a function of a pattern which associates

each PUSCH index to a transmission mode. For example, the WTRU transmits PUSCH index n_1 in STxMP mode 1, PUSCH index n_2 in STxMP mode 2, and PUSCH index n_3 in single panel. The WTRU may determine a number of PUSCHs for a first mode, a number of PUSCHs for a second mode, and a number of PUSCHs for a STxMP mode, based on the mode switching indication.

[0111] A WTRU may receive a dynamic indication in a DCI to dynamically switch between Mode 1, Mode 2, and single panel for the multiple PUSCHs of a scheduled multi-PUSCH transmission. The mode switching indication may comprise a table comprising different configuration patterns. The WTRU may determine the mode of operation based on the TDRA table configuration with different configured patterns. The dynamic indication may be a TDRA table configuration where a row indicates a pattern of modes of operation. The WTRU may determine a mapping associated with PUSCH indices as a function of a determined mode of operation for each PUSCH index. The WTRU may determine the SRI/TPMI mapping to PUSCH indices as a function of the determined mode of operation for each PUSCH index. In one example, the WTRU transmits a PUSCH for each PUSCH index based on the determined mode using the determined SRI/TPMI.

[0112] Regarding UCI multiplexing in STxMP multi-PUSCH transmission, when a UCI overlaps with a PUSCH transmission, there may be a process/rule for selecting which PUSCH index carries the UCI. For example, when a DCI format 0_1 schedules two PUSCH allocations, the aperiodic CSI (channel state information) report may be carried on the second scheduled PUSCH. When a DCI format 0_1 schedules more than two PUSCH allocations, the aperiodic CSI report may be carried on the penultimate scheduled PUSCH.

[0113] With STxMP and multi-PUSCH, two PUSCH indices may be simultaneously transmitted (SDM), or the same PUSCH index is transmitted on both panels (SFN). The WTRU may determine on which panel to multiplex the UCI (e.g., carrying a CSI report). As described herein, a WTRU may determine the UCI multiplexing process/rule in STxMP multi-PUSCH.

[0114] A WTRU may be configured to perform one or more of the following operations or procedures. The WTRU may receive an UL grant including scheduling for a multi-PUSCH STxMP transmission with one PUSCH index per panel (SDM), or the same PUSCH index on two panels (SFN). The WTRU may determine, based on the UL grant, at least one PUSCH index on which to multiplex UCI. Further, the WTRU may transmit the PUSCH transmission multiplexed with the UCI. The WTRU may be scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index. If the WTRU is scheduled to transmit a UCI in a slot that overlaps in time with more than one PUSCH index (SDM), the WTRU determines at least one PUSCH index where the UCI is multiplexed onto, where one or more of the following apply.

[0115] A WTRU may determine on which panel to multiplex the UCI. The WTRU may select the PUSCH index with the lowest ID. The WTRU may select the PUSCH index transmitted on the panel with the highest RSRP. The WTRU may select the PUSCH index transmitted on the panel with the highest RSRP as last reported by the WTRU. The WTRU may determine at least one PUSCH index on which to multiplex the UCI based on a UCI payload size. In an example, in SDM where two different PUSCH indices are simultaneously transmitted, the WTRU may multiplex the UCI on one or two of the PUSCH indices (e.g., as a function of the UCI payload size above a threshold). The WTRU may determine at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index. If two PUSCH indices are STxMP'd together, and one PUSCH index is a retransmission, and another PUSCH index is a new transmission, the WTRU may multiplex onto the PUSCH index of the new transmission. If the WTRU determines that the second last PUSCH index is a retransmission, the WTRU may check other PUSCH indices, and may map on a PUSCH index carrying a new transmission. The WTRU may multiplex the UCI on the PUSCH index based on the mode of operation of the PUSCH index (e.g., selects the ones with STxMP SFN). The WTRU may multiplex the UCI with the PUSCH of the determined PUSCH index and transmits the multiplexed UCI and PUSCH.

[0116] Regarding terminology used herein, 'a' and 'an' and similar phrases are to be interpreted as 'one or more' and 'at least one'. Similarly, any term which ends with the suffix '(s)' is to be interpreted as 'one or more' and 'at least one'. The term 'may' is to be interpreted as 'may, for example'. A sign, symbol, or mark of forward slash '/' is to be interpreted as 'and/or' unless particularly mentioned otherwise, where for example, 'A/B' may imply 'A and/or B'.

[0117] A WTRU may transmit or receive a physical channel or reference signal (RS) according to at least one spatial domain filter. The term "beam" may be used to refer to a spatial domain filter.

[0118] A WTRU may transmit a physical channel or signal using the same spatial domain filter as the spatial domain filter used for receiving an RS (such as CSI-RS – channel state information reference signal) or a SS (synchronization signal) block. The WTRU transmission may be referred to as "target", and the received RS or SS block may be referred to as "reference" or "source". In such case, the WTRU may be said to transmit the target physical channel or signal according to a spatial relation with a reference to such RS or SS block.

[0119] The WTRU may transmit a first physical channel or signal according to the same spatial domain filter as the spatial domain filter used for transmitting a second physical channel or signal. The first and second transmissions may be referred to as "target" and "reference" (or "source"), respectively. In such case, the WTRU may be said to transmit the first (target) physical channel or signal according to a spatial relation with a reference to the second (reference) physical channel or signal.

[0120] A spatial relation may be implicit, configured by RRC or signaled by MAC CE or DCI. For example, a WTRU may implicitly transmit PUSCH and DM-RS (demodulation reference signal) of PUSCH according to the same spatial domain filter as an SRS indicated by an SRS resource indicator (SRI) indicated in DCI or configured by RRC. In another example, a spatial relation may be configured by RRC for an SRI or signaled by MAC CE for a PUCCH. Such spatial relation may also be referred to as a “beam indication”.

[0121] The WTRU may receive a first (target) downlink channel or signal according to the same spatial domain filter or spatial reception parameter as a second (reference) downlink channel or signal. For example, such association may exist between a physical channel such as PDCCH or PDSCH and its respective DM-RS. At least when the first and second signals are reference signals, such association may exist when the WTRU is configured with a quasi-colocation (QCL) assumption type D between corresponding antenna ports. Such association may be configured as a transmission configuration indicator (TCI) state. A WTRU may be indicated an association between a CSI-RS or SS block and a DM-RS by an index to a set of TCI states configured by RRC and/or signaled by MAC CE. Such indication may also be referred to as a “beam indication”.

[0122] A unified transmission configuration indicator (TCI) (e.g., a common TCI, a common beam, a common RS, etc.) may refer to a beam/RS to be (simultaneously) used for multiple physical channels/signals. The term “TCI” may at least comprise a TCI state that includes at least one source RS to provide a reference (e.g., WTRU assumption) for determining QCL and/or spatial filter.

[0123] A WTRU may receive (e.g., from a gNB) an indication of a first unified TCI to be used/applied for both a downlink control channel (PDCCH) and a downlink shared channel (PDSCH) (e.g., and a downlink RS). The source reference signal(s) in the first unified TCI may provide common QCL information at least for WTRU-dedicated reception on the PDSCH and all (or subset of) CORESETs in a control channel (CC). A WTRU may receive (e.g., from a gNB) an indication of a second unified TCI to be used/applied for both an uplink control channel (PUCCH) and an uplink shared channel (PUSCH) (e.g., and an uplink RS). The source reference signal(s) in the second unified TCI may provide a reference for determining common UL TX spatial filter(s) at least for dynamic-grant/configured-grant based PUSCH and all (or subset of) dedicated PUCCH resources in a CC.

[0124] A WTRU may be configured with a first mode for unified TCI (e.g., Separate DL/UL/TCI mode) where an indicated unified TCI (e.g., the first unified TCI or the second unified TCI) may be applicable for either downlink (e.g., based on the first unified TCI) or uplink (e.g., based on the second unified TCI).

[0125] A WTRU may receive (e.g., from a gNB) an indication of a second unified TCI to be used/applied commonly for a PDCCH, a PDSCH, a PUCCH, and a PUSCH (and a DL RS and/or a UL RS).

[0126] A WTRU may be configured with a second mode for unified TCI (e.g., JointTCI mode) where an indicated unified TCI (e.g., the third unified TCI) may be applicable for both downlink and uplink (e.g., based on the third unified TCI).

[0127] A WTRU may determine a TCI state applicable to a transmission or reception by first determining a Unified TCI state instance applicable to this transmission or reception, then determining a TCI state corresponding to the Unified TCI state instance. A transmission may consist of at least PUCCH, PUSCH, SRS. A reception may consist of at least PDCCH, PDSCH, CSI-RS. A Unified TCI state instance may also be referred to TCI state group, TCI state process, unified TCI pool, a group of TCI states, a set of time-domain instances/stamps/slots/symbols, and/or a set of frequency-domain instances/RBs/subbands, etc. A Unified TCI state instance may be equivalent or identified to a Coreset Pool identity (e.g., CORESETPoolIndex, a TRP indicator, and/or the like).

[0128] Hereafter, unified TCI may be interchangeably used with one or more of unified TCI-states, unified TCI instance, TCI, and TCI-state, but still consistent with this invention.

[0129] Hereafter, a TRP (e.g., transmission and reception point) may be interchangeably used with one or more of TP (transmission point), RP (reception point), RRH (radio remote head), DA (distributed antenna), BS (base station), a sector (of a BS), a cell (e.g., a geographical cell area served by a BS), a CSI-RS resource set, but still consistent with this invention. Hereafter, Multi-TRP may be interchangeably used with one or more of MTRP, M-TRP, and multiple TRPs, but still consistent with this invention.

[0130] A WTRU may be configured with (or may receive configuration of) one or more TRPs to which the WTRU may transmit and/or from which the WTRU may receive. The WTRU may be configured with one or more TRPs for one or more cells. A cell may be a serving cell, secondary cell.

[0131] A WTRU may be configured with at least one RS for the purpose of channel measurement. This RS may be denoted as a Channel Measurement Resource (CMR) and may comprise a CSI-RS, SSB, or other downlink RS transmitted from the TRP to a WTRU. A CMR may be configured or associated with a TCI state. A WTRU may be configured with a CMR group where CMRs transmitted from the same TRP may be configured. Each group may be identified by a CMR group index (e.g., group 1). A WTRU may be configured with one CMR group per TRP, and the WTRU may receive a linkage between one CMR group index and another CMR group index, or between one RS index from one CMR group and another RS index from another group.

[0132] A WTRU may be configured with (or receive configuration of) one or more pathloss (PL) reference groups (e.g., sets) and/or one or more SRS groups, SRS resource indicator (SRI) or SRS resource sets.

[0133] A public land (PL) reference group may correspond to or may be associated with a TRP. A PL reference group may include, identify, correspond to or be associated with one or more TCI states, SRIs, reference signal sets (e.g., CSI-RS set, SRI sets), CORESET index, and or reference signals (e.g., CSI-RS, SSB).

[0134] A WTRU may receive a configuration (e.g., any configuration described herein). The configuration may be received from a gNB or TRP. For example, the WTRU may receive configuration of one or more TRPs, one or more PL reference groups and/or one or more SRI sets. A WTRU may implicitly determine an association between a RS set/group and a TRP. E.g., if the WTRU is configured with two SRS resource sets, then the WTRU may determine to transmit to TRP1 with SRS in the first resource set, and to TRP2 with SRS in the second resource set. The configuration may be via RRC signaling.

[0135] In the examples and embodiments described herein, TRP, PL reference group, SRI group, and SRI set may be used interchangeably. The terms set and group may be used interchangeably herein.

[0136] A WTRU may report a subset of channel state information (CSI) components, where CSI components may correspond to at least a CSI-RS resource indicator (CRI) which indicates one CSI-RS resource out of a CSI-RS resource set, a SSB resource indicator (SSBRI) which indicates one SSB out of a set of SSBs, an indication of a panel used for reception at the WTRU (such as a panel identity or group identity), measurements such as L1-RSRP, L1-SINR taken from SSB or CSI-RS (e.g., cri-RSRP, cri-SINR, ssb-Index-RSRP, ssb-Index-SINR), and other channel state information such as at least rank indicator (RI), channel quality indicator (CQI), precoding matrix indicator (PMI), Layer Index (LI), and/or the like.

[0137] In various embodiments, a property of a grant or assignment may comprise one or more of the following: a frequency allocation, an aspect of time allocation, such as a duration; a priority; a modulation and coding scheme; a transport block size; a number of spatial layers; a number of transport blocks; a TCI state, CRI or SRI; a number of repetitions; Whether the repetition scheme is Type A or Type B; whether the grant is a configured grant type 1, type 2 or a dynamic grant; whether the assignment is a dynamic assignment or a semi-persistent scheduling (configured) assignment; a configured grant index or a semi-persistent assignment index; a periodicity of a configured grant or assignment; a channel access priority class (CAPC); and/or any parameter provided in a DCI, by MAC or by RRC for the scheduling the grant or assignment, or any appropriate combination thereof.

[0138] In the following, an indication by DCI may comprise one or more of the following: an explicit indication by a DCI field or by radio network identifier (RNTI) used to mask CRC (cyclic redundancy check) of the PDCCH, An implicit indication by a property such as DCI format, DCI size, Coreset or search space, Aggregation Level, first resource element of the received DCI (e.g., index of first CCE - Control Channel

Element), where the mapping between the property and the value may be signaled by RRC or MAC, or any appropriate combination thereof.

[0139] Hereafter, a signal may be interchangeably used with one or more of following: sounding reference signal (SRS); channel state information – reference signal (CSI-RS); demodulation reference signal (DM-RS); phase tracking reference signal (PT-RS); and/or synchronization signal block (SSB).

[0140] Hereafter, a channel may be interchangeably used with one or more of following: physical downlink control channel (PDCCH); physical downlink shared channel (PDSCH); physical uplink control channel (PUCCH); physical uplink shared channel (PUSCH); and/or physical random access channel (PRACH).

[0141] Hereafter, downlink reception may be used interchangeably with receiving occasion, PDCCH, PDSCH, SSB reception, but still consistent with this invention.

[0142] Hereafter, uplink transmission may be used interchangeably with transmitting occasion, PUCCH, PUSCH, PRACH, SRS transmission, but still consistent with this invention.

[0143] Hereafter, RS may be interchangeably used with one or more of RS resource, RS resource set, RS port and RS port group, but still consistent with this invention.

[0144] Hereafter, RS may be interchangeably used with one or more of SSB, CSI-RS, SRS and DM-RS, but still consistent with this invention.

[0145] Hereafter, time instance may be interchangeably used with slot, symbol, subframe, but still consistent with this invention.

[0146] Regarding Multi-PUSCH retransmission with STxMP, a WTRU may be configured to determine the STxMP transmission mode as a function of the NDI values (e.g., toggled state). In a multi-PUSCH scheduled transmission, a WTRU may determine the mode of operation per PUSCH index transmission as a function of the NDI field. A first UL transmission mode may comprise a single panel mode and a second UL transmission mode may comprise a STxMP mode. The mode of operation may be single panel transmission where the WTRU transmits a PUSCH using a single panel, or STxMP where the WTRU transmits a PUSCH using both panels simultaneously. A WTRU may receive an UL grant comprising an indication of scheduling information for multi-PUSCH transmission and a set of NDI values for the multi-PUSCH transmission. A WTRU may receive a grant scheduling an UL transmission with multi-PUSCH (e.g., CG-configured grant or cell group or DG-dynamic grant) where the WTRU may determine that each PUSCH may be scheduled for transmission on a single panel based on a field in the DCI (e.g., SRS resource set, TPMI, SRI, SRS resource set indicator) indicating single panel transmission. The WTRU may determine, based on NDI values, a respective uplink transmission mode for each PUSCH transmission of

the multi-PUSCH transmission. The WTRU may receive an NDI field per PUSCH index in the UL grant, and the NDI may be toggled or untoggled. If the NDI is toggled, the NDI field is a 1 bit, and the WTRU determines to transmit a new TBS (transport block size) that was not previously transmitted. Further, the WTRU may transmit a PUSCH transmission of the multi-PUSCH transmission using the uplink transmission mode based on the NDI values indicating that the PUSCH transmission is a retransmission. For example, if the NDI is untoggled, the NDI field is a 0 bit, and the WTRU determines to retransmit a TBS that was previously transmitted in a PUSCH index scheduled in a prior UL grant. If the WTRU supports STxMP mode of operation, the WTRU may receive a configuration to interpret the NDI field such that the WTRU may determine the transmission mode (e.g., single panel or STxMP) as a function of the NDI's toggled state. For example, if the NDI is toggled, the WTRU may transmit on a single panel. If the NDI is untoggled, the WTRU may transmit in STxMP (e.g., SDM or SFN) over both panels. The two panels may be associated to the same or different panel identity (e.g., C-RNTI, or other panelwise scrambling identity), so that the WTRU may determine to scramble the PUSCH with the same or different panel identity as a function of the NDI's toggled state. Similarly, the WTRU may transmit a second PUSCH transmission of the multi-PUSCH transmission using a second uplink transmission mode, based on the set of NDI values comprising an indication the second PUSCH transmission is a transmission of new data.

[0147] A WTRU may be configured to determine the transmission panel as a function of a sequence of NDI values (e.g., toggled states). A WTRU may determine to switch panels as a function of the NDI's toggled state. For example, in a first UL grant, a WTRU may be scheduled with PUSCH index 1 on panel 1 and with a toggled NDI. In a second UL grant, a WTRU is scheduled with PUSCH index 1 with an untoggled NDI. The WTRU may determine to transmit the PUSCH index 1 in the second UL grant on panel 2 (e.g., switch panels). If the WTRU has more than one panel, a WTRU may receive a preconfigured pattern of panel indices so that the WTRU may switch panels according to a pattern. For example, the panel pattern may be configured as [panel 1, panel 2, panel3], and the WTRU may transmit on panel 1 for a toggled NDI associated with one PUSCH index, and may transmit on panel 2 if it receives a first untoggled NDI, and may transmit on panel 3 if it receives a second untoggled NDI with the same PUSCH index.

[0148] A WTRU may be configured to determine the transmission mode (e.g., single panel or STxMP) as a function of a sequence of NDI toggled states. FIG. 4 is a diagram illustrating an example of new data indicator (NDI) mode switching for multi-PUSCH retransmissions. A WTRU may transmit a PUSCH transmission of the multi-PUSCH transmission using the uplink transmission mode based on the NDI values indicating that the PUSCH transmission is a transmission of new data. A WTRU may dynamically determine the mode of operation as a function of more than one NDI field (e.g., a time-indexed sequence of NDI toggled states), where the NDI fields are associated to the same PUSCH index and received in

different UL grants (e.g., different time slots). FIG. 4 illustrates an exemplary procedure. In this example, the WTRU may receive an NDI table configuration (e.g., block 402 in FIG. 4) which indicates the mode of operation associated to a sequence of NDI. The sequence of NDI state may be time indexed such that the WTRU considers the NDI at time t_0 and at time t_1 . The WTRU may consider the sequence per PUSCH index. In this example, the RRC configured table defines that two NDIs received in scheduling grants at times n and $n+1$, (NDI _{n} , NDI _{$n+1$}), are mapped to a mode of operation (sTRP or STxMP). In this example, if the WTRU receives (0,0) (e.g., untoggled NDIs at times n and $n+1$) for a given PUSCH index the WTRU determines to transmit the given PUSCH index in STxMP. As depicted in FIG. 4, the WTRU performs the switching at time t_0 , t_1 , and t_2 as a function of the sequence of NDIs for PUSCH indices 1 and 2, and the WTRU determines to switch panels at time t_1 , and to transmit in STxMP at time t_2 .

[0149] After determining the mode of operation, the WTRU may transmit a first PUSCH index with the first determined mode of operation (e.g., single panel, or STxMP), and may transmit a second PUSCH index with a second determined mode of operation (e.g., single panel, or STxMP).

[0150] A WTRU may be configured to determine the transmission mode (e.g., single panel or STxMP) as a function of the NDI based on other parameters. A WTRU may determine the mode of operation as a function of other parameters in the grant in addition to the NDI field. The WTRU may receive a configuration which conditions the interpretation of the NDI on one or more additional parameters. If the condition is not met, the WTRU may interpret the NDI as legacy. If the condition is met, the WTRU may interpret the NDI as previously described herein. The WTRU may use one or more of the following parameters to determine the condition that may be satisfied to use the NDI field to determine the transmission mode of operation: MCS index - for example, if the MCS is greater than a threshold, the WTRU may interpret the NDI as STxMP for transmission mode of the i 'th PUSCH; Number of CWs - for example, if the number of CWs is greater than a threshold, the WTRU may interpret the NDI as STxMP for transmission mode of the i 'th PUSCH; Number of PUSCHs - for example, if the number of scheduled PUSCH indices is greater than a threshold, the WTRU may interpret the NDI as STxMP for transmission mode of the i 'th PUSCH; PUSCH index - for example, if the PUSCH index is greater than a threshold, the WTRU may interpret the NDI as STxMP for transmission mode of the i 'th PUSCH; RV index - for example, if the number of CWs is greater than a threshold, the WTRU may interpret the NDI as STxMP for transmission mode of the i 'th PUSCH; Number of toggled/untoggled NDIs - or example, if the number of toggled or untoggled NDIs is above a threshold, the WTRU interprets the NDI to determine the mode of operation, or an appropriate combination thereof.

[0151] A WTRU may be configured to reset sequence of toggled state after a certain time period (e.g., a timer expires). In some previous examples, the WTRU may keep track of the sequence of toggled states of

current and previous NDIs. However, in some cases, the sequence of toggled states may become unsynchronized between the WTRU and network. For example, a WTRU may not correctly decode an UL DCI carrying an NDI which may create an ambiguity in the sequence. In various embodiments discussed below, the WTRU may reset the sequence of toggled NDI states to an initial state.

[0152] The WTRU may receive a configured timer or time threshold, where the WTRU may reset the sequence of toggled states mapped to the transmission mode if the timer expires. For example, the timer, t_d , may be defined or configured per PUSCH index, and the timer may start counting with respect to the UL grant with the first toggled NDI for a given PUSCH index (i). For example, a WTRU may receive a toggled NDI for PUSCH index i at time t_0 . The WTRU may start counting from t_0 until the time t_0+t_d . During the period t_0 until t_0+t_d , the WTRU may map the sequence of NDIs (NDI_n , NDI_{n+1}) using the preconfigured table to determine the transmission mode of operation. After t_0+t_d , the WTRU may reset the sequence of NDIs to (0, 0). The WTRU may receive an initial state of configured (NDI_n , NDI_{n+1}) values (e.g., (0,0)) which may be the default state that the WTRU selects when the timer expires.

[0153] A WTRU may fall back to single panel transmission in slots scheduled for STxMP. A WTRU may be configured with a second fallback transmission for single panel transmissions and with a first STxMP transmission configuration. These transmission configurations may have specific correlation with SRI resources assigned per panel. Additionally, these configurations may specify specific triggering conditions related to the STxMP performance. These side conditions may be expressed as following: maximum permissible exposure (MPE) or specific absorption rate (SAR) related power reduction per transmitting panel; UL duty cycle/Power Class exceeded; power imbalance between transmitting panels exceeding a threshold; power scaling invoked for a panel transmitting a PUSCH with multiplexed UCI; and/or WTRU Panel change, or panel activation, based on panel activation delay time. In some cases, panel activation time may be a predefined delay or a WTRU capability-based value.

[0154] For the MPE or SAR related power reduction case, a WTRU may report by MAC CE power headroom (PHR) the P_{max} (FR1) and $P_{cmax} + P$ -maximum power reduction (MPR) (FR2) per beam. This may not be a very dynamic process as the SAR or MPE values may be evaluated over a certain period. Still, this power reduction does not affect a panel or multiple panels, until the WTRU triggers the PHR report, that is when the evaluation period is exceeded and the SAR/MPE conditions are met. If the WTRU is in STxMP mode while the SAR/MPE fallback triggering conditions are met, in one embodiment the WTRU may transmit the MAC CE within STxMP configuration without applying the P-MPR to maximize the chances of a successful transmission, and then fallback to the single panel (the non MPE/SAR affected panel) configured mode. The activation time of the fallback mode may be indicated by subsequent UL DCI scheduled grant or at the end of a PUSCH repetition cycle.

[0155] The WTRU may fallback immediately to single panel, and transmit the MAC CE in single panel transmission mode. If a PUSCH repetition is ongoing, the WTRU may continue in a single panel fallback mode.

[0156] A WTRU may declare under its capability a Power Class and its related duty cycle for which the MPE compliance may be guaranteed. The P-MPR application in this case may be invoked only when the duty cycle is exceeded, and the sustained UL scheduling goes beyond reported duty cycle and the MPE/SAR conditions are present (Human body proximity detected) The conditions described are in favor of maintaining the UL coverage as long as possible.

[0157] In the STxMP case, when MPE/SAR exposure may be related to a single panel, the other panel(s) may not be affected, and thus a single panel fallback may maintain a sustained UL scheduling even beyond the declared duty cycle. However, this fallback to single panel needs to be signaled to the network for correct UL reception mode from the WTRU.

[0158] In one embodiment, the WTRU may trigger a signaling message (e.g., an indication) for the single panel fallback. In an example, this message/signal may be sent over UCI (as a single bit) or as a multi-panel PHR (MAC CE) where only the single panel maintained in the fallback has the parameters set (e.g., P_{max}, panel index, or an active SRI indication), for example, according to the single panel transmission.

[0159] Regarding power imbalance between transmitting panels exceeding a threshold, a WTRU may measure the related RSRP for each active panel/beam. The RSRP measurements may consequently be used for the pathloss estimation and the power allocation for each UL transmission respectively per panel. A WTRU may detect a certain power imbalance that may lead to excessive power allocations for one of the panels. This may not be a very energy efficient mode of operation and the WTRU may switch/fallback to single panel operation.

[0160] The RSRP/Power imbalance threshold may be a configured threshold event with an associated time to trigger timer. When the WTRU detects the inter-panel power imbalance for the time to trigger period, it may reset the timer and trigger the signaling for the single panel mode fallback. This event may be sent via UCI as a fallback indication related to the configured event, via MAC CE or MAC CE PHR enhanced with the indication information (that may be a single bit), or RRC reporting.

[0161] Power scaling may be invoked for a panel transmitting a PUSCH with multiplexed UCI. While a WTRU is operating in STxMP mode the P_{max} may be computed for each UL panel transmission and then compared with the max equivalent isotropic radiated power (EIRP) and max TRP as composite powers. This operation may be executed for each scheduled STxMP slot.

[0162] These transmissions may or not share a single maximum EIRP value depending on the AoD (Angle of Departure) of each beam. However, the maximum TRP is a limit. The P_{cm} per beam is the value limit that is used in the power allocation equations in physical layer. If the power allocation suggests a power value that exceeds P_{cm} for a beam, a scaling operation may take place in order to comply with the P_{cm} limit. The scaling may be invoked for a single or both beams. When the UL power scaling is invoked, the STxMP operation mode may not be efficient, and the WTRU may use the fallback to single panel operation. If the WTRU estimates that with a single panel the power scaling is not required, it will fallback and signal the fallback to the network. The signaling may be a PHR with negative power headroom indicated for the affected beam or both beams.

[0163] Regarding an inactive panel/panel changed scheduled for STxMP case, a WTRU may have to switch active panels or activate a new panel. This situation may require a delayed scheduling due to a panel warm up or a first measurement in downlink of a related TRP RS to properly evaluate the RSRP and consequently the pathloss for power allocations.

[0164] If the WTRU is scheduled with STxMP while a single panel is active, the WTRU may use the fallback single panel operation, until the second panel can be put in active mode. If the WTRU capability contains a specific activation delay time, the WTRU may start STxMP operation after the expiration of this delay, while operating in single panel mode.

[0165] If the panel activation is from a cold state (no previous measurements or activity), and there is no WTRU warm up/activation delay specified, then the first STxMP UL transmission may occur after the first RSRP measurement report on that panel/TRP, or the first CSI feedback with the in-range values for the newly activated panel. The WTRU also may signal the next available slot (as an offset) for STxMP operation.

[0166] A WTRU may indicate a time-based pattern associated with panel indices to indicate slots where panel indices are active/inactive. A WTRU may possess more accurate/up-to-date knowledge on which of its panel is active/inactive, and when both are available for STxMP at any given slot index. The WTRU may have a plurality of panels amongst which only a subset may be used for STxMP. The availability of different panel indices may follow a predetermined pattern in time that is specific to each WTRU. For some WTRUs, all panels may be always on, but only available for STxMP in a subset of slots (e.g., to save power). In another example, a WTRU may cycle through different periods of turning one or more of its panels on and/or off to save power, reduce inter-panel interference, etc. A WTRU may provide a CSI or panel report to assist the network in determining the active times of the WTRU panels. This may provide additional information to the network when scheduling the WTRU with STxMP to select resources only when the WTRU is capable of doing it.

[0167] A WTRU may generate a new type of content for CSI report or capability where the WTRU may indicate the time-based patterns of activity for each of its panels. The time-based pattern may comprise one or more of the following: the panel index (e.g., SRS resource set index, scrambling identity such as RNTI, TCI state index), sequence of slot indices (e.g., cyclic, sequential, configurable pattern), and panel activation status (e.g., on or off, available or not for STxMP).

[0168] A WTRU may report as part of its capability that it supports two panels. The WTRU may include in the CSI report that panel index 1 has a cyclic activity pattern of [on(slot1,slot3), off(slot2,slot4)] where (slot1,slot3) and (slot2,slot4) are the slot index pairs associated with the on or off status, respectively. The pattern may map to the slot indices in the radio frame (e.g., an NR radio frame has 10 slots, and slot1 corresponds to the first slot of the NR radio frame), or to the individual OFDM symbols of one slot. The pattern may restart after slot4. The WTRU may include in the CSI report that panel index 2 has a sequential activity pattern of [on(slot1,slot2),off(slot3,slot4)]. The WTRU may also indicate that it may be scheduled for STxMP only on a subset of the slots where both panels are active, e.g., slot1. For example, based on these patterns, slot5 also has both panels active, but a WTRU may not be capable of doing STxMP during that time slot so only slot1 is indicated for STxMP. Then, the network may determine to schedule the WTRU in STxMP only on slot1 of a frame. The WTRU may also include a period of time in seconds where the pattern may be valid. For example, the WTRU may indicate that the pattern repeats indefinitely; alternatively, the WTRU may indicate that the pattern is valid for the next T_pattern seconds. After sending its pattern, the WTRU may receive an indication from the network to acknowledge the reception of the panel pattern of activity such as a field in a DCI, or MAC-CE.

[0169] The WTRU may report its set of panels, and may indicate panel pairs which may be used for STxMP. The WTRU may indicate a bitmap which maps to a pair of panel indices. For example, a WTRU may report in its capability that it supports 3 panels, with 2 bits mapping to panel pairs P1-P2 (00), P1-P3 (01), P2-P3 (10), and no pairs (11). If the WTRU reports 00, then it indicates that it supports STxMP on panels P1-P2. In this case, the WTRU determines and reports the panel pattern of activity per panel pair. For example, STxMP is supported for the panel pair P1-P2 during even slots.

[0170] The WTRU may be configured with a CSI report configuration where the reporting type is configured to include the panel pattern of activity. The WTRU may periodically transmit the time-based pattern of panel activity. The WTRU may periodically report the CSI, or may be triggered with an AP-CSI report.

[0171] A time-based pattern of panel activity may be transmitted based on occurrence of an event. An event may comprise any appropriate event, such as, for example, a channel state information (CSI) report trigger, a beam failure, a change in connection state, or any appropriate combination thereof. A WTRU

may be triggered based on an event to transmit the panel pattern of activity. An event may comprise a downlink signal (e.g., a RS such as CSI-RS, SSB) or channel (e.g., such as PDSCH or PDCCH) received by the WTRU. One or more of the following may be used to trigger the report: 1) a WTRU may determine that an AP-CSI report trigger may also trigger the WTRU to report its pattern of panel activity; 2) a WTRU may trigger a RACH (random access channel) procedure to request resources to transmit the pattern of panel activity; 3) a beam failure event may trigger the WTRU to report its pattern of panel activity; and/or 4) a change of connection state (e.g., transition from IDLE/INACTIVE to CONNECTED) may trigger the WTRU to report its pattern of panel activity.

[0172] Regarding NDI for multi-PUSCH with two CWs, a WTRU may receive an UL grant including scheduling information for a M-PUSCH (multi-PUSCH) transmission with two codewords. The scheduled 2xM codewords may be transmitted over M sequential transmission occasions defined by the indicated row of the configured TDRA. The configured TDRA table may be configured with up to M SLIVs where the SLIV determines the number of symbols per PUSCH or in other words per pair of codewords.

[0173] In each scheduling DCI, a WTRU may receive 2xM bits as NDI information where each NDI bit indicates whether the corresponding transmitted codeword in an earlier transmission has been decoded successfully.

[0174] In a multi-PUSCH transmission, when the state of an NDI bit associated to a codeword indicates an unsuccessful decoding, the failed codeword may be re-transmitted along with the new set of codewords, e.g., transport blocks, if any. For re-transmission of the failed codewords, one or more of the following pre-configured mapping procedures may be used.

[0175] A WTRU may apply the rule as a function of the number of untoggled NDIs in the scheduling grant. For example, if the number of untoggled NDI is one, a WTRU may use one mapping rule, and when the number of untoggled NDI is 4, a WTRU may use a different mapping rule.

[0176] In one embodiment, a WTRU may re-transmit each failed codeword according to its original codeword index and transmission occasion. For example, for re-transmission of a failed codeword that was originally transmitted as CW_x over a transmission opportunity identified by SLIV_y, the re-transmission will also occur as CW_x over the transmission opportunity identified by SLIV_y.

[0177] A WTRU may use one or more of the following preconfigured strategies for transmission of new and failed codewords.

[0178] FIG. 5 illustrates an example of retransmitting PUSCH CWs with multiplexing. As depicted in FIG. 5, a WTRU may first re-transmit the failed codewords, and then transmit the codewords of the new transport blocks.

[0179] A WTRU may sequentially map the PUSCH indices and CWs from the initial transmission onto the CWs of the retransmission starting with the first PUSCH index that has at least one NDI untoggled, then in ascending PUSCH index, and then in ascending CW index (e.g., stacking retransmissions first, then new transmissions). For example, if the number of untoggled NDIs is greater than or equal to 2, start with the first PUSCH index with at least one untoggled NDI, map the first two retransmissions in ascending PUSCH index order, and ascending CW order (based on the PUSCH index and CW index of the initial transmission), then continue with the next PUSCH index with at least one untoggled NDI and map the next two (one if only one left) retransmissions, and repeat until all retransmissions have been mapped. The WTRU may map the CWs with the toggled NDIs to the unused PUSCH indices in a similar fashion (e.g., ascending PUSCH index order, and ascending CW order). A WTRU may first transmit the codewords of the new transport blocks, and then re-transmits the failed codewords. When possible, a WTRU may spread re-transmission of failed codewords by pairing re-transmission of one failed codeword with transmission of a new codeword per PUSCH occasion.

[0180] For re-transmission of failed codewords, a WTRU configured with M-PUSCH transmission, may receive a scheduling grant with a reduced M to be used only for re-transmissions. For example, for an M=8 multi-PUSCH transmission, if 6 codewords out of the originally 16 scheduled codewords are not decoded successfully, the TDRA field in the new scheduling DCI may indicate a multi-PUSCH transmission with M=3 where all codewords and transmission occasions identified by the indicated row of the configured TDRA table are allocated for re-transmission.

[0181] FIG. 6 is a diagram illustrating an example of codeword (CW) multiplexing with different number of retransmitted CWs, FIG. 6 illustrates an example where the retransmissions (602) require less PUSCH indices than the initial transmission. As depicted in FIG. 6, the first PUSCH for retransmission includes two CWs whereas the second PUSCH index includes only one CW. Different PUSCH indices may be transmitted with different modes of operation (e.g., STxMP SDM for the PUSCH retransmission with two CWs, and single panel or STxMP SFN for the PUSCH retransmission with a single CW).

[0182] Mapping of the codewords for retransmission may be according to the transmission rank for the scheduled multi-PUSCH. For example, if the transmission rank is even, failed codewords may be re-transmitted as CW_1 or CW_2 in any of transmission occasions in a scheduled M-PUSCH using one or more of the exemplary rules discussed herein.

[0183] If the transmission rank is not even, e.g., rank=5 where the first and second codewords are scheduled for transmission with rank=2 and 3, respectively, a WTRU may re-transmit a failed codeword in transmission occasions where there is possibility of a re-transmission with that rank. For example, with a multi-PUSCH transmission with M=8, and assuming use of the configured mapping rule where a WTRU

may first re-transmit the failed codewords, and then transmits the codewords of the new transport blocks. If a recent transmission of two codewords CW_1 and CW_2 of two different transmission occasions, e.g., the first and the second PUSCHs, fail, for their -re-transmission, both codewords may be stacked in a same transmission occasion that is the first PUSCH occasion of the newly scheduled M-PUSCH. However, if the failed codewords of an earlier transmission are both codewords CW_1 and CW_1 of their corresponding transmission occasions, e.g., the first and the second PUSCHs, then for their re-transmission, each codeword may be mapped as the CW_1 of the first and the second PUSCH.

[0184] In a multi-PUSCH transmission with two codewords, transmission of each codeword may be assigned to a specific panel. For example, a WTRU may transmit CW_1 by a first panel and may transmit CW_2 by a second panel. In one embodiment, the mapping of the codewords for retransmission may be defined according to the supported number of SRS ports per panel for the scheduled multi-PUSCH. For example, if a same number of SRS ports is configured per panel, the failed codewords may be re-transmitted by any of the panel in any of transmission occasions in a scheduled M-PUSCH using one or more of the exemplary rules discussed earlier.

[0185] In one embodiment, if a same number of SRS ports is not configured per panel, e.g., 2 SRS ports for a first panel and 3 SRS ports for a second panel, a WTRU may re-transmit a failed codeword only in transmission occasions where there is possibility of a re-transmission with the expected number of SRS ports.

[0186] With a multi-PUSCH transmission with M=8, and assuming use of the configured mapping rule where a WTRU may first re-transmit the failed codewords, and then transmits the codewords of the new transport blocks. If a recent transmission of two codewords CW_1 and CW_2 of two different transmission occasions, e.g., the first and the second PUSCHs, fail, for their -re-transmission, both codewords can be stacked in a same transmission occasion that is the first PUSCH occasion of the newly scheduled M-PUSCH and transmitted by a first and a second panel according to their respective expected number of SRS ports. However, if the failed codewords of an earlier transmission are both codewords CW_1 and CW_1 of their corresponding transmission occasions, e.g., the first and the second PUSCHs, then for their re-transmission, each codeword may be mapped as the CW_1 of the first and the second PUSCH and transmitted by the panel that has the expected number of SRS ports.

[0187] Regarding multi-PUSCH with hybrid STxMP mappings, a WTRU may receive configuration indicating at least one of following modes of operation on combinations of STxMP and multi-PUSCH.

[0188] FIG. 7 is a diagram illustrating an example of STxMP per PUSCH (Mode 1) transmission. In Mode 1, a WTRU may transmit multi-PUSCH where each PUSCH is a STxMP transmission, as illustrated in FIG. 7.

[0189] FIG. 8 is a diagram illustrating an example of STxMP across PUSCHs (Mode 2) transmission. In Mode 2, a WTRU may transmit multi-PUSCH with STxMP of different PUSCH indices, as illustrated in FIG. 8.

[0190] FIG. 9 is a diagram illustrating an example of STxMP multi-PUSCH hybrid mode of operation. In Mode 3, a WTRU may transmit multi-PUSCH where STxMP is done across PUSCHs or per PUSCH as a function of the time index, e.g., as illustrated in FIG. 9.

[0191] Mode 1 is an example of multi-PUSCH via STxMP in the layer domain. Based on Mode 1 (as illustrated in FIG. 7) being configured, enabled, activated, or indicated (e.g., by RRC, MAC-CE, and/or DCI), a WTRU may receive a UL grant including scheduling information for a M-PUSCH transmission (multi-PUSCH), with performing STxMP transmission in the layer domain for each (or at least one) PUSCH of the M-PUSCH transmission. The UL grant (e.g., UL-DCI) may indicate $N (>1)$ different beam indications (e.g., via SRIs, UL-TCIs, joint UL/DL TCIs, etc.) and/or N different UL precoding indications (e.g., TPMIs), where the value of N may be based on the number of (active) UE-panels used for STxMP transmission.

[0192] The N different beam indications may be signaled by N SRI fields, N UL-TCI fields, or N (joint) TCI fields, e.g., in the same UL grant. The UL grant may further indicate 1 index to the row of a TDRA table, e.g., configured as `pusch-TimeDomainAllocationListForMultiPUSCH`, where the WTRU may determine a value of $K2_1$ indicating a starting time for the M-PUSCH transmission. Based on the Mode 1, the WTRU may transmit PUSCH1 via STxMP where N separated sets of PUSCH layers, each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) UE-panels simultaneously on the starting time determined by $K2_1$. After the transmission of PUSCH1, the WTRU may transmit PUSCH2 via STxMP where N separated sets of PUSCH layers, each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) WTRU-panels simultaneously, K_offset after the end of the transmission of PUSCH1, and so forth. The value of K_offset may be configured (or indicated) to the WTRU, or determined based on a pre-defined rule. The value of K_offset may be zero, which means there may be no time gap between two consecutive PUSCHs of the M-PUSCH transmission.

[0193] A WTRU may be indicated to apply at least one different PUSCH layer split on one or more PUSCHs of the M-PUSCH transmission. For example, the PUSCH1 and PUSCH2 may be transmitted according to above such that N separated sets of PUSCH layers (e.g., a 1st set of layers $L1 = 2$, a 2nd set of layers $L2 = 2$, in case of $N=2$ WTRU-panels, total 4-layer transmission via STxMP) are transmitted across N WTRU-panels as STxMP, while a PUSCH3 may be transmitted via STxMP by applying $L1=1$ (e.g., 1 layer from 1st WTRU-panel) and $L2=3$ (e.g., 3 layers from 2nd WTRU-panel), with other related parameter(s) (e.g., each associated TPMI on each set of layers). This may provide flexibility on having

different numbers of layers (and/or different corresponding TPMIs, etc.) for STxMP across different PUSCHs of the M-PUSCH transmission. Such different parameter combinations (e.g., $\{L1=2, L2=2\}$ or $\{L1=1, L2=3\}$, etc.) may be indicated via the UL grant (e.g., via the index indicating a row of TDRA table) or separately indicated (e.g., based on an association with a value indicated by the UL grant).

[0194] Mode 2: Multi-PUSCH via STxMP for PUSCH-pairs: Based on Mode 2 (as illustrated in FIG. 8) being configured, enabled, activated, or indicated (e.g., by RRC, MAC-CE, and/or DCI), a WTRU may receive a UL grant including scheduling information for a M-PUSCH transmission (multi-PUSCH), with performing STxMP transmission for at least two PUSCHs of the M-PUSCH transmission. The UL grant (e.g., UL-DCI) may indicate $N (>1)$ different beam indications (e.g., via SRIs, UL-TCIs, joint UL/DL TCIs, etc.) and/or N different UL precoding indications (e.g., TPMIs), where the value of N may be based on the number of (active) WTRU-panels used for STxMP transmission.

[0195] The N different beam indications may be signaled by N SRI fields, N UL-TCI fields, or N (joint) TCI fields, e.g., in the same UL grant. The UL grant may further indicate 1 index to the row of a TDRA table, e.g., configured as `pusch-TimeDomainAllocationListForMultiPUSCH`, where the WTRU may determine a value of $K2$ indicating a starting time for the M-PUSCH transmission. Based on the Mode 2, the WTRU may transmit PUSCH1 and PUSCH2 via STxMP where N separated sets of PUSCH layers (e.g., 1st set for PUSCH1 and 2nd set for PUSCH2), each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) WTRU-panels simultaneously on the starting time determined by $K2$. After the transmission of PUSCH1 and PUSCH2, the WTRU may transmit PUSCH3 and PUSCH4 via STxMP where N separated sets of PUSCH layers (e.g., 1st set for PUSCH3 and 2nd set for PUSCH4), each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) WTRU-panels simultaneously, K_offset after the end of the transmission of PUSCH1 and PUSCH2, and so forth. The value of K_offset may be configured (or indicated) to the WTRU, or determined based on a pre-defined rule. The value of K_offset may be zero, or a non-zero value.

[0196] A WTRU may be indicated to apply at least one different PUSCH layer combination across at least two PUSCHs of the M-PUSCH transmission. For example, the PUSCH1 (or PUSCH3) and PUSCH2 (or PUSCH4) may be transmitted according to above such that the N sets of PUSCH layers (e.g., a 1st set of layers $L1 = 2$, a 2nd set of layers $L2 = 2$, in case of $N=2$ WTRU-panels, total 4-layer transmission via STxMP for the two PUSCHs) are transmitted across N WTRU-panels as STxMP, while a PUSCH5 and a PUSCH6 may be transmitted via STxMP by applying $L1=1$ (e.g., 1 layer from 1st WTRU-panel for PUSCH5) and $L2=3$ (e.g., 3 layers from 2nd WTRU-panel for PUSCH6), with other related parameter(s) (e.g., each associated TPMI on each set of layers). This may provide flexibility on having different layer

combinations (and/or different corresponding TPMIs, etc.) for STxMP across different PUSCH pairs of the M-PUSCH transmission. Such different parameter combinations (e.g., {L1=2, L2=2} or {L1=1, L2=3}, etc.) may be indicated via the UL grant (e.g., via the index indicating a row of TDRA table) or separately indicated (e.g., based on an association with a value indicated by the UL grant).

[0197] Based on a Hybrid Mode (as illustrated in FIG. 9) being configured, enabled, activated, or indicated (e.g., by RRC, MAC-CE, and/or DCI), the WTRU may receive a UL grant including scheduling information for a M-PUSCH transmission (multi-PUSCH), with performing STxMP (e.g., based on Mode 1 or Mode 2) or even a single-WTRU-panel (and/or a single-TRP (sTRP)) transmission across different PUSCHs of the M-PUSCH transmission, as a function of the time index. The UL grant (e.g., UL-DCI) may indicate N (>1) different beam indications (e.g., via SRIs, UL-TCIs, joint UL/DL TCIs, etc.) and/or N different UL precoding indications (e.g., TPMIs), where the value of N may be based on the number of (active) WTRU-panels used for STxMP transmission.

[0198] The N different beam indications may be signaled by N SRI fields, N UL-TCI fields, or N (joint) TCI fields, e.g., in the same UL grant. The UL grant may further indicate 1 index to the row of a TDRA table, e.g., configured as `pusch-TimeDomainAllocationListForMultiPUSCH`, where the WTRU may determine one or more values of K2_1 (e.g., for Mode 1), K2_2 (e.g., for Mode 2), and/or K2_3 (e.g., for sTRP Tx) indicating a starting time for at least one PUSCH of the M-PUSCH transmission. Based on the Hybrid Mode, the WTRU may transmit PUSCH1 via STxMP where N separated sets of PUSCH layers, each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) WTRU-panels simultaneously on a 1st starting time determined by K2_1. After the transmission of PUSCH1, the WTRU may transmit PUSCH2 and PUSCH3 via STxMP where N separated sets of PUSCH layers (e.g., 1st set for PUSCH2 and 2nd set for PUSCH3), each based on each of the N different beam indications and/or UL precoding indications, are transmitted across N (active) WTRU-panels simultaneously on a 2nd starting time determined by K2_2. After the transmission of PUSCH2 and PUSCH3, the WTRU may transmit a PUSCH4 via a sTRP (and/or single-WTRU-panel) transmission on a 3rd starting time determined by K2_3.

[0199] A WTRU may determine from which WTRU-panel the sTRP transmission is to be performed, based on a configuration (or indication) provided, e.g., from a gNB, or based on a pre-defined rule (e.g., the sTRP transmission is to be performed from the lowest indexed WTRU-panel). For example, the WTRU may explicitly receive (a separate) indication (or configuration) indicating to use a 2nd WTRU-panel to transmit the sTRP (and/or single-WTRU-panel) transmission on a 3rd starting time determined by K2_3. Then, the WTRU may perform the sTRP transmission from the 2nd WTRU-panel.

[0200] A WTRU may determine how many PUSCH(s) are to be transmitted according to Mode 1, based on at least one of: $K2_1$, $K2_2$, $K2_3$, M , and $SLIV1$ (e.g., for Mode 1). For example, on condition that the WTRU determines that L times PUSCH-symbol-length (e.g., determined by $SLIV1$) are belonging to the time duration based on $K2_2$ minus $K2_1$, the WTRU may determine that the number of PUSCHs to be transmitted via Mode 1 is L . In an example, the WTRU may determine $L=3$, if the PUSCH-symbol-length multiplied by $L=3$ are included in the time duration of $K2_2 - K2_1$. Then, the WTRU may transmit PUSCH1, PUSCH2, and PUSCH3 (consecutively) based on Mode 1.

[0201] A WTRU may determine how many PUSCH(s) (or PUSCH-pairs) are to be transmitted according to Mode 2, based on at least one of: $K2_1$, $K2_2$, $K2_3$, N , M , and $SLIV2$ (e.g., for Mode 2). For example, on condition that the WTRU determines that L times PUSCH-symbol-length (e.g., determined by $SLIV2$) are belonging to the time duration based on $K2_3$ minus $K2_2$, the WTRU may determine that the number of PUSCH pairs to be transmitted via Mode 2 is L . In an example, the WTRU may determine $L=2$, if the PUSCH-symbol-length multiplied by $L=2$ are included in the time duration of $K2_3 - K2_2$. Then, the WTRU may transmit, e.g., if $N=2$ WTRU-panels, 1st PUSCH pair of {PUSCH4, PUSCH5} and 2nd PUSCH pair of {PUSCH6, PUSCH7} (consecutively) based on Mode 2.

[0202] A WTRU may determine how many PUSCH(s) are to be transmitted according to sTRP Tx, based on at least one of: $K2_1$, $K2_2$, $K2_3$, M , and $SLIV3$ (e.g., for sTRP Tx). For example, on condition that a value of M_STxMP ($\leq M$) PUSCH(s), e.g., $M_STxMP = 7$ where PUSCH1, 2, 3 for Mode 1 and PUSCH4, 5, 6, 7 for Mode 2, are determined to be transmitted based on Mode 1 and/or Mode 2 as in the above examples, the WTRU may determine $M - M_STxMP$ (e.g., $8 - 7 = 1$) PUSCH (e.g., PUSCH8) is remaining to be transmitted via the sTRP Tx mode of operation. And, the transmission of PUSCH8 may be performed at a starting time determined by the value of $K2_3$.

[0203] A WTRU may receive an explicit indication (or configuration) indicating a time-domain pattern of multi-PUSCH STxMP Modes of operation. Based on the indication (or configuration), the WTRU may determine how many PUSCH(s) of the M -PUSCH transmission are to be transmitted based on each of Mode 1, Mode 2, and a sTRP Tx. The WTRU may receive a mode switching indication, where the WTRU may switch between Mode 1 (STxMP with the same PUSCH index on both panels), Mode 2 (STxMP with different PUSCH indices on the panels), and single panel (and/or sTRP) transmission. Based on the mode switching indication (and/or the time-domain pattern), the WTRU may determine $M1$ (the number of PUSCH(s) for Mode 1), $M2$ (the number of PUSCH(s) for Mode 2), and/or $M3$ (the number of PUSCH(s) for sTRP Tx) where $M1 + M2 + M3$ may be equal or less than M . $M1$ may be zero or non-zero integer, $M2$ may be zero or non-zero integer, and $M3$ may be zero or non-zero integer. In one embodiment, the WTRU may receive a dynamic indication (e.g., in a DCI) to dynamically switch between Mode 1, Mode 2, and single

panel (sTRP) Tx for the multiple PUSCHs of a scheduled multi-PUSCH transmission. WTRU may determine the mode of operation based on the TDRA table configuration with different configured patterns. The dynamic indication may be a TDRA table configuration where a row indicates a pattern of Modes of operation.

[0204] A WTRU may receive an RRC/MAC-CE configuration indicating which Mode to use and/or parameters/thresholds associated with each of one or more of the Modes. The Mode to use may be a function of the number of PUSCHs, n (e.g., in a slot), compared to a threshold. For example, if $n < n_1$ PUSCH, the WTRU may determine to transmit in STxMP Mode 1 (e.g., in the slot). If $n_1 < n < n_2$ PUSCH, the WTRU may determine to transmit in STxMP Mode 2 (e.g., in the slot). If $n > n_2$, the WTRU may determine to transmit in single panel (sTRP) transmission (e.g., in the slot). In an example, the Mode to use may be a function of a pattern which associates each PUSCH index to a transmission mode, where the WTRU may transmit PUSCH index n_1 in STxMP Mode 1, PUSCH index n_2 in STxMP Mode 2, and PUSCH index n_3 in single panel (sTRP) transmission.

[0205] A WTRU may receive a configuration for the SRS resource set indicator to operate in the hybrid mode of operation, where the SRS resource set indicator consists of 2 bits mapped to 4 different configurable modes of operation. For example, bits 00 may map to Mode 1, bits 01 may map to Mode 2, bits 10 may map to sTRP to TRP1, and bits 01 may map to sTRP to TRP2. The WTRU may receive an UL grant with the SRS resource set indicator, and may determine to transmit the multi-PUSCH with the mode of operation determined as a function of the SRS resource set indicator bits.

[0206] Regarding UCI multiplexing in STxMP multi-PUSCH, a WTRU may be scheduled to transmit a UCI on PUSCH in a slot that overlaps in time with one or more than one PUSCH transmission, or PUSCH index. The WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on at least one of following.

[0207] PUSCH indices may be assigned respective identifiers (IDs) and the WTRU may determine at least one PUSCH index on which to multiplex the UCI based the PUSCH IDs of the multi-PUSCH simultaneous transmission. A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on PUSCH ID. A PUSCH index may be assigned an ID based on its association with a time-unit (e.g., a slot) and/or a spatial-unit (e.g., a panel). A WTRU may determine a PUSCH index for multiplexing UCI based on its ID (e.g., lowest or highest ID).

[0208] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on RSRP, A WTRU may determine a PUSCH index for multiplexing UCI based on a panel index (e.g., a panel index transmitted on a panel with the highest RSRP as last reported by the WTRU).

[0209] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on *UCI multiplexing on one or more PUSCH indices*: in one embodiment, a WTRU may be configured or indicated (e.g., by RRC, MAC-CE, and/or DCI) to multiplex UCI on one or more PUSCH indices based on one or more of the following requirements and/or conditions: UCI Payload size, UCI latency, UCI reliability, and/or UCI priority.

[0210] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on UCI payload size. A WTRU may be configured or indicated (e.g., by RRC, MAC-CE, and/or DCI) for determining the number of time and/or frequency domain resources for multiplexing UCI on a first PUSCH index. In an example, a WTRU may receive a DCI indication, indicating the number of resources required for multiplexing HARQ-ACK, CSI part 1, and/or CSI part 2 on a first PUSCH index. In one embodiment, a WTRU may multiplex UCI on one PUSCH index if its payload size is less than or equal to a threshold (e.g., the configured time/frequency resources on a first PUSCH index are sufficient for UCI reporting), and on two or more PUSCH indices if its payload size is greater than a threshold (e.g., the configured time/frequency resources on a first PUSCH index are not sufficient for UCI reporting). A WTRU may determine the UCI payload size based on (e.g., the codebook Type I or Type II, the number of TRP/TRP-groups, number of antenna ports, CSI-RS resource configuration, layers, beams, panels, BWP (bandwidth part), carrier frequency, Doppler-related parameters, and/or the configured time/frequency domain compression parameters). A WTRU may determine the threshold based on the number of resources indicated for UCI reporting on a first PUSCH index and the payload size of the UCI. Alternatively, the threshold may be configured or indicated to the WTRU (e.g., by RRC, MAC-CE, and/or DCI). A WTRU may derive the number of resources required on a second PUSCH index for reporting the UCI, based on the determined/indicated threshold and the number of resources indicated for the first PUSCH index. A WTRU may also assume the same time/frequency UCI resources on a first PUSCH index for the leftover UCI multiplexing on a second PUSCH index. A WTRU may report null information on one or more of the determined and/or allocated time and/or frequency resources for UCI reporting on a second PUSCH index, if the resources are more than required for the transmission of the leftover UCI. In another embodiment, a WTRU may determine a mode of STxMP and multi-PUSCH operation (e.g., STxMP per PUSCH (Mode 1), STxMP across PUSCHs (Mode 2), and/or STxMP multi-PUSCH hybrid mode.) for reporting UCI. In an example, a WTRU may determine and report the UCI on the first two PUSCH indices on any of the three modes. A WTRU may also report the leftover UCI payload size on at least one PUSCH index, e.g., the lowest PUSCH index used for the transmission of UCI. A WTRU may also report the leftover UCI type (e.g., Type-II CSI part 1, Group 0, 1, and/or 2 of Type-II CSI part 2) transmitted on the second PUSCH index.

[0211] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on UCI latency. A WTRU may be configured or indicated (e.g., by RRC, MAC-CE, and/or DCI)

to report UCI with a certain latency requirement, (e.g., high, medium, or low). In one embodiment, a WTRU may equally or un-equally partition the UCI into one or more groups and multiplex one or more UCI groups on a separate PUSCH index. A WTRU may determine the PUSCH indices for multiplexing UCI groups based on the STxMP and Multi-PUSCH mode of operation (e.g., Mode 1, Mode 2, or hybrid) and the association of the PUSCH indices to time-units (e.g., PUSCH indices associated with the lowest slot for low latency requirements). In an example, for a low latency UCI, a WTRU may partition it into two groups and multiplex them on PUSCH indices associated with the lowest slot on Mode 2 (STxMP across PUSCHs). A WTRU may be configured or indicated (e.g., by RRC, MAC-CE and/or DCI) for determining the number of time and/or frequency domain resources for multiplexing UCI on one PUSCH index (e.g., a first PUSCH index). A WTRU may assume the same resources for multiplexing UCI on a second PUSCH index. A WTRU may report the UCI payload size multiplexed on at least one PUSCH index.

[0212] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on UCI reliability. A WTRU may be configured or indicated (e.g., by RRC, MAC-CE, and/or DCI) to report UCI with a certain reliability requirement (e.g., based on a redundancy value). In one embodiment, a WTRU may multiplex the UCI on a first PUSCH index and may also multiplex the same UCI (e.g., in full or in partial based on the configured redundancy value) on a second PUSCH index. In an example, a WTRU may multiplex full UCI on a first PUSCH index and a partial UCI (e.g., Type-II CSI part 1, indication of the UCI payload size, first N high priority UCI, full, partial, even, and/or odd numbered UCI elements of Type-II part 2 CSI) on a second PUSCH index. A WTRU may determine the first PUSCH index for multiplexing UCI based on a panel with the highest RSRP as last reported by the WTRU. A WTRU may determine the second PUSCH index based on the PUSCH ID (e.g., the lowest PUSCH index or a PUSCH index transmitted on a panel with the second highest RSRP as last reported by the WTRU, or the second lowest PUSCH index transmitted on a panel with the highest RSRP in mode 2). If the determined second PUSCH index is the same as the first PUSCH index, a WTRU may determine another PUSCH ID as the second PUSCH index (e.g., second lowest PUSCH index). A WTRU may derive the number of time/frequency resources for multiplexing UCI on the second PUSCH index based on the indicated resources for the first PUSCH index and/or the UCI type on the second PUSCH index (e.g., Type-II CSI part 1, indication of the UCI payload size, and/or full, partial, even, and/or odd numbered Type-II CSI part 2) and/or the configured redundancy value. A WTRU may indicate the UCI payload size multiplexed on the second PUSCH index. A WTRU may also indicate the UCI type on the second PUSCH index.

[0213] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on UCI priority. A WTRU may be configured or indicated (e.g., by RRC, MAC-CE, and/or DCI) to multiplex UCI on PUSCH indices based on their priority values. In an example, a WTRU may multiplex a high priority UCI element(s) (e.g., high priority elements of a CSI report, Type-II CSI part 1) on a first

PUSCH index (e.g., a PUSCH index associated with a panel having the highest RSRP as last reported by the WTRU or a PUSCH index associated with the earliest slot), and a UCI with a smaller priority UCI elements on a second PUSCH index (e.g., a PUSCH index associated with the second earliest slot). In another example, a WTRU may multiplex a high priority UCI (e.g., a CSI report with the highest priority) on a first PUSCH index (e.g., a PUSCH index associated with a panel having the highest RSRP, as last reported by the WTRU or a PUSCH index associated with the earliest slot) and a second highest priority UCI (e.g., a CSI report with the second highest priority) on a second PUSCH index (e.g., a PUSCH index associated with a panel having the second highest RSRP as last reported by the WTRU or a PUSCH index associated with the second earliest slot).

[0214] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on HARQ related parameter. A WTRU may determine a PUSCH index which may be indicated for a new transmission (e.g., a PUSCH index associated with retransmission is deprioritized, or vice-versa). If all PUSCH indices are scheduled for retransmission, the PUSCH index with smaller number of retransmissions may be prioritized or deprioritized.

[0215] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on MCS level. A WTRU may determine a PUSCH index which may be scheduled with a higher MCS level may be selected or determined (e.g., a PUSCH index associated with a higher MCS level may be prioritized)

[0216] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on Mode of operation. For example, one or more PUSCH indices may be associated with STxMP operation mode. A first STxMP operation mode may be associated with a first PUSCH index and a second STxMP operation mode may be associated with a second PUSCH index. A WTRU may determine a PUSCH index which may be associated with the corresponding STxMP operation mode (e.g., SDM)

[0217] The WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on Target TRP. A WTRU may determine a PUSCH index which may be associated with a primary TRP for STxMP SDM, wherein a primary TRP may be at least one of following: 1) a TRP index with lower TRP-ID. The TRP-ID may be interchangeably used with cell-ID, Physical cell-ID, and carrier-ID; and/or 2) a TRP configured as a primary TRP.

[0218] A WTRU may determine at least a PUSCH transmission or index where the UCI is multiplexed onto based on UCI types. If UCI includes a HARQ related parameters, a WTRU may determine a first PUSCH index; otherwise, the WTRU may determine a second PUSCH index.

[0219] Although features and elements are provided above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations may be made without departing from its spirit and scope, as will be apparent to those skilled in the art. No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly provided as such. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods or systems.

[0220] The foregoing embodiments are discussed, for simplicity, with regard to the terminology and structure of infrared capable devices, i.e., infrared emitters and receivers. However, the embodiments discussed are not limited to these systems but may be applied to other systems that use other forms of electromagnetic waves or non-electromagnetic waves such as acoustic waves.

[0221] It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting. As used herein, the term "video" or the term "imagery" may mean any of a snapshot, single image and/or multiple images displayed over a time basis. As another example, when referred to herein, the terms "user equipment" and its abbreviation "UE", the term "remote" and/or the terms "head mounted display" or its abbreviation "HMD" may mean or include (i) a wireless transmit and/or receive unit (WTRU); (ii) any of a number of embodiments of a WTRU; (iii) a wireless-capable and/or wired-capable (e.g., tetherable) device configured with, inter alia, some or all structures and functionality of a WTRU; (iii) a wireless-capable and/or wired-capable device configured with less than all structures and functionality of a WTRU; or (iv) the like. Details of an example WTRU, which may be representative of any WTRU recited herein, are provided herein with respect to FIGs. 1A-1D. As another example, various disclosed embodiments herein *supra* and *infra* are described as utilizing a head mounted display. Those skilled in the art will recognize that a device other than the head mounted display may be utilized and some or all of the disclosure and various disclosed embodiments can be modified accordingly without undue experimentation. Examples of such other device may include a drone or other device configured to stream information for providing the adapted reality experience.

[0222] In addition, the methods provided herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor.

Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media, which are differentiated from signals, include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

[0223] Variations of the method, apparatus and system provided above are possible without departing from the scope of the invention. In view of the wide variety of embodiments that can be applied, it should be understood that the illustrated embodiments are examples only, and should not be taken as limiting the scope of the following claims. For instance, the embodiments provided herein include handheld devices, which may include or be utilized with any appropriate voltage source, such as a battery and the like, providing any appropriate voltage.

[0224] Moreover, in the embodiments provided above, processing platforms, computing systems, controllers, and other devices that include processors are noted. These devices may include at least one Central Processing Unit ("CPU") and memory. In accordance with the practices of persons skilled in the art of computer programming, reference to acts and symbolic representations of operations or instructions may be performed by the various CPUs and memories. Such acts and operations or instructions may be referred to as being "executed," "computer executed" or "CPU executed."

[0225] One of ordinary skill in the art will appreciate that the acts and symbolically represented operations or instructions include the manipulation of electrical signals by the CPU. An electrical system represents data bits that can cause a resulting transformation or reduction of the electrical signals and the maintenance of data bits at memory locations in a memory system to thereby reconfigure or otherwise alter the CPU's operation, as well as other processing of signals. The memory locations where data bits are maintained are physical locations that have particular electrical, magnetic, optical, or organic properties corresponding to or representative of the data bits. It should be understood that the embodiments are not limited to the above-mentioned platforms or CPUs and that other platforms and CPUs may support the provided methods.

[0226] The data bits may also be maintained on a computer readable medium including magnetic disks, optical disks, and any other volatile (e.g., Random Access Memory (RAM)) or non-volatile (e.g., Read-Only Memory (ROM)) mass storage system readable by the CPU. The computer readable medium may include cooperating or interconnected computer readable medium, which exist exclusively on the processing

system or are distributed among multiple interconnected processing systems that may be local or remote to the processing system. It should be understood that the embodiments are not limited to the above-mentioned memories and that other platforms and memories may support the provided methods.

[0227] In an illustrative embodiment, any of the operations, processes, etc. described herein may be implemented as computer-readable instructions stored on a computer-readable medium. The computer-readable instructions may be executed by a processor of a mobile unit, a network element, and/or any other computing device.

[0228] There is little distinction left between hardware and software implementations of aspects of systems. The use of hardware or software is generally (but not always, in that in certain contexts the choice between hardware and software may become significant) a design choice representing cost versus efficiency tradeoffs. There may be various vehicles by which processes and/or systems and/or other technologies described herein may be effected (e.g., hardware, software, and/or firmware), and the preferred vehicle may vary with the context in which the processes and/or systems and/or other technologies are deployed. For example, if an implementer determines that speed and accuracy are paramount, the implementer may opt for a mainly hardware and/or firmware vehicle. If flexibility is paramount, the implementer may opt for a mainly software implementation. Alternatively, the implementer may opt for some combination of hardware, software, and/or firmware.

[0229] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples include one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples may be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In an embodiment, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), and/or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, may be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein may be distributed as a program product in a variety of forms, and that an

illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a CD, a DVD, a digital tape, a computer memory, etc., and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

[0230] Those skilled in the art will recognize that it is common within the art to describe devices and/or processes in the fashion set forth herein, and thereafter use engineering practices to integrate such described devices and/or processes into data processing systems. That is, at least a portion of the devices and/or processes described herein may be integrated into a data processing system via a reasonable amount of experimentation. Those having skill in the art will recognize that a typical data processing system may generally include one or more of a system unit housing, a video display device, a memory such as volatile and non-volatile memory, processors such as microprocessors and digital signal processors, computational entities such as operating systems, drivers, graphical user interfaces, and applications programs, one or more interaction devices, such as a touch pad or screen, and/or control systems including feedback loops and control motors (e.g., feedback for sensing position and/or velocity, control motors for moving and/or adjusting components and/or quantities). A typical data processing system may be implemented utilizing any suitable commercially available components, such as those typically found in data computing/communication and/or network computing/communication systems.

[0231] The herein described subject matter sometimes illustrates different components included within, or connected with, different other components. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality may be achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable" to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0232] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0233] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, where only one item is intended, the term "single" or similar language may be used. As an aid to understanding, the following appended claims and/or the descriptions herein may include usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim including such introduced claim recitation to embodiments including only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should be interpreted to mean "at least one" or "one or more"). The same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the

possibilities of "A" or "B" or "A and B." Further, the terms "any of" followed by a listing of a plurality of items and/or a plurality of categories of items, as used herein, are intended to include "any of," "any combination of," "any multiple of," and/or "any combination of multiples of" the items and/or the categories of items, individually or in conjunction with other items and/or other categories of items. Moreover, as used herein, the term "set" is intended to include any number of items, including zero. Additionally, as used herein, the term "number" is intended to include any number, including zero. And the term "multiple", as used herein, is intended to be synonymous with "a plurality".

[0234] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0235] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein may be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as "up to," "at least," "greater than," "less than," and the like includes the number recited and refers to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0236] Moreover, the claims should not be read as limited to the provided order or elements unless stated to that effect. In addition, use of the terms "means for" in any claim is intended to invoke 35 U.S.C. §112, ¶ 6 or means-plus-function claim format, and any claim without the terms "means for" is not so intended.

[0237] A processor in association with software may be used to implement a radio frequency transceiver for use in a wireless transmit receive unit (WTRU), user equipment (UE), terminal, base station, Mobility Management Entity (MME) or Evolved Packet Core (EPC), or any host computer. The WTRU may be used conjunction with modules, implemented in hardware and/or software including a Software Defined Radio (SDR), and other components such as a camera, a video camera module, a videophone, a speakerphone, a vibration device, a speaker, a microphone, a television transceiver, a hands free headset, a keyboard, a Bluetooth® module, a frequency modulated (FM) radio unit, a Near Field Communication (NFC) Module, a liquid crystal display (LCD) display unit, an organic light-emitting diode (OLED) display unit, a digital music

player, a media player, a video game player module, an Internet browser, and/or any Wireless Local Area Network (WLAN) or Ultra Wide Band (UWB) module.

[0238] Although the invention has been described in terms of communication systems, it is contemplated that the systems may be implemented in software on microprocessors/general purpose computers (not shown). In certain embodiments, one or more of the functions of the various components may be implemented in software that controls a general-purpose computer.

CLAIMS

What is claimed is:

1. A wireless transmit/receive unit (WTRU) comprising:
 - a transceiver; and
 - a processor configured to:
 - receive, via the transceiver, an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels;
 - determine, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI); and
 - transmit, via the transceiver, a PUSCH transmission multiplexed with the UCI.
2. The WTRU of claim 1, wherein the WTRU is scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index.
3. The WTRU of claim 1, wherein the processor is further configured to determine on which panel to multiplex the UCI.
4. The WTRU of claim 1, wherein the processor is further configured to determine the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a highest reference signal received power (RSRP) value.
5. The WTRU of claim 1, wherein the processor is further configured to determine the at least one PUSCH index on which to multiplex the UCI based on a UCI payload size.
6. The WTRU of claim 1, wherein the processor is further configured to determine the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index.

7. The WTRU of claim 1, wherein PUSCH indices are assigned respective identifiers (IDs), and the processor is further configured to determine the at least one PUSCH index on which to multiplex the UCI based the PUSCH IDs of the multi-PUSCH simultaneous transmission.
8. A method performed by a wireless transmit/receive unit (WTRU), the method comprising:
 - receiving an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels;
 - determining, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI); and
 - transmitting a PUSCH transmission multiplexed with the UCI.
9. The method of claim 8, wherein the WTRU is scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index.
10. The method of claim 8, further comprising determining on which panel to multiplex the UCI.
11. The method of claim 8, further comprising determining the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a highest reference signal received power (RSRP) value.
12. The method of claim 8, further comprising determining the at least one PUSCH index on which to multiplex the UCI based on a UCI payload size.
13. The method of claim 8, further comprising determining the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index.
14. The method of claim 8, wherein PUSCH indices are assigned respective identifiers (IDs), and the method further comprises determining the at least one PUSCH index on which to multiplex the UCI based on the PUSCH IDs of the multi-PUSCH simultaneous transmission.

15. At least one non-transitory computer-readable storage medium comprising executable instructions for configuring at least one processor to:

receive an uplink grant comprising an indication of scheduling for a multi-physical uplink shared channel (PUSCH) simultaneous transmission over multiple panels (STxMP) transmission with one PUSCH index per panel or a same PUSCH index on two panels;

determine, based on the received uplink grant, at least one PUSCH index on which to multiplex uplink control information (UCI); and

transmit a PUSCH transmission multiplexed with the UCI.

16. The at least one non-transitory computer-readable storage medium of claim 15, wherein the WTRU is scheduled to transmit the UCI in a time slot that overlaps in time with more than one PUSCH index.

17. The at least one non-transitory computer-readable storage medium of claim 15, the executable instructions further for configuring the at least one processor to determine on which panel to multiplex the UCI.

18. The at least one non-transitory computer-readable storage medium of claim 15, the executable instructions further for configuring the at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a PUSCH index transmitted on a panel with a highest reference signal received power (RSRP) value.

19. The at least one non-transitory computer-readable storage medium of claim 15, the executable instructions further for configuring the at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a UCI payload size.

20. The at least one non-transitory computer-readable storage medium of claim 15, the executable instructions further for configuring the at least one processor to determine the at least one PUSCH index on which to multiplex the UCI based on a mode of operation of a PUSCH index.

100

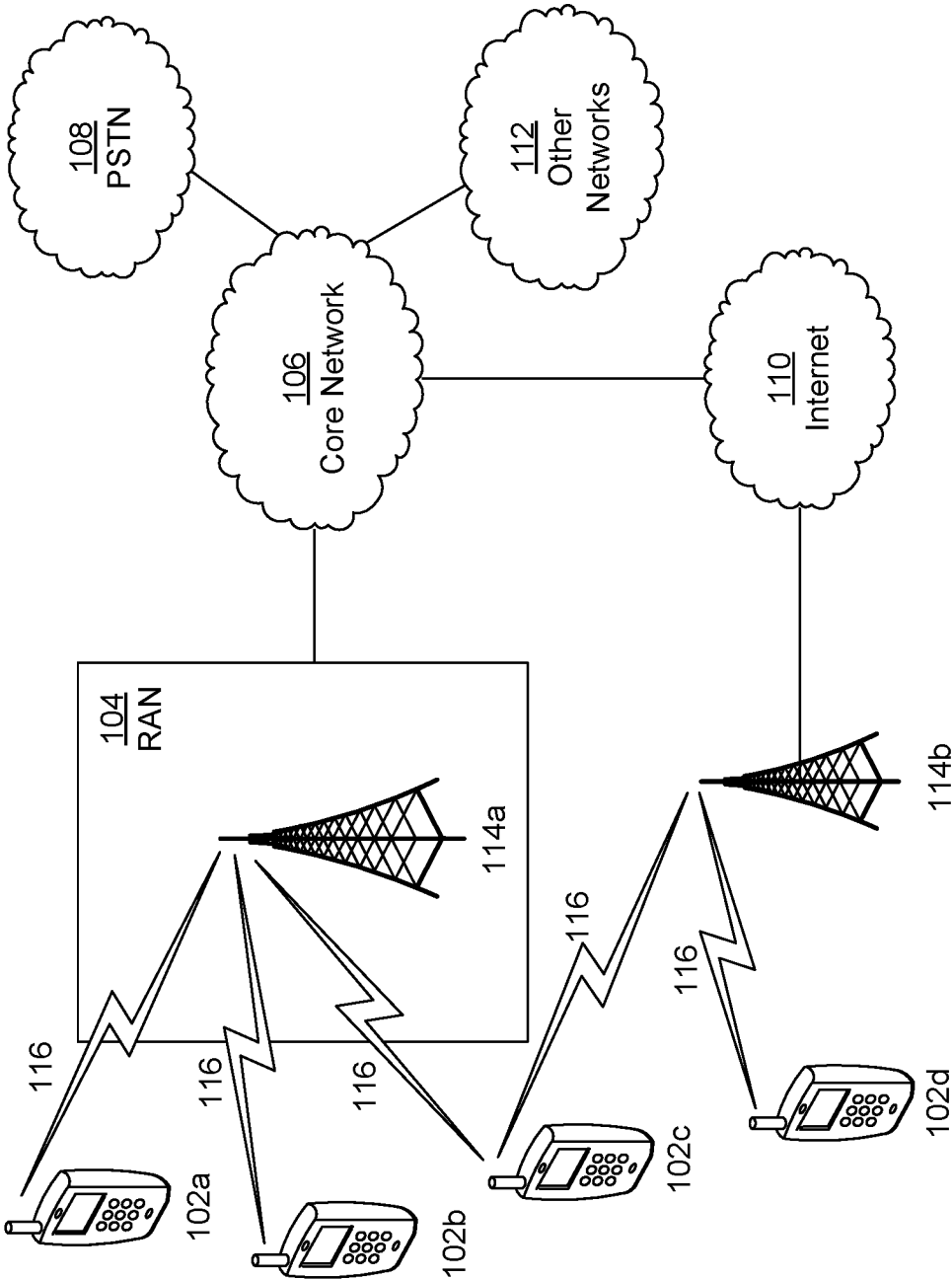


FIG. 1A

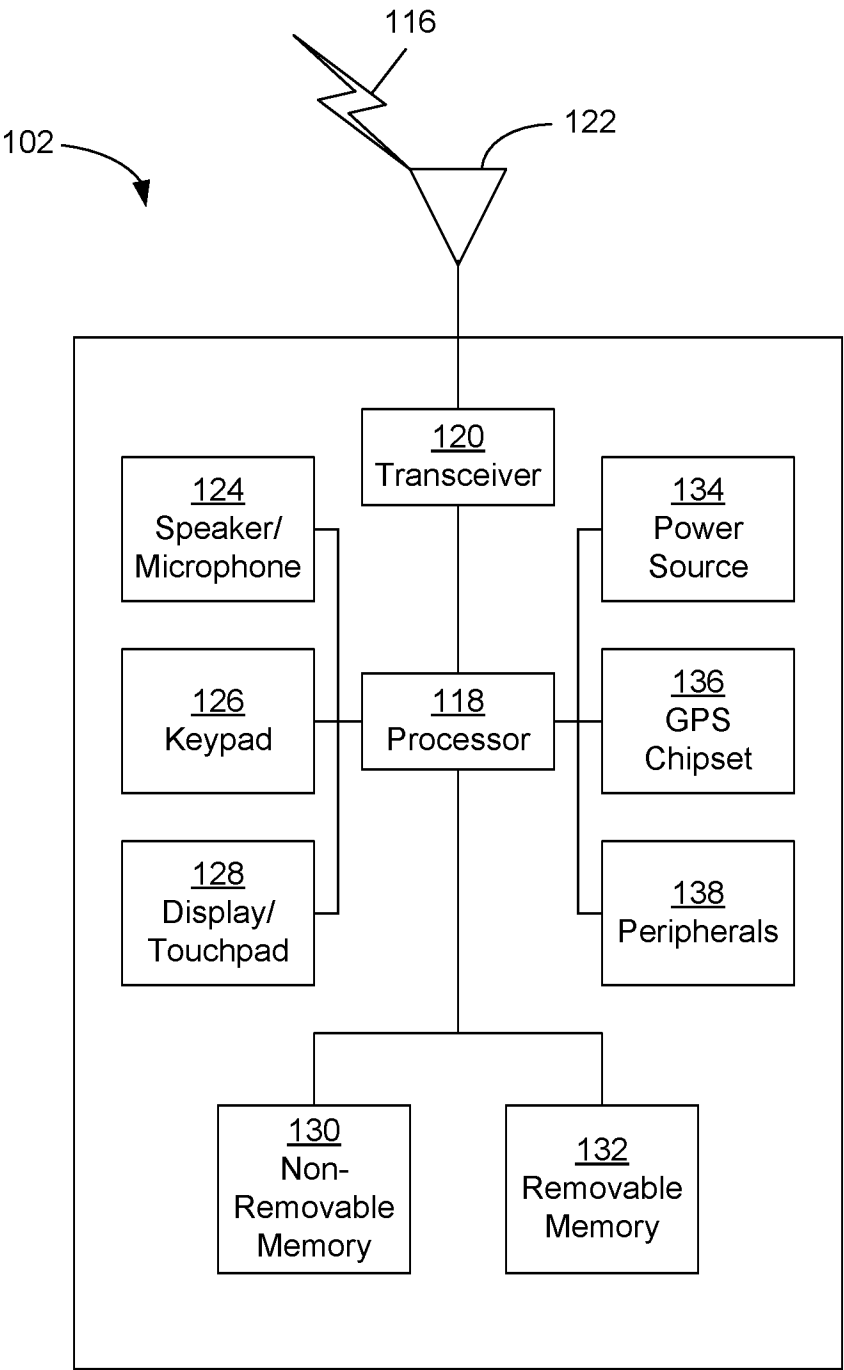


FIG. 1B

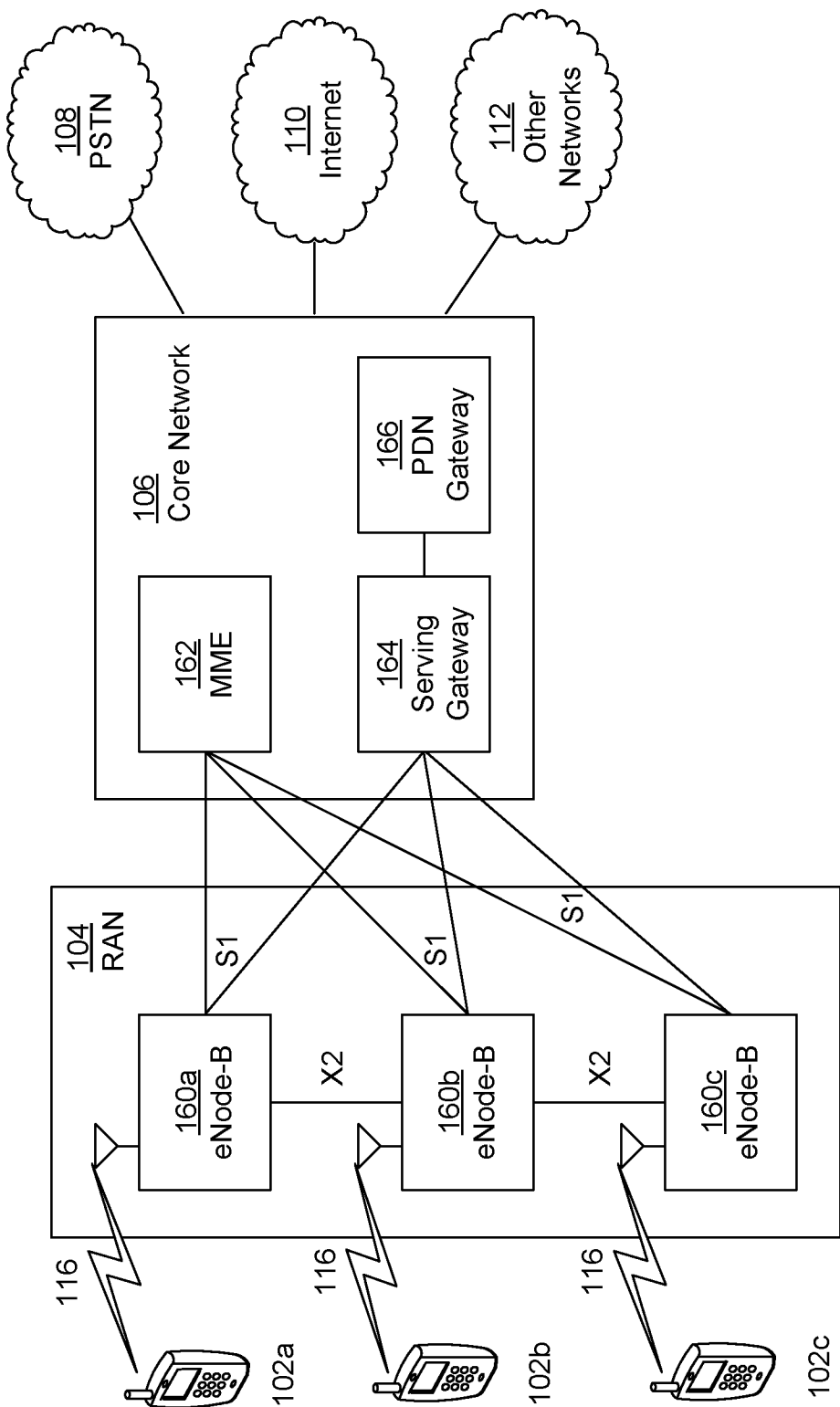


FIG. 1C

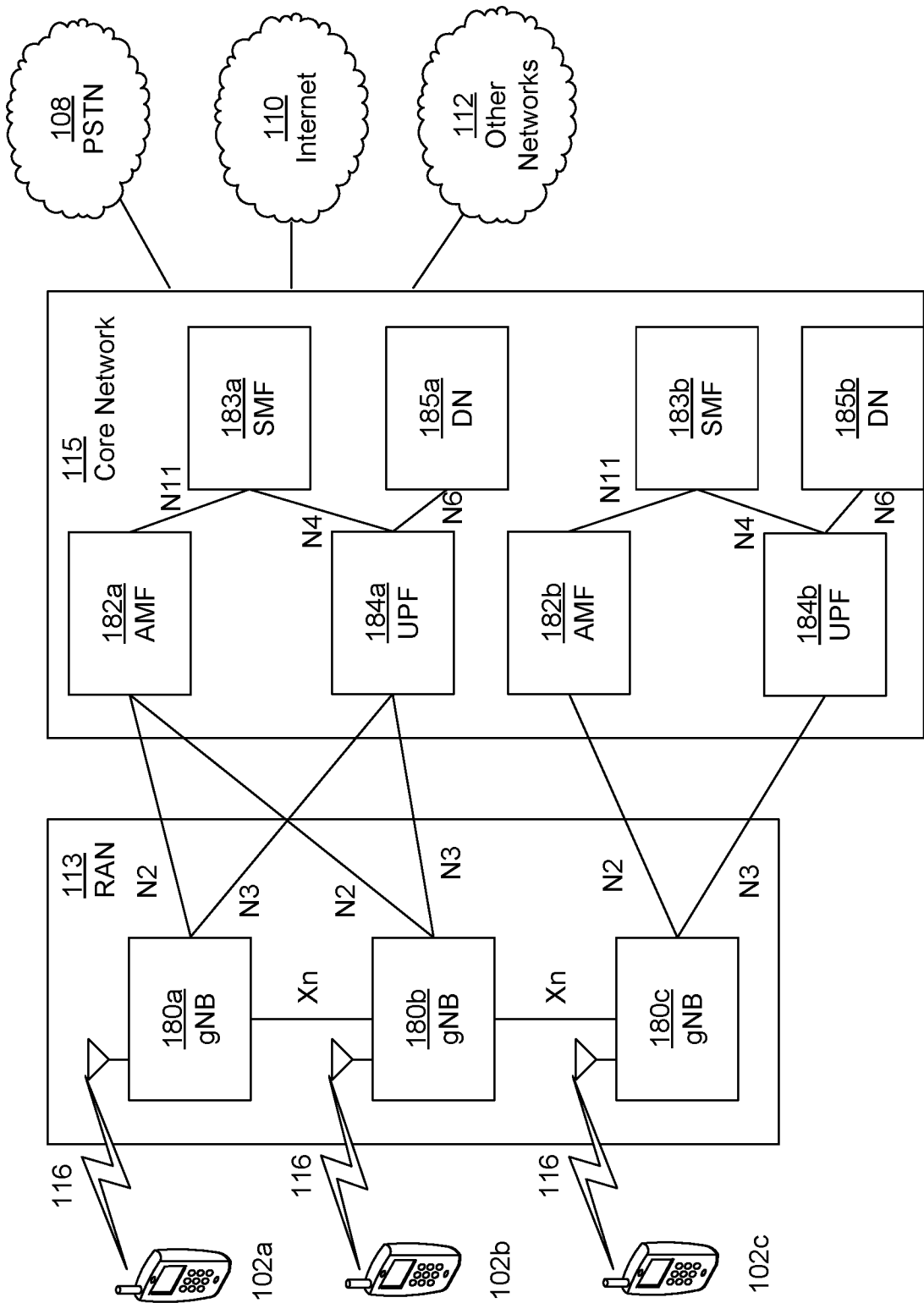


FIG. 1D

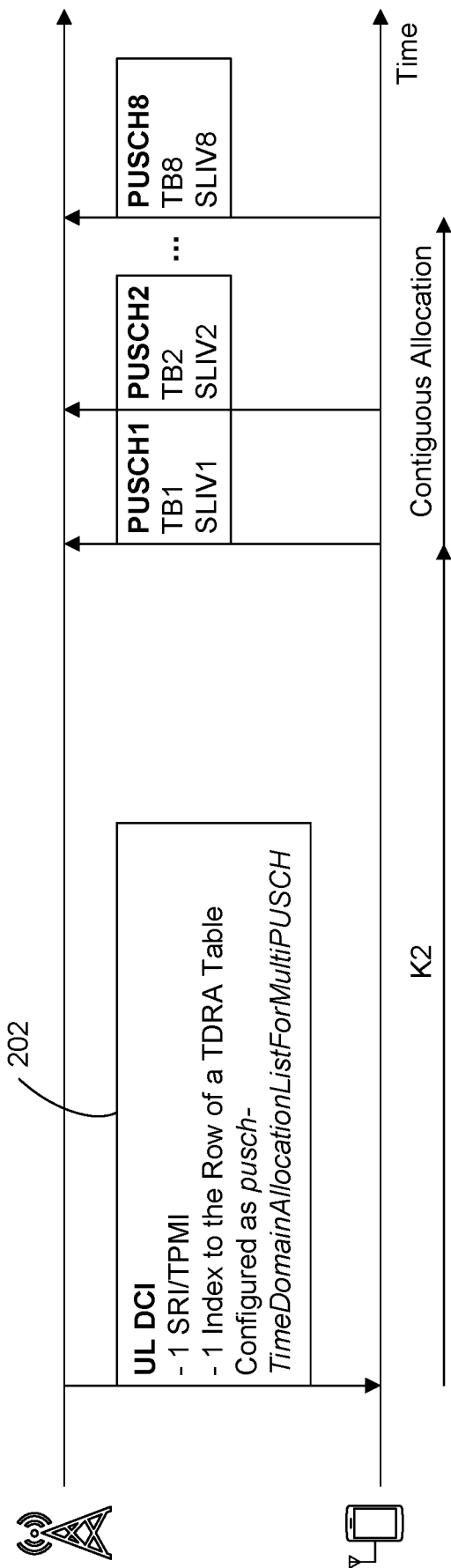


FIG. 2

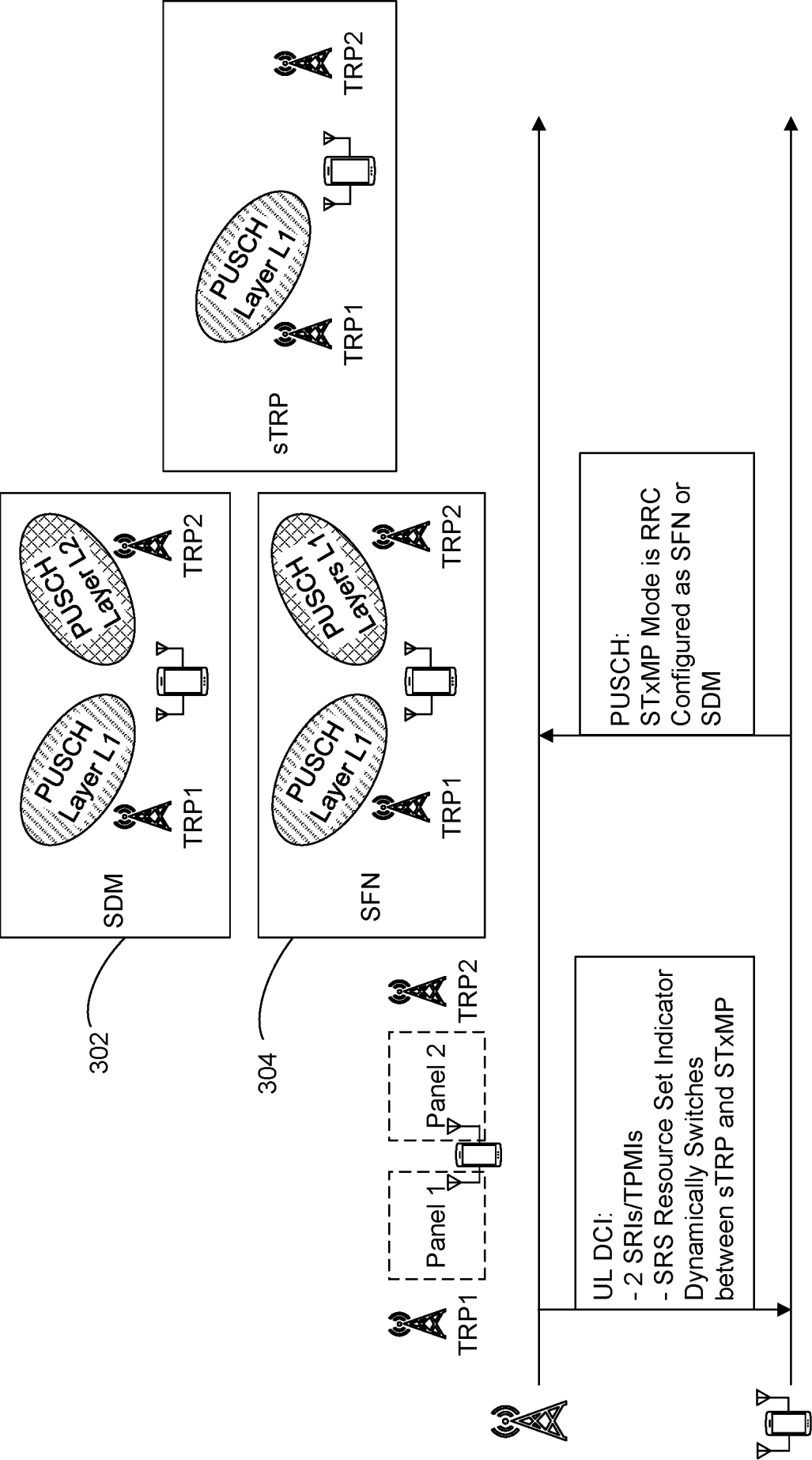
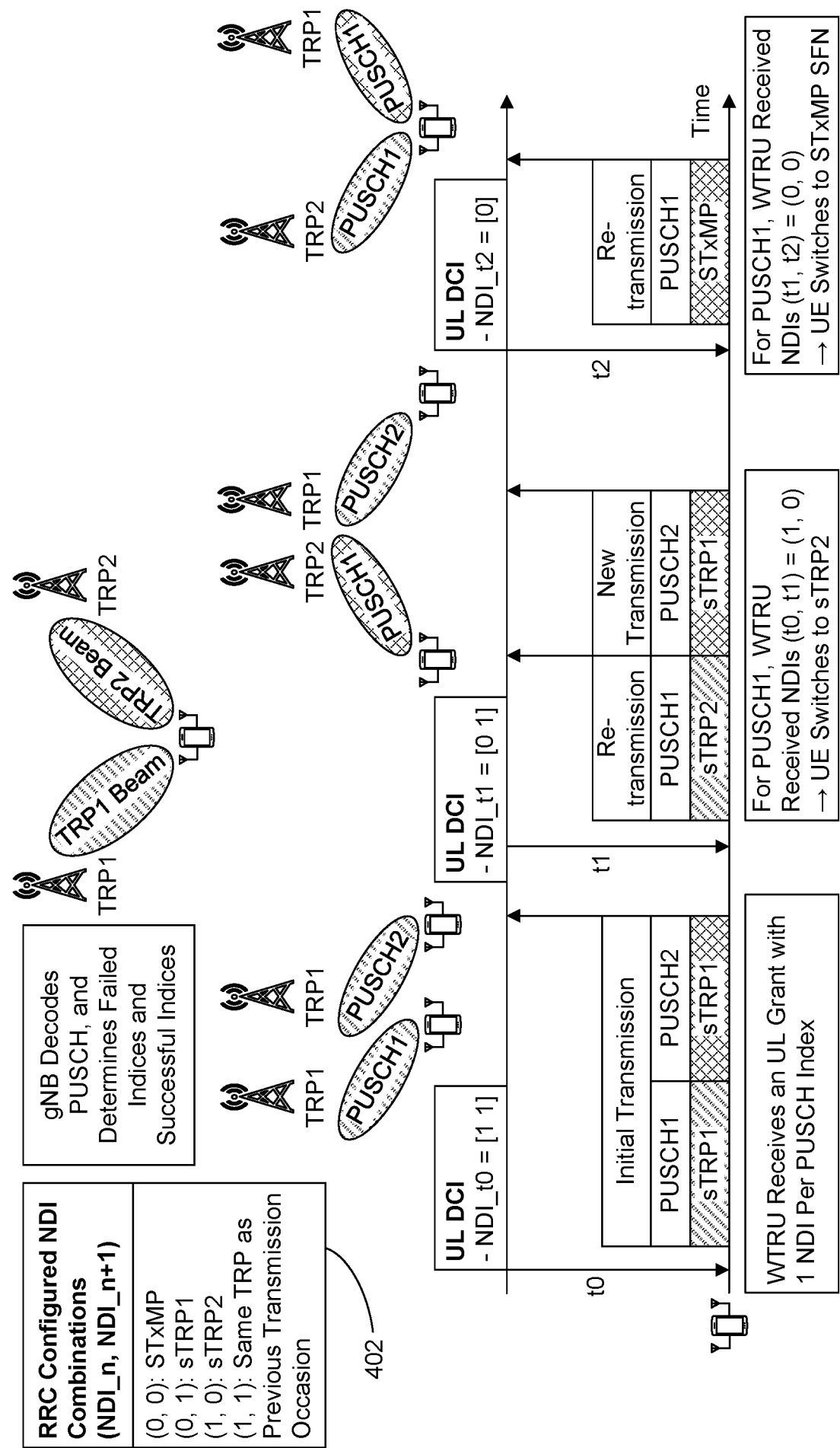


FIG. 3



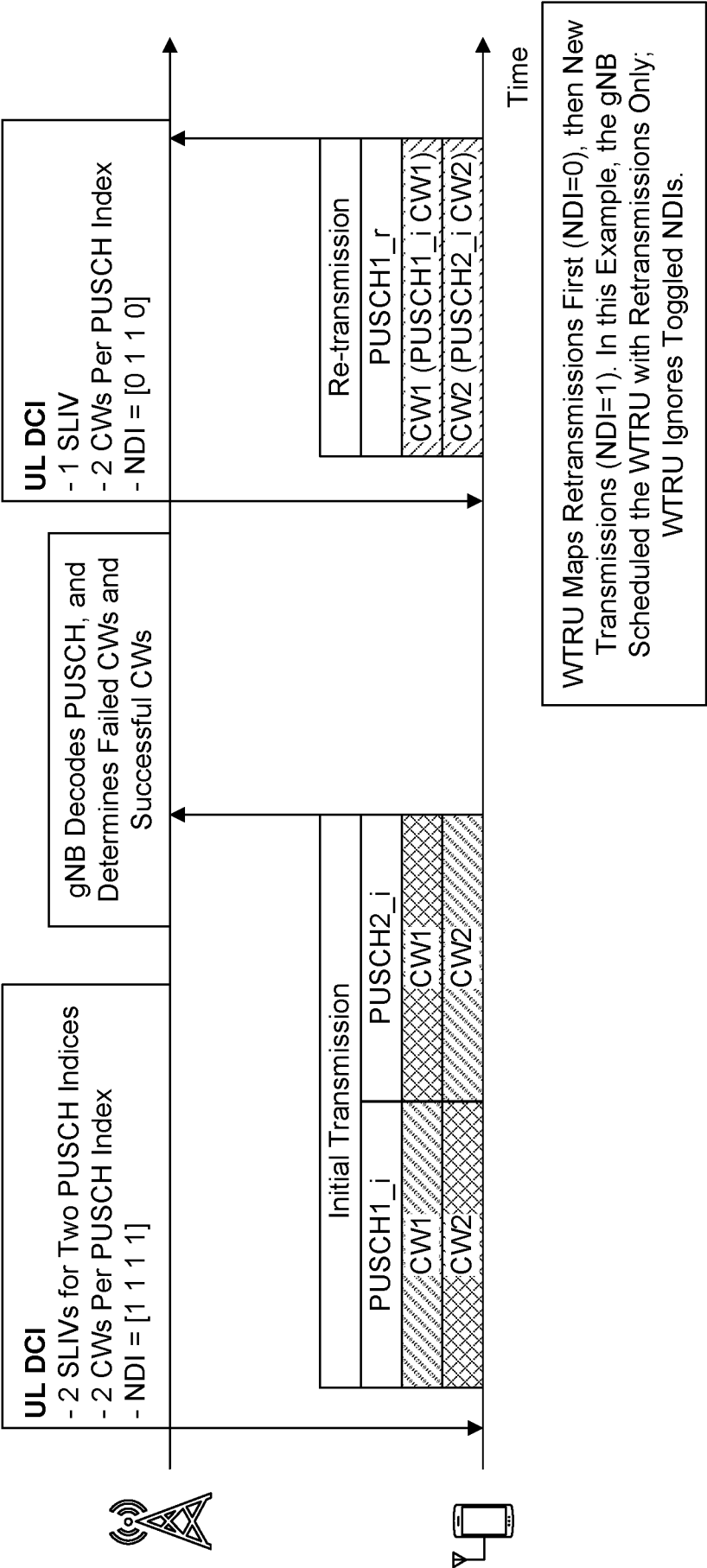


FIG. 5

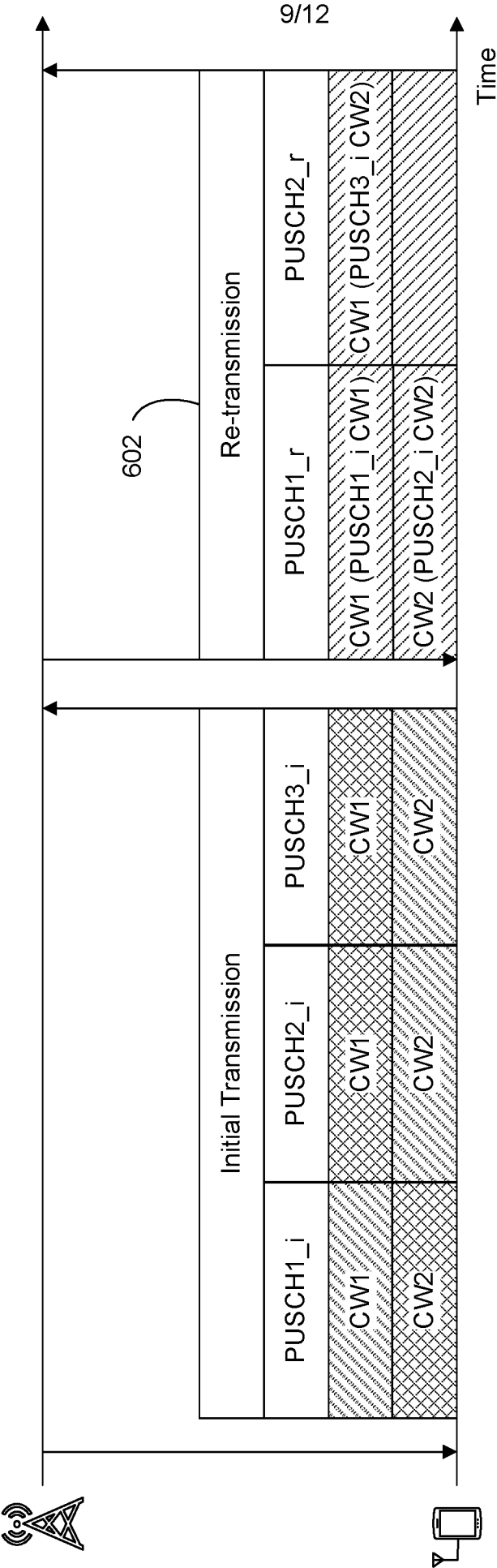


FIG. 6

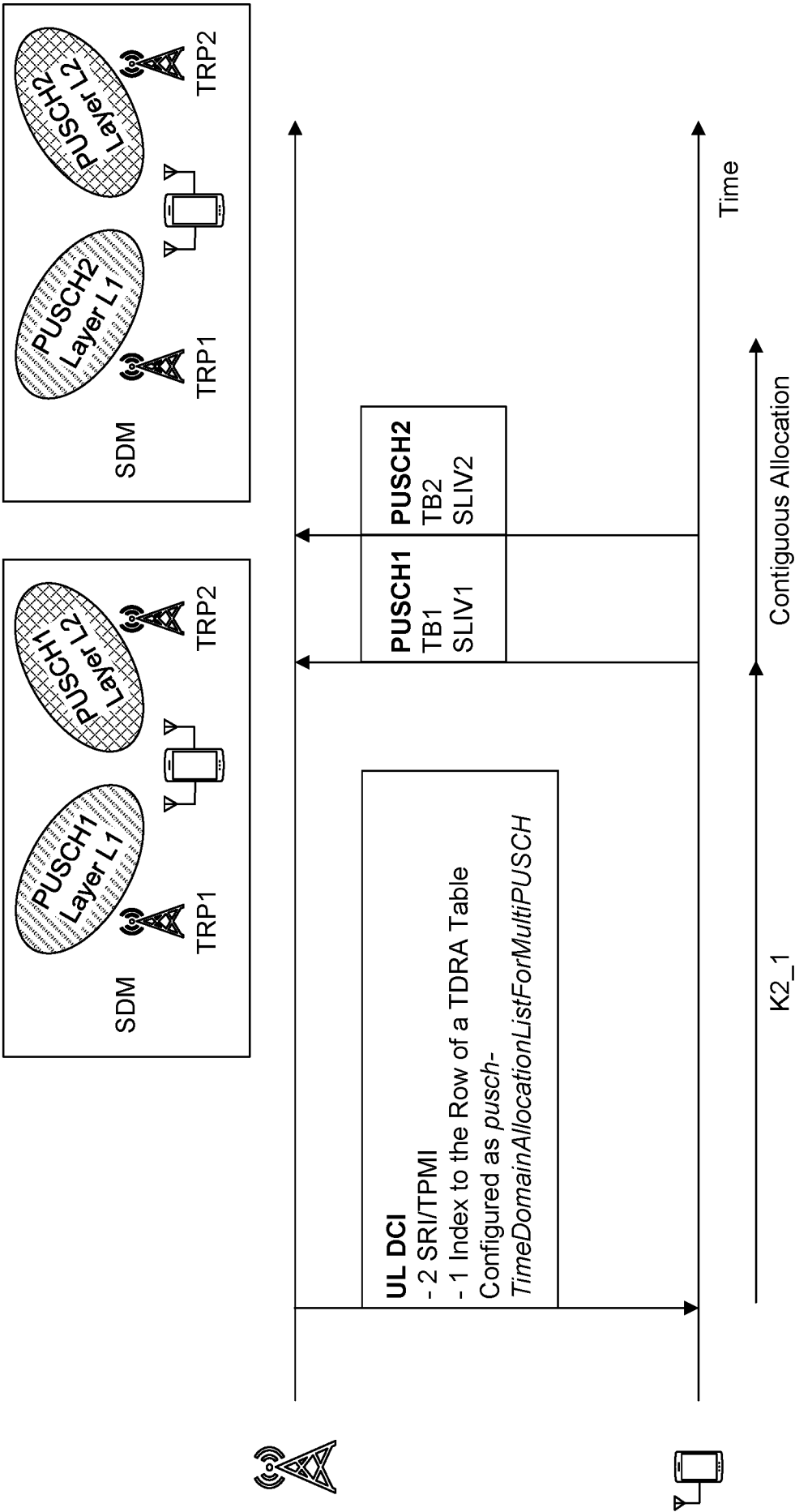


FIG. 7

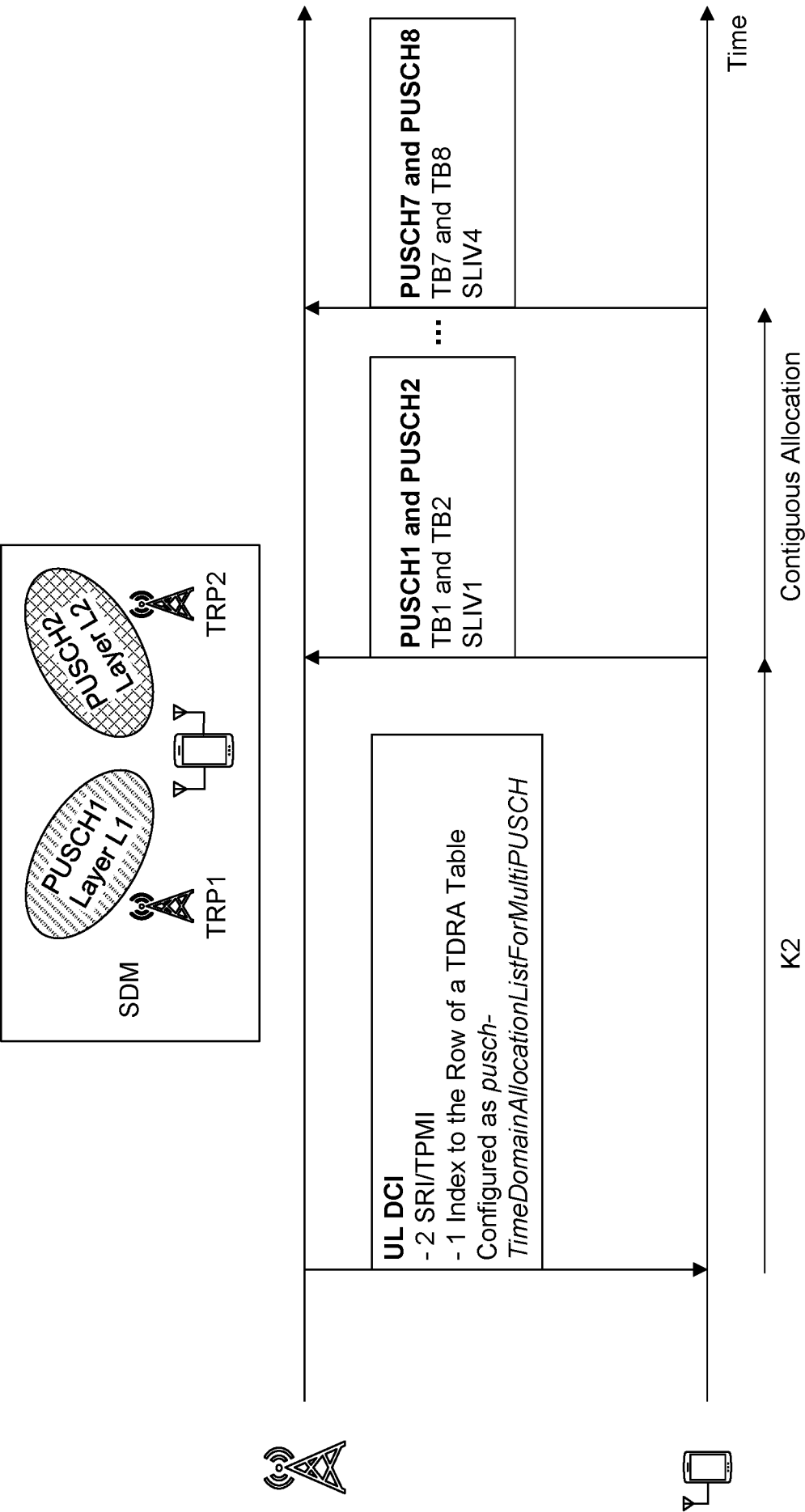


FIG. 8

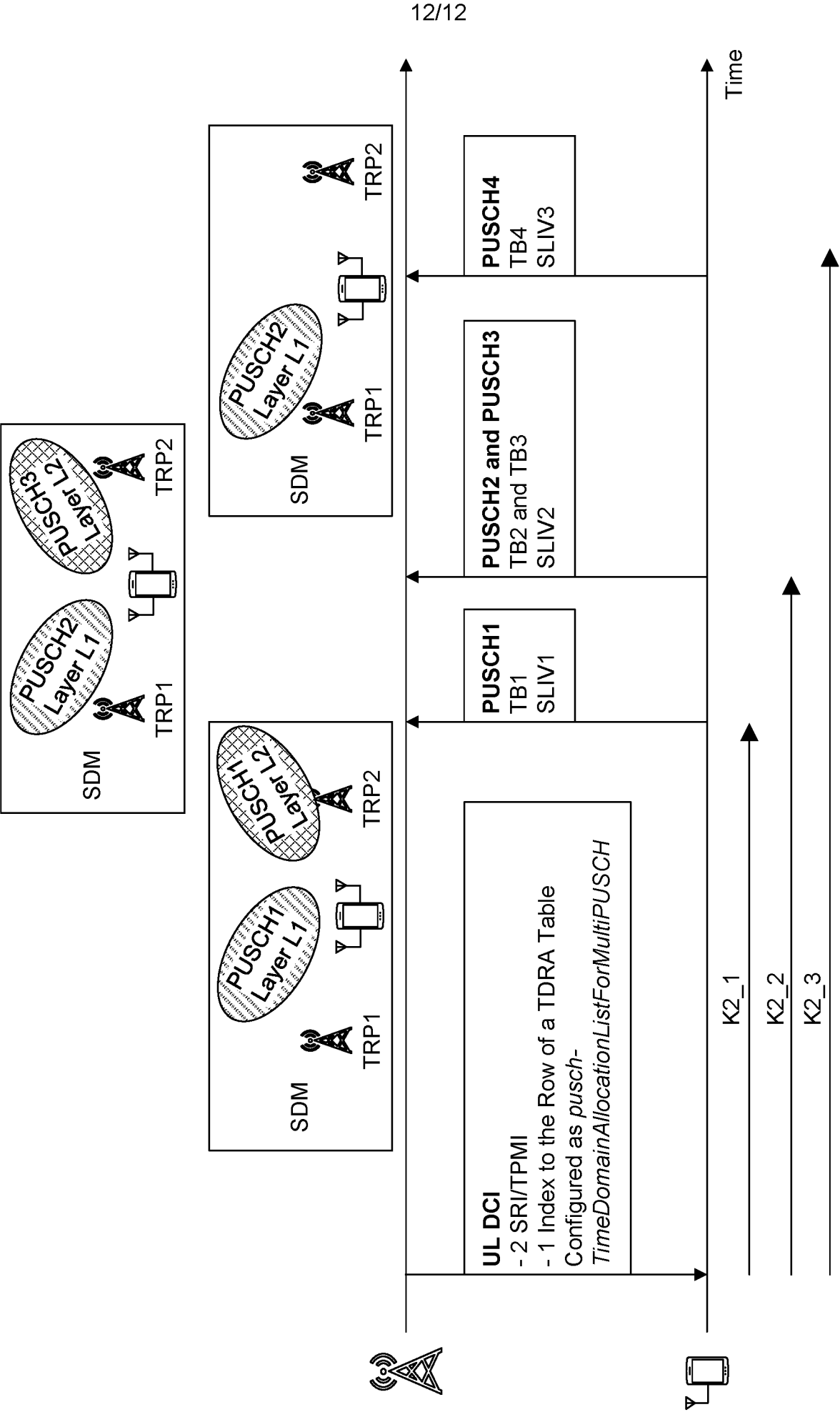


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/036692

A. CLASSIFICATION OF SUBJECT MATTER INV. H04W72/1268 H04W72/21 ADD. H04B7/0404 H04L5/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H04W H04L H04B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO - Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2023/199758 A1 (YUAN FANG [CN] ET AL) 22 June 2023 (2023-06-22) paragraphs [0093] - [0094] figure 10 ----- - / - -	1 - 20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 8 October 2024		Date of mailing of the international search report 18/10/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Franz, Stefan

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/036692

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