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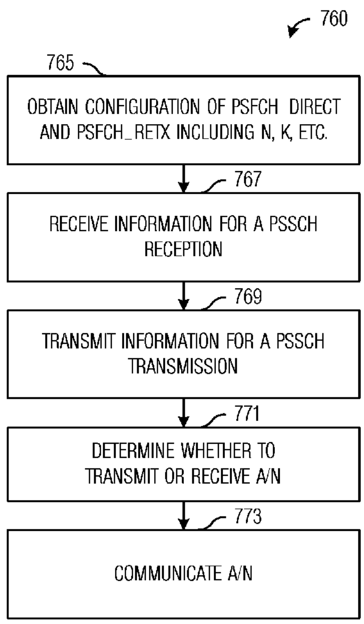

Fig. 7D

(57) Abstract: A method includes receiving a first scheduling information in a first slot, the first scheduling information including a first assignment for a reception of a first transport block (TB), and a first communication priority for a transmission of a first HARQ feedback message associated with the reception of the first TB and being scheduled for transmission in a first resource of a feedback slot; transmitting a second scheduling information in a second slot, the second scheduling information comprising a second assignment for a transmission of a second TB, and a second communication priority for a transmission of a second HARQ feedback message associated with the transmission of the second TB and being scheduled for transmission in a second resource of the feedback slot; and communicating the first HARQ feedback message and the second HARQ feedback message in accordance with comparison of the first communication priority with the second communication priority.

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Methods and Apparatus for Reliable Acknowledgements In Sidelink Communications Systems

This application claims the benefit of U.S. Provisional Application No. 62/884938, filed on August 9, 2019, entitled "Methods and Apparatus for Reliable Acknowledgements in Sidelink Communications Systems," which application is hereby incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to methods and apparatus for digital communications, and, in particular embodiments, to methods and apparatus for reliable acknowledgements in sideline communications systems.

BACKGROUND

It is expected that vehicle-to-everything (V2X) communications will play an essential role in the evolution of the automotive industry in the near future and revolutionize the field. Dedicated short-range communication (DSRC) by IEEE and the long-term evolution - vehicular (LTE-V) developed by the third generation partnership project (3GPP) are two major vehicular communication technologies developed thus far.

The 3GPP has also approved a work item in **Error! Reference source not found.**"Revised WID on 5G V2X with NR sidelink," LGE, RAN#85, Newport Beach, USA, September 16-20, 2019, which is hereby incorporated herein by reference in its entirety, for the standardization of the fifth generation (5G) new radio access technology (NR) vehicle-to-everything (V2X) wireless communication with the goal of providing 5G-compatible high-speed reliable connectivity for vehicular communications in the near future for applications such as safety systems and autonomous driving. High data rates, low latencies and high reliabilities are some of the key areas that are being investigated and standardized.

V2X communications constitute communications on the sidelink (SL) between devices such as user equipment (UEs), road side units (RSUs), pedestrians (P), in addition to downlink (DL) (base station to UE) and uplink (UL) (UE to base station). One of the main features being introduced for NR V2X communication is the introduction of unicast communications on the sidelink at the lower layers along with hybrid automatic repeat request (HARQ) to provide high reliability. HARQ for NR V2X is supported by a feedback channel, referred to as the physical sidelink feedback channel (PSFCH) at the physical layer. In order to ensure that HARQ can be performed in an effective manner, it is crucial for messages carried in the PSFCH to be received reliably.

The present disclosure propose apparatus and methods for addressing issues related to the reliability acknowledgements, thereby impacting the reliability of the feedback channel in presence of half-duplex constraints, beamforming constraints, temporary loss of communications due to deep fading or line-of-sight blockage.

SUMMARY

According to a first aspect, a method for operating a first device is provided. The method comprising: receiving, by the first device, from a second device, a first scheduling information in a first slot, the first scheduling information including a first assignment for a reception of a first transport block (TB), and a first communication priority for a transmission of a first hybrid automatic repeat request (HARQ) feedback message associated with the reception of the first TB, the first HARQ feedback message being scheduled for transmission in a first resource of a feedback slot; transmitting, by the first device, to a third device, a second scheduling information in a second slot, the second scheduling information including a second assignment for a transmission of a second TB, and a second communication priority for a transmission of a second HARQ feedback message associated with the transmission of the second TB, the second HARQ feedback message being scheduled for transmission in a second resource of the feedback slot; and communicating, by the first device, the first HARQ feedback message and the second HARQ feedback message in accordance with a comparison of the first communication priority with the second communication priority.

In a first implementation form of the method according to the first aspect, the first HARQ feedback message being transmitted by the first device to the second device.

In a second implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, the second HARQ feedback message being received from the third device.

In a third implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, the first resource being determined in accordance with a first time assignment and a periodicity of feedback resource pools for transmission of HARQ feedback messages, and the second resource being determined in accordance with a second time assignment and the periodicity of feedback resource pools for transmission of HARQ feedback messages.

In a fourth implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, communicating the first and second HARQ feedback messages comprising transmitting, by the first device, the first HARQ feedback message when the first communication priority exceeds the second communication priority.

In a fifth implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, communicating the first and second HARQ feedback messages comprising receiving, by the first device, the second HARQ feedback message when the second communication priority exceeds the first communication priority.

In a sixth implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, the first slot and the second slot being different slots.

In a seventh implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, a number of slots between the first slot and the feedback slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the feedback slot.

In an eighth implementation form of the method according to the first aspect or any preceding implementation form of the first aspect, the first and second communication priority comprising one of a transmission or a reception priority, a quality of service (QoS) requirement, or a number of retransmissions of the first HARQ feedback message and the second HARQ feedback message.

According to a second aspect, a method for operating a first device is provided. The method comprising: transmitting, by the first device, to a second device, a scheduling information in a first slot including an assignment for a transmission of a transport block (TB) in a first slot, and an instruction for a transmission of a first hybrid automatic repeat request (HARQ) feedback message associated with the transmission of the TB, the first HARQ feedback message being scheduled for transmission in a first resource of a second slot configured for feedback transmission, a first number of slots between the first slot and the second slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the second slot; monitoring, by the first device, the first resource of the second slot for the transmission of the first HARQ feedback message; and monitoring, by the first device, a second resource of a third slot configured for feedback transmission for a transmission of a second HARQ feedback message, the second HARQ feedback message comprising the first HARQ feedback message, and a second number of slots between the second slot and the third slot being at least equal to the periodicity of slots configured for feedback transmission.

In a first implementation form of the method according to the second aspect, further comprising determining, by the first device, a status of the TB in accordance with a reception of the first HARQ feedback message and a reception of the second HARQ feedback message.

In a second implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, determining the status of the TB comprising determining that the transmission being successful when the first HARQ feedback message comprises an acknowledgement.

In a third implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, the second HARQ feedback message being received from a third device.

In a fourth implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, the first HARQ feedback message being received from the second device.

In a fifth implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, the first number of slots comprising a sum of a minimum time gap between the slot associated with the decoding of the first TB and the first second slot, and the periodicity of slots configured for feedback transmission.

In a sixth implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, the second number of slots comprising a sum of the minimum time gap between the slot associated with the decoding of the first TB and the second slot, the number of slots between the first slot and the second slot, and a number of slots between the second slot and the third slot.

In a seventh implementation form of the method according to the second aspect or any preceding implementation form of the second aspect, the TB comprising a sidelink data transmission.

According to a third aspect, a first device is provided. The first device comprising: one or more processors; and a non-transitory memory storage comprising instructions that, when executed by the one or more processors, cause the first device to: receive, from a second device, a first scheduling information in a first slot, the first scheduling information including a first assignment for a reception of a first transport block (TB), and a first communication priority for a transmission of a first HARQ feedback message associated with the reception of the first TB, the first HARQ feedback message being scheduled for transmission in a first resource of a feedback slot; transmit, to a third device, a second scheduling information in a second slot, the second scheduling information a second assignment for a transmission of a second TB, and a second communication priority for a transmission of a second HARQ feedback message associated with the transmission of the second TB, the second HARQ feedback message being scheduled for transmission in a second resource of the feedback slot; and communicate the first HARQ feedback message and the second HARQ feedback message in accordance with a comparison of the first communication priority with the second communication priority.

In a first implementation form of the first device according to the third aspect, the first HARQ feedback message being transmitted by the first device to the second device.

In a second implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, the second HARQ feedback message being received from the third device.

In a third implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, the first resource being determined in accordance with a first time assignment and a periodicity of feedback resource pools for transmission of HARQ feedback messages, and the second resource being determined in accordance with a second time assignment and the periodicity of feedback resource pools for transmission of HARQ feedback messages.

In a fourth implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, wherein the instructions are further executed by the one or more processors to cause the first device to: receive the second HARQ feedback message when the second communication priority exceeds the first communication priority.

In a fifth implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, wherein the instructions are further executed by the one or more processors to cause the first device to: transmit the first HARQ feedback message when the first communication priority exceeds the second communication priority.

In a sixth implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, the first slot and the second slot being different slots.

In a seventh implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, a number of slots between the first slot and the feedback slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the feedback slot.

In an eighth implementation form of the first device according to the third aspect or any preceding implementation form of the third aspect, the first and second communication priority comprising one of a transmission or a reception priority, a quality of service (QoS) requirement, or a number of retransmissions of the first HARQ feedback message and the second HARQ feedback message.

According to a fourth aspect, a first device is provided. The first device comprising: one or more processors; and a non-transitory memory storage comprising instructions that, when executed by the one or more processors, cause the first device to: transmit, to a second device, a scheduling information in a first slot including an assignment for a transmission of a transport block (TB) in a first slot, and an instruction for a transmission of a first HARQ feedback message associated with the transmission of the TB, the first HARQ feedback message being scheduled for transmission in a first resource of a second slot configured for feedback transmission, a first number of slots between the first slot and the second slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the second slot; monitor the first resource of the second slot for the transmission of the first HARQ feedback message; and monitor a second resource of a third slot configured for feedback transmission for a transmission of a second HARQ feedback message, the second HARQ feedback message comprising the first HARQ feedback message, and a second number of slots between the second slot and the third slot being at least equal to the periodicity of slots configured for feedback transmission.

In a first implementation form of the first device according to the fourth aspect, wherein the instructions are further executed by the one or more processors to cause the first device to: determine a status of the TB in accordance with a reception of the first HARQ feedback message and a reception of the second HARQ feedback message.

In a second implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, wherein the instructions are further executed by the one or more processors to cause the first device to: determine that the transmission being successful when the first HARQ feedback message comprises an acknowledgement.

In a third implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, the second HARQ feedback message being received from a third device.

In a fourth implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, the first HARQ feedback message being received from the second device.

In a fifth implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, the first number of slots comprising a sum of a minimum time gap between the slot associated with the decoding of the first TB and the first second slot, and the periodicity of slots configured for feedback transmission.

In a sixth implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, the second number of slots comprising a sum of the minimum time gap between the slot associated with the decoding of the first TB and the second slot, the number of slots between the first slot and the second slot, and a number of slots between the second slot and the third slot.

In a seventh implementation form of the first device according to the fourth aspect or any preceding implementation form of the fourth aspect, the TB comprising a sidelink data transmission.

An advantage of a preferred embodiment is that acknowledgements are relayed, thereby improving the probability that the intended recipient of the acknowledgements receive them. Improved acknowledgement reception may lead to fewer retransmissions, which helps to improve overall communications performance.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present disclosure, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

Figure 1 illustrates a time-frequency resource grid and an example of a resource pool (RP);

Figure 2 illustrates an example physical sidelink feedback channel (PSFCH) configuration;

Figure 3 illustrates a diagram of an example mapping of physical sidelink shared channel (PSSCH) resources to corresponding PSFCHs;

Figure 4 illustrates a diagram of an example of such a situation where a UE is not able to receive an intended ACK/NACK (A/N);

Figure 5 illustrates a diagram of an example situation where a UE misses the ability to transmit or receive A/N;

Figure 6 illustrates a diagram highlighting the relaying of HARQ feedback according to example embodiments presented herein;

Figure 7A illustrates a flow diagram of example operations occurring in a TxUE participating in relaying HARQ feedback according to example embodiments presented herein;

Figure 7B illustrates a flow diagram of example operations occurring in a RxUE participating in relaying HARQ feedback according to example embodiments presented herein;

Figure 7C illustrates a flow diagram of example operations occurring in a relay UE participating in relaying HARQ feedback according to example embodiments presented herein;

Figure 7D illustrates a flow diagram of example operations occurring in a first UE participating in communications with feedback according to example embodiments presented herein;

Figure 8A illustrates a flow diagram of example operations occurring in a UE communicating A/N messages based on a communication priority of the TBs associated with the A/N messages according to example embodiments presented herein;

Figure 8B illustrates a flow diagram of example operations occurring in a UE communicating A/N messages based on a QoS requirement of the TBs associated with the A/N messages according to example embodiments presented herein;

Figure 8C illustrates a flow diagram of example operations occurring in a UE communicating A/N messages based on a transmission history of the TBs associated with the A/N messages according to example embodiments presented herein;

Figure 9 illustrates a diagram of an example where PSFCH resources for relaying A/N messages originally transmitted or received in slot n+a are allocated in slot n+a+1 according to example embodiments presented herein;

Figure 10 illustrates a diagram highlighting a situation where repetition symbols 1005 are used for relaying A/N messages according to example embodiments presented herein;

Figure 11 illustrates a diagram highlighting FDM operation, where different subbands are used to relay and/or retransmit A/N messages according to example embodiments presented herein;

Figure 12 illustrates a diagram of a sequence-based HARQ feedback according to example embodiments presented herein;

Figure 13 illustrates a diagram highlighting assigning directions to each PSFCH instance according to example embodiments presented herein;

Figure 14A illustrates a flow diagram of example operations occurring in a TxUE participating in directional communications according to example embodiments presented herein;

Figure 14B illustrates a flow diagram of example operations occurring in a RxUE participating in directional communications according to example embodiments presented herein;

Figure 14C illustrates a flow diagram of example operations occurring in a relay UE participating in directional communications according to example embodiments presented herein;

Figure 15 illustrates a first example communication system according to example embodiments presented herein;

Figure 16 illustrates a second example communication system according to example embodiments presented herein;

Figures 17A and 17B illustrate example devices that may implement the methods and teachings according to this disclosure; and

Figure 18 is a block diagram of a computing system that may be used for implementing the devices and methods disclosed herein.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The structure and use of disclosed embodiments are discussed in detail below. It should be appreciated, however, that the present disclosure provides many applicable concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific structure and use of embodiments, and do not limit the scope of the disclosure.

For the purpose of sidelink (SL) communications, the notion of resource pools (RPs) was introduced for the third generation partnership project (3GPP) long term evolution (LTE) sidelink, and is being reused for fifth generation (5G) new radio (NR) sidelink. A resource pool (RP) is a set of resources that can be used for SL communication. Resources in a RP are configured for different channels including control channels, shared channels, feedback channels, synchronization signals, reference signals, broadcast channels (e.g., master information block), and so on. The standard defines rules on how the resources are shared and used for a particular configuration of the resource pool.

However, the rules usually allow a possibility of conflicts between multiple communications by a user equipment (UE). For example, a UE may need to transmit and receive at the same time, which may not be possible for the UE due to a half-duplex constraint (where simultaneous transmission and reception by the UE may not be possible). Another example is when a UE needs to transmit signals beamformed to different directions through a same antenna. If the antenna employs analog beamforming, which is the common practice at high frequencies (such as millimeter wave (mmWave) frequencies, frequency range 2 (FR2) (>24 GHz), and so on), the UE may not be able to perform the communications in multiple directions simultaneously. Frequency range 1 (FR1) can represent frequency bands < 7 GHz.

Figure 1 illustrates a time-frequency resource grid 100 and an example of a RP 105. According to the current agreements in 3GPP working group RAN1, a RP for SL can be configured in units of slots (such as slot 110) in the time domain and physical resource blocks (PRBs) or sub-channels (such as PRB 115) in the frequency domain. A sub-channel may consist of one or more PRBs.

The resource grid (such as resource grid 100) may be configured in a band, a carrier component, a bandwidth part (BWP), and so on. The number of PRBs in a RP may differ in each slot. In addition, the location of the RP may differ in each slot. As shown in Figure 1, some slots do not include resources of RP 105, while other slots do include resources of RP 105.

In the rest of this disclosure, resources in the RPs are illustrated with simplifications. For example, resources are shown contiguous in both time and frequency domains although they may not be contiguous in the resource grid (as shown in the example shown in Figure 1). Also, the frequency resources are not necessarily shown at the PRB/sub-channel resolution in the frequency domain.

For NR mobile broadband (MBB), each PRB in the resource grid is defined as a slot of 14 consecutive orthogonal frequency division multiplexed (OFDM) symbols in the time domain and 12 consecutive subcarriers in the frequency domain, i.e., each resource block contains 12×14 resource elements (REs). When used as a frequency-domain unit, a PRB is 12 consecutive subcarriers. There are 14 symbols in a slot when a normal cyclic prefix is used and 12 symbols in a slot when an extended cyclic prefix is used. The duration of a symbol is inversely proportional to the subcarrier spacing (SCS). For a {15, 30, 60, 120} kHz SCS, the duration of a slot is {1, 0.5, 0.25, 0.125} ms, respectively. Each PRB may be allocated to combinations of a control channel, a shared channel, a feedback channel, reference signals, and so on. In addition, some REs of a PRB may be reserved. A similar structure is likely to be used on the SL as well. A communication resource may be a PRB, a set of PRBs, a code (if CDMA is used, similarly as for the physical uplink control channel (PUCCH)), a physical sequence, a set of REs, and so on.

The feedback channel in the NR SL is used for communication of hybrid automatic repeat request (HARQ) feedback, which comprises an acknowledgment (ACK) or a negative acknowledgement (NACK) of successful receipt of a block of data in a shared channel. The amount of ACK/NACK (A/N) information is small and, therefore, the physical sidelink feedback channel (PSFCH) does not need to be configured in every slot of a RP if the latency constraints allow it. Instead, as agreed in RAN1, a PSFCH can be configured on one or a few symbols every N slots in the RP, where N may take integer values such as 1, 2, 4, etc. Therefore, if slot n_f in the RP contains PSFCH resources, so do slots n_f+N, n_f+2N, n_f+3N, ... The notation k mod N=n_f can be used to indicate every slot k that contains a PSFCH 'instance' or a PSFCH 'opportunity'.

When a transmitting UE (TxUE) transmit signals (e.g. for a shared channel) to a receiving UE (RxUE), the RxUE attempts to demodulate and decode the signals. If the process (e.g. decoding) is successful, the RxUE may send an ACK to the TxUE; otherwise, the RxUE may send a NACK to the TxUE. An example of an ACK is a logical / binary “1” while a NACK is a logical / binary “0”. Whether the RxUE sends an ACK/NACK depends on the standard and the HARQ process configuration. There are generally four possible cases for ACK/NACK transmission:

Transmit ACK	Transmit NACK	Remarks
Y	Y	Referred to as “option 2” in RAN1 agreements; useful for unicast
N	Y	Referred to as “option 1” in RAN1 agreements; useful for groupcast
Y	N	Similar to IEEE 802.11
N	N	E.g., when a HARQ process is not configured; useful for broadcast

A typical operation is for the TxUE to transmit a control channel and a shared channel. The control channel contains SL control information (SCI) indicating the scheduling of a shared channel, where the scheduling provides information for the location (e.g., start and size) of the shared channel, the modulation-coding scheme (MCS), etc. Additional information may include fields related to the HARQ process, such as a redundancy version, a new data indicator, and a HARQ process number. If the RxUE is unable to decode the control channel for a single transmission, no feedback signal may be transmitted by the RxUE. However, if a periodic or semi-persistent transmission is scheduled for a TxUE, and the RxUE fails to receive a transport block (TB) in accordance with the periodic or semi-persistent transmission, the RxUE can send a NACK to the TxUE.

Except for the last case in the table, where no ACK/NACK is transmitted, the RxUE may need to transmit a feedback. Having knowledge of n_f and N, as well as other configuration parameters, the RxUE can locate PSFCH resources that can be used for transmitting the feedback. However, there is another parameter that the RxUE needs to consider. When RxUE receives the signals, it needs time to process and decode the signal, create the ACK/NACK signals, and so on. The minimum time needed between receiving the last symbol of the signal and transmitting the feedback signals should be known.

It is agreed in RAN1 to have a parameter K as the minimum slot number difference between the slot containing the last symbol of a physical SL shared channel (PSSCH) and the slot containing its associated PSFCH. The value of K may be determined by the standard, may be (pre)configured, can be determined by the numerology / related to subcarrier spacing, or may depend on a UE capability. In any case, should the RxUE receiving signals on a PSSCH transmit a feedback, the RxUE does so in slot n+a, where n is the slot containing the last symbol of the PSSCH and a is the smallest integer larger than or equal to K with the condition that slot n+a contains PSFCH. Therefore, $K \leq a \leq K+N-1$.

Another parameter X can be defined as the number of PSFCH symbols in a PSFCH format with a repetition of a one-symbol PSFCH. For example, when X=1, A/N feedback is not repeated; but when X=2, the RxUE retransmits the A/N feedback, which can improve reliability by increasing the effective signal-to-noise ratio (SNR) of the feedback signal received by the TxUE.

Figure 2 illustrates an example PSFCH configuration 200. PSFCH configuration 200, as shown in Figure 2, pertains to a situation where a TxUE transmits signals on $PSSCH_m$ in slot n 205. In this example, the earliest possible slot for the corresponding A/N_m, i.e., n+K, slot n+3 210, does not contain PSFCH resources. Hence, the RxUE should wait an additional number of slots in order to transmit feedback.

In the example illustrated in Figure 2, an OFDM symbol is designated as a guard period (GP) immediately preceding the PSFCH symbols in order to allow UEs to switch (possibly) between transmission and reception modes. As an example, GP 215 (before PSFCH symbols 220) allows UEs to possibly switch between transmission and reception modes, if needed. In addition, time may be needed for automatic gain control (AGC) circuitry to settle at the UE receiving the PSFCH. This time may be part of a guard period symbol or be another symbol. Another AGC symbol, not shown in Figure 2, may be the first symbol of a slot. AGC and GP symbols, as well as other signals, such as reference signals in a slot, may be omitted in figures of this disclosure unless needed. Also X is usually assumed 1 unless stated otherwise.

Figure 3 illustrates a diagram 300 of an example mapping of PSSCH resources to corresponding PSFCH. In an example, first PSSCH resources correspond to PSFCH resources located in second PSSCH resources. For example, PSSCH resources 305 correspond to PSFCH 307, and PSSCH resources 310 correspond to PSFCH 312.

Similar to the design of PUCCH formats, different PSFCH formats are possible and likely to be approved for different scenarios. The different formats can be categorized as short (e.g., 1-2 OFDM symbols) and long (e.g., longer than 4 OFDM symbols), which can be used for different SNR needs. Another possible format may include more PRBs. Also, in terms of the payload size, different formats can be defined that carry a small payload of 1 or 2 bits versus larger payloads, the latter case is useful if ACK/NACK bundling (e.g., aggregation of several A/N) will be adopted. The following summarizes the NR Rel-15 PUCCH formats:

	Short PUCCH	Long PUCCH
Small Payload	Format 0	Format 1
Moderate/Large Payload	Format 2	Format 3 / Format 4

Typical PSFCH formats could be based on PUCCH format 0 and format 2, both short formats, but suitable for carrying $\leq$2 bits and >2 bits, respectively. A PSFCH format based on PUCCH format 0 can be designed based on sequence selection, which can be utilized for application of some embodiments in this disclosure.

Although a short-format PSFCH is usually illustrated in the figures of the present disclosure and the discussion thereof, the same or similar methods are applicable to long-format PSFCHs.

As discussed previously, depending on the configuration, a PSFCH may be transmitted in limited resources, especially in the time domain. For example, PSFCHs are transmitted only the last one or few symbols in certain slots in a pool. As a result, multiple HARQ ACK/NACK messages may need to be simultaneously transmitted and/or received by a UE.

Several constraints may be applicable to simultaneous communications by a device:

- Half-duplex constraint: When a UE transmits signals, the UE may be incapable of receiving signals on the same carrier.

- Beamforming constraint: If a device employs analog or radio frequency (RF) beamforming, which is common at FR2, each antenna/RF chain can be used for communication through a beam. Practically, this is aiming a beam at a certain direction at a time. Therefore, communications to/from multiple directions may not be possible for the device.

These constraints can have an impact on the PSFCH as follows:

- A UE may have to transmit and receive on the PSFCH during the same symbol. In such a case, the UE could prioritize A/N transmissions over receptions. Hence the UE (TxUE) would not be able to listen to its intended A/N, and would automatically assume NACKs for the feedback that it (the TxUE) was not able to receive, thereby resulting in unnecessary retransmissions. This is applicable for both FR1 and FR2. Figure 4 illustrates a diagram 400 of an example of such a situation where a UE is not able to receive an intended A/N. As shown in Figure 4, in slot N+A 405, UE2 410 is to transmit an A/N to UE1 415 and to receive an A/N from UE 3 420. However, due to the half-duplex constraint, UE2 410 is unable to do both. Hence, as shown in Figure 4, UE2 410 prioritizes transmissions over receptions and transmits the A/N to UE1 415.

- A UE may have to transmit and/or receive A/Ns to/from different directions. At FR2, if analog beamforming is used (as is generally the case), the UE may be able to point an antenna in only one direction at a time, therefore missing the ability to transmit or receive some A/Ns. Figure 5 illustrates a diagram 500 of an example situation where a UE misses the ability to transmit or receive A/N. As shown in Figure 5, each of beam 1 505 and beam 2 507 is a UE2 510 beam that can be used for transmission or reception of signals. However, due to the beamforming constraint, UE2 510 is unable to use both beams simultaneously. Hence, in slot N+A 515, UE2 510 is able to transmit using beam 1 505 but is unable to transmit using beam 2 507. Another point of consideration is how to select the recipient of the A/N. In the example shown in Figure 5, UE2 510 determines that it will transmit to UE1 520.

These issues affect the PSFCH reliability, thus these issues may result in decreased efficiency of the HARQ for the PSSCH. Consequently, there is a need for apparatus and methods to improve the PSFCH reliability.

One possible approach to address the above disclosed issues is to avoid conflicts by proper scheduling. As an example, in mode 1 SL communications with central scheduling by an access node (e.g., a gNB, a base station, etc.), the access node can, in principle, ensure that each UE can expect to either transmit or receive HARQ feedback in a slot, but not both. In order to implement this scheduling constraint, the access node ensures that in each group of N slots that are associated with a particular PSFCH, shown by a same cross-hatch pattern in Figure 3, for example, each UE either transmits or receives data, but not both.

In mode 2 SL communications, UEs may not be able to fully avoid such scheduling conflicts due to distributed scheduling by different UEs (e.g., each UE may implement an independent scheduler), but it may still be possible to take actions to reduce the probability of scheduling conflicts. As an example, a UE that is scheduled to receive a PSSCH in a group of N slots can avoid scheduling PSSCH transmissions of its own in order to avoid a half-duplex conflict in the associated PSFCH.

This technique may be made particularly more effective if scheduling by UEs follows a two-stage process, which can be implemented though a two-stage SCI communication or any other control signaling technique that allows the UEs to perform an initial stage of prior reservations in a first stage, before transmitting the SCI that schedules a PSSCH in a second stage. Then, during the initial stage, a UE can accept or decline a prior reservation for a PSSCH based on whether the UE finds PSFCH conflicts. This approach for mode 1 and mode 2 operations can be further extended to cover cases where PSFCH conflicts are due to beamforming conflicts in FR2 as explained in more detail below.

However, there may be issues with this approach. An issue is that in mode 1 operation, the access node normally grants resources to a transmitting UE without knowing the identity of the receiving UE(s). The access node may send the TxUE a scheduling grant within a DL control information (DCI) in a physical downlink control channel (PDCCH).

However the access node may not know to whom the TxUe is transmitting. Therefore, the access node may not have the information needed to meet the constraints by scheduling, such as in the approach described above.

Furthermore, satisfying the constraints in a large population of UEs is complex and may also introduce excessive delay. Consider a simple example with three UEs, each UE having data to transmit to both of the remaining UEs. It can be seen that two PSFCHs (corresponding to two groups of N slots) are not sufficient to meet the constraints, and at least three PSFCHs are needed. Larger number of UEs introduce a larger number of constraints, retransmissions may introduce further constraints, and the resulting graph-coloring problem is not only complex, but can lead to poor performance in terms of delay and resource utility.

Implementing scheduling constraints to avoid PSFCH conflicts for mode 2 communications is even more complex. Furthermore, in the case of FR2 systems where beamforming constraints are applicable, the use of scheduling constraints to avoid PSFCH conflicts becomes even more difficult. Therefore, there is a need for methods and apparatus for reliable acknowledgements in SL communications systems.

According to an example embodiment, systems and methods for reliable acknowledgements in SL communications systems are provided. In an embodiment, a UE relays a received HARQ feedback message when it is not the intended recipient of the HARQ feedback message. The HARQ feedback message may be received over a direct PSFCH resource (referred to as a PSFCH_DIRECT resource) or a retransmitted PSFCH resource (referred to as a PSFCH_RETX resource). The retransmission of the HARQ feedback message may take place over a PSFCH_RETX resource. The retransmitting of the HARQ feedback message is referred to as relaying and the UEs performing the retransmission are referred to as relay UEs. In an embodiment, the relay UEs are SL UEs.

According to an example embodiment, UEs relay HARQ feedback messages received on a previous PSFCH to improve PSFCH reliability. A relay UE receives a PSFCH transmitted by an RxUE intended for TxUE due to a packet transmission from the TxUE to the RxUE. In an embodiment, the relay UE later transmits the PSFCH (or its contents) to the TxUE, or to another relay UE that will relay the PSFCH (or its contents) to the TxUE. A frame structure and protocol to relay the A/N messages is provided. This technique is applicable for both FR1 and FR2. Priority rules are also introduced that determine the UE behavior when it faces PSFCH conflicts.

In an embodiment, additional variations and embodiments are provided for operation at FR2, operation with mixed numerology, and so on. For FR2 operation, each PSFCH opportunity is configured for a particular direction. The UE selects where to transmit the PSFCH according to the direction it uses to receive the corresponding PSFCH.

According to an example embodiment, as related to relaying HARQ feedback, a UE receiving the PSSCH (i.e., a RxUE) transmits the PSFCH on the resources associated with the PSSCH. Neighboring UEs listen to the PSFCH even if they do not expect A/Ns and receive the A/N from the RxUE. In a second PSFCH instance, the neighboring UEs may retransmit the received A/Ns from the RxUE. Thus, if the initial UE transmitting the PSSCH (i.e., a TxUE) is unable to receive the A/N message corresponding to the PSSCH, the initial UE can receive the A/N message when the neighboring UEs retransmit the A/Ns messages.

Figure 6 illustrates a diagram 600 highlighting the relaying of HARQ feedback. As shown in Figure 6, in slot n 605 TxUE 610 transmits signals on a PSSCH to RxUE 615. Next, in slot n+a 620 RxUE 615 transmits HARQ feedback (i.e., a A/N message) to TxUE 610. Here, the value 'a' is related a number of slots between a slot corresponding to a decoding of the signals on the PSSCH and a slot configured for feedback transmission, and the slot corresponding to the decoding of the signals is the slot being received as the decoding of the signals is occurring. However, TxUE 610 is communicating with RxUE2 625 at the time, which may result in the failure of TxUE 610 to receive the A/N message transmitted by RxUE 615 due to the half-duplex constraints or the beamforming constraints or both. However, a relaying UE 630 is able to receive the A/N message. Then, having received the A/N message, relaying UE 630 transmits (relays) the A/N message in separate resources, e.g., in slot n+a+b 635, during which TxUE 610 listens to the A/N message and receives it successfully. Here, the value 'b' is related to the periodicity of slots configured for feedback transmission. In addition, RxUE 615 (the target RxUE of the PSSCH transmitted by TxUE 610) may retransmit the A/N message in separate resources, e.g., in slot n+a+b 635, to further improve the likelihood of successful PSFCH reception.

The above illustrated example (shown in Figure 6) show how TxUE 610 can benefit from the example embodiment. However, it is also possible for RxUE 615 to benefit from the example embodiment as well. For example, RxUE 615 may encounter the half-duplex constraint where it is scheduled to transmit and receive A/N messages simultaneously in slot n+a 620. In this case, RxUE 615 can listen to PSFCH resources in slot n+a 620, but because RxUE 615 has missed the opportunity to transmit its own A/N message(s) in slot n+a 620, RxUE 615 uses PSFCH resources in slot n+a+b 635 for retransmitting the A/N message(s). In this case, the UEs expecting A/N messages from RxUE 615 in slot n+a 620 do not receive the expected A/N messages in their first attempt, but UEs continue to listen to PSFCH resources in slot n+a+b 635, when the UEs do receive the A/N messages.

Figure 7A illustrates a flow diagram of example operations 700 occurring in a TxUE participating in relaying HARQ feedback. Operations 700 may be indicative of operations occurring in a TxUE as the TxUE participates in relaying HARQ feedback.

Operations 700 begin with the TxUE obtaining PSFCH configuration (block 705). In an embodiment, the TxUE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc.

In an embodiment, the TxUE obtains (pre)configuration of PSFCH resources in a RP. This (pre)configuration can be obtained in several ways:

- (Pre)configuration by the higher layers.
- Receiving an RRC configuration from the network or from another UE (such as a group leader or master UE) either through dedicated or common signaling.
- Received on a physical sidelink broadcast channel (PSBCH).
- Received in an SCI: In such a case, the TxUE obtains the resource allocation for the PSFCH(s) for each transmitted packet.

The PSFCH (pre)configuration contains information on what resources are allocated to the PSFCH, and how the resources are assigned to UEs and/or how they are associated with PSSCH resources. Furthermore, a PSFCH (pre)configuration may determine resources that can be used for retransmitting and/or relaying HARQ feedback (A/N) messages. One solution is to have resources for the transmission of the initial PSFCH (PSFCH_DIRECT), and resources for the retransmissions (relayed or retransmitted by the same UE) of the PSFCH (PSFCH_RETX).

The TxUE transmits data (block 707). The TxUE transmits data signals on a PSSCH scheduled by the network (mode 1 operation) or by a UE (mode 2 operation). Each block of data may be referred to as a TB, a packet, and so on. The UE transmits an SCI in a PSCCH associated with the PSSCH (in case of scheduled transmission, for example). Alternatively, for grant-free transmission (also referred to as configured SL grant operation) or semi-persistent scheduling ("SPS"), the resources to use for PSCCH transmission may be indicated by RRC signaling (either from the access node or on the SL), or a combination of RRC/SCI signaling.

The transmission grant may indicate resources to use for transmission of the PSFCH on PSFCH_DIRECT. The resources may be explicitly indicated (e.g., by a field in the SCI), or may be implicitly determined (e.g., depending on the resources selected for the PSSCH transmission, such as starting PRB/sub-channel number). A combination of both may be used, with the time resources explicitly signaled, and the frequency/code resources implicitly derived, for example.

The transmission grant may indicate resources to use for retransmission/relaying of the PSFCH on PSFCH_RETX. The resources may be explicitly indicated (e.g., by a field in the SCI), or may be implicitly determined (e.g., depending on the resources selected for the PSSCH transmission). A combination of both may be used, with the time resources explicitly signaled, and the frequency/code resources implicitly derived, for example. The resource on PSFCH_RETX may also be determined by the resources used on PSFCH_DIRECT; for instance, the same frequency/code resource as on PSFCH_DIRECT may be used, but the time resources may be offset from the resources on PSFCH_DIRECT, for example as follows:

- By configuration: e.g., there may be a configuration in the PSFCH configuration described previously, relating to obtaining configuration, indicating that PSFCH_RETX occurs L slots later than PSFCH_DIRECT.

- By SCI signaling (for scheduled mode) or RRC signaling (for grant free transmission, semi-persistent scheduling), by explicitly signaling L, for example.

The TxUE receives direct A/N feedback on associated PSFCH_DIRECT resources (block 709). In general, receiving the direct A/N feedback comprises monitoring resources associated with the direct A/N feedback and decoding signals associated with the direct A/N feedback. The TxUE expects to receive an A/N message on the resources allocated with the PSSCH that the TxUE used to transmit data. Therefore, the TxUE monitors resources assigned to the UE(s) or associated with the PSSCH resources to receive A/N message(s). The TxUE attempts to detect and decode on the PSFCH_DIRECT resources. As explained previously, it may not always be possible to do so because of half-duplex or beamforming constraints, for example.

The TxUE receives relayed A/N feedback on associated PSFCH_RETX resources (block 711). In general, receiving the relayed A/N feedback comprises monitoring resources associated with the relayed A/N feedback and decoding signals associated with the relayed A/N feedback. The TxUE may receive an A/N message on the resources allocated with the PSSCH that the TxUE used to transmit data. Therefore, the TxUE monitors resources assigned to the UE(s) or associated with the PSSCH resources to receive A/N message(s). The TxUE attempts to detect and decode on the PSFCH_RETX resources. This is optional – if the TxUE has successfully received A/N feedback previously, the TxUE may not need to receive relayed A/N feedback on PSFCH_RETX resources.

The TxUE determines if the packet is successfully received (block 713). Having received signals associated with possibly multiple replicas of the A/N message(s), the TxUE determines whether the data were received by the RxUE(s) successfully. This, in turn, may determine whether to make a HARQ retransmission at a later PSSCH, etc. Some rules can be used to determine if the packet was successfully received, e.g.:

- If an ACK is received on PSFCH_DIRECT, the packet transmission is deemed successful.
- If no A/N is received on PSFCH_DIRECT, but an ACK is received on PSFCH_RETX, the packet transmission is deemed successful (or if an NACK is received on PSFCH_RETX, the packet transmission is deemed unsuccessful).
- If multiple A/Ns are received, a technique using the majority-vote rule can be employed, for example. As an example, if 3 A/N messages were received, and there are 2 ACKs, then the majority vote is ACK. Prioritization of A/Ns may be used. As an example, greater priority or weight can be given to an A/N message directly received from the RxUE compared to an A/N relayed by other UEs.

Figure 7B illustrates a flow diagram of example operations 720 occurring in a RxUE participating in relaying HARQ feedback. Operations 720 may be indicative of operations occurring in a RxUE as the RxUE participates in relaying HARQ feedback.

Operations 720 begin with the RxUE obtaining PSFCH configuration (block 725). The RxUE obtains configuration of PSFCH resources in a RP. In an embodiment, the RxUE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc. Details regarding the PSFCH configuration may be as described previously for the TxUE and will not be discussed again here.

The RxUE receives data (block 727). The RxUE receives data signals on a PSSCH. Details may be similar to the corresponding step in TxUE operation. If the PSSCH contains a retransmission, the RxUE may combine elements from the initial transmission with the retransmission before decoding.

The RxUE transmits an A/N message (block 729). The RxUE may transmit an A/N message to the TxUE on PSFCH_DIRECT resources. However, the RxUE may not always be able to do so, because of half-duplex or beamforming constraints, for example. If this is the case, the RxUE retransmits an A/N message on PSFCH_RETX resources. This may be an optional operation depending on the (pre)configuration.

Figure 7C illustrates a flow diagram of example operations 740 occurring in a relay UE participating in relaying HARQ feedback. Operations 740 may be indicative of operations occurring in a relay UE as the relay UE participates in relaying HARQ feedback.

Operations 740 begin with the relay UE obtaining PSFCH configuration (block 745). The relay UE obtains configuration of PSFCH resources in a RP. In an embodiment, the relay UE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc.

The relaying UE receives an A/N message on PSFCH_DIRECT resources (block 747). Depending on the (pre)configuration, the relay UE may listen to the PSFCH_DIRECT resources and receive A/N messages from RxUEs in the area. The relay UE may also listen to the PSFCH_RETX resources and receive retransmitted (or relayed) A/N messages from UEs in the area.

The relay UE determines to relay an A/N message or not (block 749). Depending on the (pre)configuration and UE behavior rules, the relay UE determines whether or not and which A/N messages to transmit (relay) on the PSFCH_RETX resources. In an embodiment, the determination may be based on deterministic or probabilistic rules. The rules may require the relay UE to always relay the A/N; relay with a fixed probability of retransmission; relay with a probability of transmission determined based on, for example, load on the PSFCH, load on the PSSCH, etc.; and so on. Additional details are provided below.

The relay UE relays an A/N message (block 751). If the relay UE has determined to relay, the relay UE transmits the PSFCH signals that the relay UE has received on associated PSFCH_RETX resources.

As discussed previously, a UE may prioritize A/N transmission over reception if there is a half-duplex conflict that the UE cannot resolve. However, prioritizing A/N transmission over A/N reception is not the only option. In an embodiment, a UE encountering PSFCH conflicts may prioritize A/N transmission or A/N reception based on criteria such as the following:

- A quality-of-service (QoS) indicator associated with the TBs. If a TB has a stricter QoS requirement, for example, lower latency or higher reliability, transmitting or receiving a A/N message associated with that TB can take higher priority.
- Number of retransmissions thus far: If a TB is being retransmitted due to a lack of prior successful A/N signaling, its A/N signaling can be given higher priority compared to A/N signaling for a TB transmitted for the first time or retransmitted for a fewer number times.
- A UE may choose between A/N transmission and A/N reception randomly if no other criterion has been determined as being a priority.
- A combination thereof.

In an embodiment, a UE utilizes a prioritizing criteria or criterion to determine if the UE should perform either the transmission of an A/N message or the reception of an A/N message. The prioritizing criteria or criterion is referred to as a communication priority. In an embodiment, a UE utilizes a combination of multiple prioritizing criterion to determine if the UE should perform either the transmission of an A/N message or the reception of an A/N message.

Figure 7D illustrates a flow diagram of example operations 760 occurring in a first UE participating in communications with feedback. Operations 760 may be indicative of operations occurring in a first UE as the first UE participates in communications with feedback.

Operations 760 begin with the first UE obtaining PSFCH configuration (block 765). In an embodiment, the TxUE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc.

The first UE receives scheduling information for a PSSCH reception (block 767). The scheduling information (i.e., a transmission grant) may include information about an assignment of a reception of a TB and a first communication priority of an A/N message associated with the reception of the TB. The A/N message may be scheduled for transmission in a first resource of a feedback slot. The scheduling information may be received in a first slot. In an embodiment, the scheduling information for the PSSCH reception is received from a second UE. The location of the first resource may be based on a first time assignment and a periodicity of feedback resource pools for transmission of A/N messages. Furthermore, the number of slots between the first slot and the feedback slot is at least a minimum of slots between a slot when the TB is decoded and the feedback slot.

The first UE transmits scheduling information for a PSSCH transmission (block 769). The scheduling information (i.e., a transmission grant) may include information about an assignment of a transmission of a TB and a second communication priority of an A/N message associated with the transmission of the TB. The A/N message may be scheduled for transmission in another resource of the feedback slot. The scheduling information may be transmitted in a second slot. In an embodiment, the scheduling information for the PSSCH reception is transmitted to a third UE. In an embodiment, the first and second slots may be different slots. The location of the second resource may be based on a second time assignment and the periodicity of feedback resource pools for transmission of A/N messages. Furthermore, the number of slots between the second slot and the feedback slot is at least a minimum of slots between a slot when the TB is decoded and the feedback slot.

The first UE determines whether to transmit or receive an A/N message (block 771). Because the transmission of the A/N message corresponding to the PSSCH reception and the reception of the A/N message corresponding to the PSSCH transmission are scheduled in the same slot, the first UE may be unable to perform both the transmission and the reception. Hence, the first UE determines which to perform. In an embodiment, the first UE utilizes the communication priority associated with the A/N messages to determine whether to transmit or receive. A detailed description of the communication priorities is provided below.

The first UE communicates an A/N message (block 773). The UE communicates (i.e., either transmit or receive) an A/N message based on the communication priority, as determined in block 771. As an example, if the first communication priority exceeds the second communication priority, the first UE transmits the A/N message corresponding to the PSSCH reception. Conversely, if the second communication priority exceeds the first communication priority, the first UE receives the A/N message corresponding to the PSSCH transmission.

Figure 8A illustrates a flow diagram of example operations 800 occurring in a UE communicating A/N messages based on a communication priority of the TBs associated with the A/N messages. Operations 800 may be indicative of operations occurring in a UE as the UE communicates A/N messages based on a priority of the TBs associated with the A/N messages. As used herein, communicating A/N messages may involve transmitting A/N messages, receiving A/N messages, or both transmitting and receiving A/N messages. The UE may be any UE that is capable of relaying A/N messages, such as a TxUE, a RxUE, or a relay UE.

Operations 800 begin with the UE having to transmit a first TB in a first PSSCH resource and receive a second TB in a second PSSCH resource (block 805). When the UE transmits the first TB, the UE expects to receive a corresponding A/N message. Similarly, when the UE receives the second TB, the UE expects to transmit a corresponding A/N message. However, due to the half-duplex constraint, the UE may not be able to transmit and receive in the next PSFCH opportunity. The UE performs a check to determine which one of A/N message transmission or A/N message reception has higher communication priority (block 807). If the A/N message transmission has higher communication priority, the UE transmits an A/N message for the second TB (block 809). If the A/N message reception has higher communication priority, the UE receives an A/N message for the first TB (block 811).

Although the discussion of Figure 8A focusses on the situation where the UE transmits on the first TB and receives on the second TB, the example embodiments presented herein are operable with the UE receiving on the first TB and transmitting on the second TB. Therefore, the focus on transmitting on the first TB and receiving on the second TB should not be construed as being limiting to the scope of the example embodiments.

Figure 8B illustrates a flow diagram of example operations 820 occurring in a UE communicating A/N messages based on a QoS requirement of the TBs associated with the A/N messages. Operations 820 may be indicative of operations occurring in a UE as the UE communicates A/N messages based on a QoS requirement of the TBs associated with the A/N messages. In Figure 8B, the QoS requirement is the communication priority.

Operations 820 begin with the UE having to transmit a first TB in a first PSSCH resource and receive a second TB in a second PSSCH resource (block 825). When the UE transmits the first TB, the UE expects to receive a corresponding A/N message. Similarly, when the UE receives the second TB, the UE expects to transmit a corresponding A/N message. However, due to the half-duplex constraint, the UE may not be able to transmit and receive in the next PSFCH. The UE performs a check to determine which TB (e.g., the first TB or the second TB) has a higher QoS requirement (i.e., the higher communication priority) (block 827). If the second TB has a higher QoS requirement, the UE transmits an A/N message for the second TB (block 829). If the first TB has a higher QoS requirement, the UE receives an A/N message for the first TB (block 831).

It may be possible for both TBs to have equal or substantially equal QoS requirements. In such a situation, the UE may utilize additional prioritizing criteria or criterion. As an example, in addition to the QoS requirement criteria, the UE may utilize the priority of the TBs as another prioritizing criterion. Other prioritizing criteria or criterion may be used.

Although the discussion of Figure 8B focusses on the situation where the UE performs a check to determine which TB has higher QoS priority, the example embodiments presented herein are operable with the UE performing a check to determine which TB has lower QoS priority. Therefore, the focus on checking for higher QoS priority should not be construed as being limiting to the scope of the example embodiments.

Figure 8C illustrates a flow diagram of example operations 840 occurring in a UE communicating A/N messages based on a transmission history of the TBs associated with the A/N messages. Operations 840 may be indicative of operations occurring in a UE as the UE communicates A/N messages based on a transmission history of the TBs associated with the A/N messages. In Figure 8C, the transmission history is the communication priority.

Operations 840 begin with the UE having to transmit a first TB in a first PSSCH resource and receive a second TB in a second PSSCH resource (block 845). When the UE transmits the first TB, the UE expects to receive a corresponding A/N message. Similarly, when the UE receives the second TB, the UE expects to transmit a corresponding A/N message. However, due to the half-duplex constraint, the UE may not be able to transmit and receive in the next PSFCH. The UE performs a check to determine which TB (e.g., the first TB or the second TB) has been transmitted or retransmitted more times (i.e., the communication priority) (block 847). If the second TB has been transmitted or retransmitted more times, then the UE transmits an A/N message for the second TB (block 849). If the first TB has been transmitted or retransmitted more times, then the UE receives an A/N message for the first TB (block 851). One possible reason for selecting the TB that has been transmitted or retransmitted more for another transmission or reception is that the TB may have been waiting longer and it is desirable to complete the HARQ process for the TB as soon as possible.

It may be possible for both TBs to have equal number of transmissions or retransmissions. In such a situation, the UE may utilize additional prioritizing criteria or criterion. As an example, in addition to the number of transmissions or retransmissions, the UE may utilize the priority of the TBs or QoS requirement as another prioritizing criterion. Other prioritizing criteria or criterion may be used.

Although the discussion of Figure 8C focusses on the situation where the UE performs a check to determine which TB has higher number of transmissions or retransmissions, the example embodiments presented herein are operable with the UE performing a check to determine which TB has lower number of transmissions or retransmissions. Therefore, the focus on checking for higher number of transmissions or retransmissions should not be construed as being limiting to the scope of the example embodiments.

In an embodiment, after a period of slots, the TxUE can proceed with a retransmission (with perhaps a different redundancy version). If there is a limit to the number of retransmissions, the TxUE can stop transmitting the packet when the limit is reached and start transmitting a new packet if one is available. The limit may be predefined, configured, based on quality of service, and so on.

It can be seen in the above examples that different cases are possible for receiving A/N transmissions, retransmissions, and relaying. A UE may receive multiple replicas of an A/N message, the UE may receive only one replica in a retransmission period or a relaying period, and so on. Because the different replicas may not be identical due to errors, the technical standard should determine the UE behavior for making a determination whether a TB was or was not received successfully if the different replicas of an A/N message are not identical, as discussed previously. The absence of receiving an A/N message at the TxUE may be considered as a NACK and trigger a behavior corresponding to a NACK. Additional details are provided below.

In an embodiment, in a time division multiplexing (TDM) deployment, regular PSSCH resources are allocated every N slots, and PSFCH resources for each PSSCH in a slot are allocated in a later slot. Figure 9 illustrates a diagram 900 of an example where PSFCH resources for relaying A/N messages originally transmitted or received in slot n+a 905 are allocated in slot n+a+1 910 (i.e., b=L=1).

In another embodiment, in a TDM deployment, where X>1, the repetition symbols can be used for relaying A/N by other UEs. Figure 10 illustrates a diagram 1000 highlighting a situation where repetition symbols 1005 are used for relaying A/N messages. Alternatively, the symbols allocated to relaying A/N messages may not be taken from repetition symbols. In this case, it is possible to allow guard gaps between PSFCH_DIRECT and PSFCH_RETX symbols so as to allow time for any UE(s) to switch between transmission and reception.

In the above examples related to TDM deployment, a whole symbol time in a bandwidth is allocated to PSFCH. However, A/N messages are generally small, and therefore, allocating whole symbols to PSFCH may result in many unused frequency resources. Thereby, overall communication system inefficiency is increased. Hence, in yet another embodiment, in a frequency division multiplexing (FDM) deployment, unused frequency resources of a next PSFCH (e.g., N slots later) can be allocated to relaying and/or retransmitting A/N messages. Figure 11 illustrates a diagram 1100 highlighting FDM operation, where different subbands are used to relay and/or retransmit A/N messages, such as subband 1105.

The HARQ feedback message should be designed to provide high reliability, because missing a HARQ feedback message can be interpreted as a NACK, and trigger a wasteful retransmission. Furthermore, HARQ feedback messages carry small amount of information, for example, one bit to determine ACK/NACK or multiple bits if ACK/NACK bundling or multiplexing of HARQ feedback is supported.

In an embodiment, a sequence-based message is a message format that is suitable for use as a HARQ feedback message. The sequence used in the message can carry information such as whether the message is an ACK or a NACK, the identity of the sender or the TB number the message is associated with, and so on. As an example, two sequences may be used in a sequence-based message, and if a first sequence is used, then the sequence-based message is an ACK and if a second sequence is used, then the sequence-based message is a NACK, or vice versa. As another example, eight sequences may be used in a sequence-based message, and if a sequence with sequence index between 0-3 is used, then the sequence-based message is an ACK for sender ID (or TB number) 0-3, and if a sequence with sequence index between 4-7 is used, then the sequence-based message is a NACK for sender ID (or TB number) 0-3, where sender ID (or TB number) is determined from the sequence number modulo 4. Other examples are possible.

The sequence design for the PSFCH may be intended at increasing the SNR and reducing interference from other messages sent on overlapping time-frequency resources, which is essentially a resource allocation in the code domain.

The methods proposed in the present disclosure can adopt a sequence-based HARQ feedback in a variety of embodiments. In an example embodiment, PSFCH resources are configured for transmission of HARQ feedback. As an example, the RxUE uses a sequence from a codebook C that is a function of the content of the message (ACK or NACK) as well as other information. Furthermore, another codebook of sequences C' can be used for retransmission and/or relaying of HARQ feedback messages, possibly on the same PSFCH resources. If the sequences in the codebooks C and C' are orthogonal or have low cross-correlation, the "regular" HARQ feedback messages can be distinguished from the retransmitted/relayed messages.

Figure 12 illustrates a diagram 1200 of a sequence-based HARQ feedback. As shown in Figure 12, the PSFCH for $PSSCH_M$ 1205 of slot n 1210 is transmitted in slot n+a 1215, as A/N message A/N_M 1220, and relayed in slot n+a+N 1225 as A/N message A/N_M 1230. Also transmitted in slot n+a+N 1225 is A/N message A/N_K 1235. A/N message A/N_M 1230 and A/N message A/N_K 1235 are transmitted on similar time-frequency resources, but use sequences from a different codebook (illustrated by a different cross-hatch pattern). Because a different codebook is used for relaying, overlapping resources used in $PSFCH_k$ do not cause a destructive interference and the overlapping messages can be decoded successfully.

The codebooks C and C' may be a set of sequences, waveforms, and so on, and may be defined by the technical standard and/or determined by a (pre)configuration. Examples of sequences are Zadoff-Chu sequences, m-sequences, etc. Once the sequences are defined by the technical standard, parameters defining the codebooks can be conveyed in the RP configuration and/or the PSFCH configuration. Then, each sequence/waveform in a codebook can be referred to as a codeword.

It may not be strictly required that cross-correlation between every codeword in C and every codeword in C' be low. Instead, the design and configuration of the codebook ensures that any two codes that may overlap in resources have low cross-correlation in the overlapped parts.

In practice, resource allocation and multiplexing rules should be determined through any or all of:

- Technical standard rules,
- Higher layer / RRC (pre)configuration, or
- Lower layer indication.

For example, a (pre)configuration of PSFCH may not only determine the resources allocated to PSFCH, but also an unambiguous mapping of PSSCH resources to PSFCH resources. As an illustrative example, PRBs in a PSFCH symbol can be associated with a PSSCH based on a function of the slot number offset (e.g., a scalar in the range 0,1,...,N-1) and/or other PSSCH resource parameters. Furthermore, for example, PRBs with a constant offset can be used for retransmitting/relaying A/N messages.

For the case of code division multiplexing (CDM), i.e., sequence-based design, the sequence-based A/N can substantially be retransmitted/relayed in the same frequency resources on a later PSFCH symbol, which possibly collides with other A/N messages being transmitted for the first time. However, because the sequences are taken from two different codebooks with low cross-correlation, they may be detected successfully.

Emphasis was given in the previously presented examples on the case of A/N relaying. However, similar details and alternatives can be applied to the case of A/N retransmission. There may or may not be a distinction between retransmission and relaying, or otherwise the two may coexist on different PSFCH resources. In the case that there is no distinction between retransmission and relaying, retransmitted and relayed signals may be superposed on overlapping resources. This may only be useful with amplify-and-forward relaying because the collision would be destructive otherwise. Details on relaying schemes are provided below.

As related to UE behavior for relaying, the decision box in the flowchart for relaying UEs, a relaying UE needs to make a determination whether or not it relays A/N messages on PSFCH resources. Details and alternatives are as follows:

- Relaying an A/N message is only allowed by a UE if relaying resources are allocated by a (pre)configuration to the A/N message, to the PSFCH containing the A/N message, to the PSSCH associated with the A/N message or the PSFCH, etc.

- A (pre)configuration may further determine which UE(s) are allowed or required to relay an A/N message. For example, in order to avoid an overwhelming number of relayed messages that increase interference and waste transmission power, UEs with certain IDs may relay an A/N message. The UE IDs may be explicitly mentioned in a configuration or may be obtained by implicit rules. For instance, only UEs belonging to a groupcast or UEs using a RP or UEs belonging to a particular group can relay an A/N message.

- As another example, only UE IDs that belong to the same modulo M group as the TxUE ID or RxUE ID may relay an A/N message. Consider the example where UEs with IDs {UE1, UE2, ..., UE10} are present in a vicinity and M=4 for modulo matching with the TxUE. Then, if UE5 makes a PSSCH transmission and UE6 transmits an A/N message, UE1 and UE9 may relay the A/N message because (1 mod 4) = (5 mod 4) = (9 mod 4) = 1. M may be obtained from a (pre)configuration. The UE ID can be based on an RNTI or a group ID (such as a destination ID, for example).

- Furthermore, in order to avoid degradation of signal quality due to the superposition of signal with different propagation delays, UEs may be allowed to relay an A/N message only if they are within a certain distance, which may be obtained from a (pre)configuration.

- Alternatively, UEs may employ a probabilistic approach to relay an A/N message to reduce the interference further. For example, each UE may determine to relay an A/N message with a probability p, which may be obtained from a (pre)configuration, or may be calculated based on the current PSFCH load, and so on.

- Yet furthermore, UEs may be allowed by a (pre)configuration to perform A/N relaying in PSFCH resources allocated to A/N retransmission. In this case, there may be no distinction between retransmission of an A/N message by the RxUE versus relaying by other UEs. This scheme simplifies resource allocation, but may suffer from unintended interference.

- UEs may further take transmission power into consideration. If a UE is going to relay a number of A/N messages, but multiplexing the A/N messages results in exceeding a power limit, the UE may not relay some of the A/N messages in order to meet the power requirement.

As related to operating at high frequencies, such as FR2, analog beamforming at FR2 imposes additional constraints on PSFCH configuration and scheduling. In particular, if a UE is expected to transmit A/N messages or receive A/N messages on the same PSFCH symbols, and if the transmissions or receptions require applying different beams by an antenna, the UE will be unable to perform both communications simultaneously even though the half-duplex constraint is met.

Techniques to address this issue includes:

- Avoiding beamforming conflicts by the access node in mode 1.
- Omnidirectional communications for PSFCH.
- Assigning an explicit direction to a PSFCH instance.
- Assigning an implicit direction to a UE using a PSFCH instance, which corresponds to a PSSCH.

As related to avoiding beamforming conflicts: Similar to the techniques for avoiding half-duplex conflicts, the access node can schedule communications in mode 1 SL that aims at avoiding beamforming conflicts. A simple method to satisfy the constraint for every UE is to schedule transmissions or receptions to/from a UE with only another UE in each period of N slots that are associated with a PSFCH opportunity. In this case, because a UE is expected to communicate with at most one other UE in each PSFCH instance, beamforming conflicts are avoided. A/N bundling and/or communicating multiple A/N messages by a UE is still possible, but they are limited to communications with at most one other UE. This technique is simple, but may introduce an excessive delay, for example for groupcast communications.

Another technique to avoid beamforming conflicts involves each UE informing the access node of the beams it uses for communication with every other UE. For example, each time the UE performs a beam management operation and obtains a new beam or updates an obsolete beam, the UE communicates the new beam information to the access node. Alternatively, beam information can be sent to the access node upon demand and immediately before scheduling a PSSCH. Then, the access node can schedule PSSCHs in a way that PSFCH transmission or reception by each UE does not require applying different beams. This approach requires signaling of beam information to the access node, which can impose a large overhead, hence making the technique impractical unless for a small number of UEs.

As related to assigning an explicit direction to a PSFCH instance: An extension to omnidirectional PSFCH is that each PSFCH instance can be associated with a particular direction for transmission and/or reception of A/N signals. A direction may be determined by:

1. Association with a vehicle orientation (useful for highway vehicular applications),
2. Association with a geographical direction (useful for urban vehicular applications),
3. Spatial quasi-co-location (QCL) indication to a reference signal.

Figure 13 illustrates a diagram 1300 highlighting assigning directions to each PSFCH instance. As shown in Figure 13, in a first PSFCH instance 1305, only beams oriented in a first direction (e.g., upward or northerly) are used to transmit or receive A/N signals, while in a second PSFCH instance 1310, only beams oriented in a second direction (e.g., right or easterly) are used to transmit or receive A/N signals. Similarly, in a third PSFCH instance 1315, only beams oriented in a third direction (e.g., downward or southerly) are used to transmit or receive A/N signals, while in a fourth PSFCH instance 1320, only beams oriented in a fourth direction (e.g., left or westerly) are used to transmit or receive A/N signals.

Figure 14A illustrates a flow diagram of example operations 1400 occurring in a TxUE participating in directional communications. Operations 1400 may be indicative of operations occurring in a TxUE as the TxUE participates in directional communications. The TxUE operations may be similar to the operations discussed previously, but additionally, the TxUE applies the following for beamforming. It may be generally assumed that TxUE and RxUE acquire and maintain beam pair information for communication by executing beam management procedures such as beam training, beam tracking, beam failure recovery, and beam/QCL indications.

Operations 1400 begin with the TxUE obtaining PSFCH configuration (block 1405). In an embodiment, the TxUE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc. The configuration also includes spatial or directional information.

The TxUE applies transmit beam(s) to the data and transmits the beamformed data (block 1407). If the TxUE applies a transmit beam for transmitting PSSCH signals to RxUE, it can apply a dual receive beam to receive PSFCH signals from RxUE (blocks 1409 and 1411). The PSFCH signals may be received on PSFCH_DIRECT resources (block 1409) and/or PSFCH_RETX resources (block 1411).

The TxUE determines if the packet is successfully received (block 1413). Having received signals associated with possibly multiple replicas of the A/N message(s), the TxUE determines whether the data were received by the RxUE(s) successfully. This, in turn, may determine whether to make a HARQ retransmission at a later PSSCH, etc. The TxUE may utilize some or all of the rules discussed previously to determine if the packet was successfully received.

Figure 14B illustrates a flow diagram of example operations 1420 occurring in a RxUE participating in directional communications. Operations 1420 may be indicative of operations occurring in a RxUE as the RxUE participates in directional communications. The RxUE operations may be similar to the operations discussed previously, but additionally, the RxUE applies the following for beamforming.

Operations 1420 begin with the RxUE obtaining PSFCH configuration (block 1425). The RxUE obtains configuration of PSFCH resources in a RP. In an embodiment, the RxUE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc. The configuration also includes spatial or directional information. Details regarding the PSFCH configuration may be as described previously for the TxUE and will not be discussed again here.

The RxUE receives data (block 1427). The RxUE applies receive beam(s) and receives data signals on a PSSCH. Details may be similar to the corresponding step in TxUE operation. If the PSSCH contains a retransmission, the RxUE may combine elements from the initial transmission with the retransmission before decoding.

The RxUE transmits an A/N message (block 1429). The RxUE may apply dual transmit beams and transmits an A/N message to the TxUE on PSFCH_DIRECT resources. However, the RxUE may not always be able to do so, because of half-duplex or beamforming constraints, for example. If this is the case, the RxUE applies dual transmit beams and retransmits an A/N message on PSFCH_RETX resources. This may be an optional operation depending on the (pre)configuration.

Figure 14C illustrates a flow diagram of example operations 1440 occurring in a relay UE participating in directional communications. Operations 1440 may be indicative of operations occurring in a relay UE as the relay UE participates participating in directional communications. The relay UE operations may be similar to the operations discussed previously, but additionally, the relay UE applies the following for beamforming

Operations 1440 begin with the relay UE obtaining PSFCH configuration (block 1445). The relay UE obtains configuration of PSFCH resources in a RP. In an embodiment, the relay UE obtains configurations for PSFCH_DIRECT resources and PSFCH_RETX resources. The configuration may be: per RP, per BWP, per UE. The configuration may also be associated with a specific packet or type of packet. Examples of the configurations include n, k, etc. The configuration also includes spatial or directional information.

The relaying UE applies receive beam(s) and receives an A/N message on PSFCH_DIRECT resources (block 1447). Depending on the (pre)configuration, the relay UE may use the receive beam(s) and listen to the PSFCH_DIRECT resources and receive A/N messages from RxUEs in the area. The relay UE may also listen to the PSFCH_RETX resources and receive retransmitted (or relayed) A/N messages from UEs in the area, also using the receive beam(s).

The relay UE determines to relay an A/N message or not (block 1449). Depending on the (pre)configuration and UE behavior rules, the relay UE determines whether or not and which A/N messages to transmit (relay) on the PSFCH_RETX resources. In an embodiment, the determination may be based on deterministic or probabilistic rules. The rules may require the relay UE to always relay the A/N; relay with a fixed probability of retransmission; relay with a probability of transmission determined based on, for example, load on the PSFCH, load on the PSSCH, etc.; and so on. Additional details are provided below.

The relay UE applies transmit beam(s) and relays an A/N message (block 1451). If the relay UE has determined to relay, the relay UE transmits the PSFCH signals that the relay UE has received on associated PSFCH_RETX resources using transmit beam(s) associated with the PSFCH_RETX resources.

Because the beam pairs acquired and maintained between a pair of UEs may not exactly match the beams/directions/QCL associated with a PSFCH resource, the UEs may apply beams that are angularly "close" to the indicated beams/directions/QCL; and furthermore, the UEs may select the PSFCH resources associated with beams/directions/QCL that are angularly "close" or "closest" to the directions of the beam pairs. Determining angularly close beams may be specified by the standard or may be left to implementation.

There is also a possibility that a pair of UEs does not have up-to-date beam information, and instead, they apply multiple beams to communicate multiple replicas of data. In this case, multiple PSFCH resources associated with the multiple beams can be used for conveying HARQ feedback. Moreover, this method can be used as an implicit beam training/tracking method – UEs can acquire/update beam information to that of the beams that have recently provided successful communication of PSSCH and PSFCH. The UEs can then reset beam maintenance timers, which may reduce from aperiodic CSI-RS overhead for beam management.

Because beam information may be updated during the time that the RxUE is waiting for the next suitable PSFCH opportunity, it can be defined as UE behavior (both TxUE and RxUE) to use the PSFCH opportunity that matches corresponding PSSCH beams even if the beam information is updated between the PSSCH and PSFCH communications. For example, the UEs may continue to use the dual beams they used for transmit and receive signals on a PSSCH in order to receive and transmit signals on the PSFCH, respectively, even if they are obsolete meanwhile. Any resulting failures in communication can then be addressed by A/N relaying and/or any failed acknowledgement can be treated as a NACK.

As related to RP switching, a PSFCH configuration may be associated with a RP. Configuration parameters such as the resources allocated to PSFCH for direct transmission of HARQ feedback and retransmission/relaying determine the PSFCH reliability, latency, and so on. Therefore, the QoS that a UE experiences when using a RP can depend on the PSFCH configuration for the RP, in addition to other factors such as the load on the RP.

Consider that a UE has a stream data to transmit with QoS requirements. An access node or a device such as UE itself assigns a RP to the data/UE based on factors including the QoS requirements. In an embodiment, the access node/device assigns the RP based on the reliability/latency requirements of the data/UE compared to the reliability/latency that the PSFCH configuration provides. For example, a data/UE demanding a higher reliability is assigned a RP with a PSFCH configuration that provides more resources for direct transmission of HARQ feedback and/or retransmission/relaying of HARQ feedback.

In some embodiments, if the UE determines that the currently assigned RP does not satisfy its QoS requirement for the data, it can request the access node/device to assign a different RP that satisfies the QoS requirement. A special case is when no HARQ process or PSFCH is configured in a RP, but the UE requests a more reliable RP. In this case, the UE may be reassigned a different RP with a HARQ process and PSFCH resources configured.

Alternatively, PSFCH configuration of a RP can be modified, for example, by updating the value of N, in order to meet the QoS requirements.

At least 3 cases of relaying techniques can be distinguished for A/N relaying. They are mainly based on amplify-and-forward (AF) and decode-and-forward (DF) relaying in combination with Fast Fourier Transform (FFT) operation at the receiver of an OFDM-based air interface. Other options are not precluded.

As related to pre-FFT AF: In this technique, the receiver samples the signals in the time domain and retransmits (relays) the signals by reconstructing a time-domain signal directly based on the samples without further processing.

As related to post-FFT AF: In this technique, the receiver samples the signals in the time domain and passes the samples through a FFT block to obtain frequency domain samples. The receiver then is able to shift the signal in the frequency domain, for example to other frequency resources, before passing them through an inverse FFT (IFFT) block and retransmitting (relaying) the signals.

As related to DF: In this technique, the signal sampled in the time domain is converted to the frequency domain and processed at the digital/baseband unit before reconstruction and transmission. If an A/N message is a sequence, the reconstructed signal may resemble the exact sequence. Otherwise, the relay UE may encode the A/N message differently, may bundle the information with other information such as other A/N messages, and so on. In these cases, the reconstructed physical signal may not resemble the original A/N signal despite carrying the same information.

In any of the techniques described in the present disclosure, the messages carrying information are mentioned as examples and do not mean to limit the scope of the example embodiments. For example, the information described to be carried by PHY signaling such as DCI, SCI, SFCI, and UCI, can instead be carried by MAC or RRC messages or performed by higher layers. Furthermore, a proposed signaling technique may or may not be executed for every scheduling instance.

In mode 1, the TxUE can receive signals from the access node directly, but the RxUE may not be able to receive the signals. Instead, the RxUE receives control signaling information on an SCI. Also, it is possible that one of the UEs is not in network coverage. In such cases, it is possible that one UE communicates the control information received from the access node to the other UE. For example, a UE receiving a DCI message containing scheduling information may communicate the information in an SCI message prior to PSSCH communications. Other information such as configuration/indication messages, ACK/NACK, request messages, and so on may also be communicated by a UE between an access node and another UE.

An RP/PSFCH configuration may be associated with a carrier, a bandwidth part, time-domain resources such as slots or frames, a RP, a pattern in resources such as a time-frequency repetition pattern (TFRP), and so on. In the description of embodiments, an emphasis is on association with RPs, but other alternatives are not precluded. Each RP/PSFCH configuration may be UE-specific or, alternatively, may be used by all or a group of UEs. Consequently, if the configurations are obtained by signaling, the signaling may be broadcast, groupcast, geocast, multicast, unicast to a specific UE, etc.

Figure 15 illustrates a first example communication system 1500. Communication system 1500 includes an access node 1505 serving user equipments (UEs), such as UEs 1510, 1512, 1514, 1516, and 1515. In a first operating mode, communications to and from UE 1515 pass through access node 1505. In a second operating mode, communications to and from UE 1515 do not pass through access node 1505, however, access node 1505 typically allocates resources used by UE 1515 to communicate when specific conditions are met. Access nodes may also be commonly referred to as Node Bs, evolved Node Bs (eNBs), next generation (NG) Node Bs (gNBs), master eNBs (MeNBs), secondary eNBs (SeNBs), master gNBs (MgNBs), secondary gNBs (SgNBs), network controllers, control nodes, base stations, access points, transmission points (TPs), transmission-reception points (TRPs), cells, carriers, macro cells, femtocells, pico cells, and so on, while UEs may also be commonly referred to as mobile stations, mobiles, terminals, users, subscribers, stations, and the like. Access nodes may provide wireless access in accordance with one or more wireless communication protocols, e.g., the Third Generation Partnership Project (3GPP) long term evolution (LTE), LTE advanced (LTE-A), 5G, 5G LTE, 5G NR, High Speed Packet Access (HSPA), the IEEE 802.11 family of standards, such as 802.11a/b/g/n/ac/ad/ax/ay/be, etc. While it is understood that communications systems may employ multiple access nodes capable of communicating with a number of UEs, only one access node and five UE are illustrated for simplicity.

Figure 16 illustrates a second example communication system 1600. In general, the system 1600 enables multiple wireless or wired users to transmit and receive data and other content. The system 1600 may implement 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), or non-orthogonal multiple access (NOMA).

In this example, the communication system 1600 includes electronic devices (ED) 1610a-1610c, radio access networks (RANs) 1620a-1620b, a core network 1630, a public switched telephone network (PSTN) 1640, the Internet 1650, and other networks 1660. While certain numbers of these components or elements are shown in Figure 16, any number of these components or elements may be included in the system 1600.

The EDs 1610a-1610c are configured to operate or communicate in the system 1600. For example, the EDs 1610a-1610c are configured to transmit or receive via wireless or wired communication channels. Each ED 1610a-1610c represents any suitable end user device and may include such devices (or may be referred to) as a user equipment or device (UE), wireless transmit or receive unit (WTRU), mobile station, fixed or mobile subscriber unit, cellular telephone, personal digital assistant (PDA), smartphone, laptop, computer, touchpad, wireless sensor, or consumer electronics device.

The RANs 1620a-1620b here include base stations 1670a-1670b, respectively. Each base station 1670a-1670b is configured to wirelessly interface with one or more of the EDs 1610a-1610c to enable access to the core network 1630, the PSTN 1640, the Internet 1650, or the other networks 1660. For example, the base stations 1670a-1670b may include (or be) one or more of several well-known devices, such as a base transceiver station (BTS), a Node-B (NodeB), an evolved NodeB (eNodeB), a Next Generation (NG) NodeB (gNB), a Home NodeB, a Home eNodeB, a site controller, an access point (AP), or a wireless router. The EDs 1610a-1610c are configured to interface and communicate with the Internet 1650 and may access the core network 1630, the PSTN 1640, or the other networks 1660.

In the embodiment shown in Figure 16, the base station 1670a forms part of the RAN 1620a, which may include other base stations, elements, or devices. Also, the base station 1670b forms part of the RAN 1620b, which may include other base stations, elements, or devices. Each base station 1670a-1670b operates to transmit or receive wireless signals within a particular geographic region or area, sometimes referred to as a “cell.” In some embodiments, multiple-input multiple-output (MIMO) technology may be employed having multiple transceivers for each cell.

The base stations 1670a-1670b communicate with one or more of the EDs 1610a-1610c over one or more air interfaces 1690 using wireless communication links. The air interfaces 1690 may utilize any suitable radio access technology.

It is contemplated that the system 1600 may use multiple channel access functionality, including such schemes as described above. In particular embodiments, the base stations and EDs implement 5G New Radio (NR), LTE, LTE-A, or LTE-B. Of course, other multiple access schemes and wireless protocols may be utilized.

The RANs 1620a-1620b are in communication with the core network 1630 to provide the EDs 1610a-1610c with voice, data, application, Voice over Internet Protocol (VoIP), or other services. Understandably, the RANs 1620a-1620b or the core network 1630 may be in direct or indirect communication with one or more other RANs (not shown). The core network 1630 may also serve as a gateway access for other networks (such as the PSTN 1640, the Internet 1650, and the other networks 1660). In addition, some or all of the EDs 1610a-1610c may include functionality for communicating with different wireless networks over different wireless links using different wireless technologies or protocols. Instead of wireless communication (or in addition thereto), the EDs may communicate via wired communication channels to a service provider or switch (not shown), and to the Internet 1650.

Although Figure 16 illustrates one example of a communication system, various changes may be made to Figure 16. For example, the communication system 1600 could include any number of EDs, base stations, networks, or other components in any suitable configuration.

Figures 17A and 17B illustrate example devices that may implement the methods and teachings according to this disclosure. In particular, Figure 17A illustrates an example ED 1710, and Figure 17B illustrates an example base station 1770. These components could be used in the system 1600 or in any other suitable system.

As shown in Figure 17A, the ED 1710 includes at least one processing unit 1700. The processing unit 1700 implements various processing operations of the ED 1710. For example, the processing unit 1700 could perform signal coding, data processing, power control, input/output processing, or any other functionality enabling the ED 1710 to operate in the system 1600. The processing unit 1700 also supports the methods and teachings described in more detail above. Each processing unit 1700 includes any suitable processing or computing device configured to perform one or more operations. Each processing unit 1700 could, for example, include a microprocessor, microcontroller, digital signal processor, field programmable gate array, or application specific integrated circuit.

The ED 1710 also includes at least one transceiver 1702. The transceiver 1702 is configured to modulate data or other content for transmission by at least one antenna or NIC (Network Interface Controller) 1704. The transceiver 1702 is also configured to demodulate data or other content received by the at least one antenna 1704. Each transceiver 1702 includes any suitable structure for generating signals for wireless or wired transmission or processing signals received wirelessly or by wire. Each antenna 1704 includes any suitable structure for transmitting or receiving wireless or wired signals. One or multiple transceivers 1702 could be used in the ED 1710, and one or multiple antennas 1704 could be used in the ED 1710. Although shown as a single functional unit, a transceiver 1702 could also be implemented using at least one transmitter and at least one separate receiver.

The ED 1710 further includes one or more input/output devices 1706 or interfaces (such as a wired interface to the Internet 1650). The input/output devices 1706 facilitate interaction with a user or other devices (network communications) in the network. Each input/output device 1706 includes any suitable structure for providing information to or receiving information from a user, such as a speaker, microphone, keypad, keyboard, display, or touch screen, including network interface communications.

In addition, the ED 1710 includes at least one memory 1708. The memory 1708 stores instructions and data used, generated, or collected by the ED 1710. For example, the memory 1708 could store software or firmware instructions executed by the processing unit(s) 1700 and data used to reduce or eliminate interference in incoming signals. Each memory 1708 includes any suitable volatile or non-volatile storage and retrieval device(s). Any suitable type of memory may be used, such as random access memory (RAM), read only memory (ROM), hard disk, optical disc, subscriber identity module (SIM) card, memory stick, secure digital (SD) memory card, and the like.

As shown in Figure 17B, the base station 1770 includes at least one processing unit 1750, at least one transceiver 1752, which includes functionality for a transmitter and a receiver, one or more antennas 1756, at least one memory 1758, and one or more input/output devices or interfaces 1766. A scheduler, which would be understood by one skilled in the art, is coupled to the processing unit 1750. The scheduler could be included within or operated separately from the base station 1770. The processing unit 1750 implements various processing operations of the base station 1770, such as signal coding, data processing, power control, input/output processing, or any other functionality. The processing unit 1750 can also support the methods and teachings described in more detail above. Each processing unit 1750 includes any suitable processing or computing device configured to perform one or more operations. Each processing unit 1750 could, for example, include a microprocessor, microcontroller, digital signal processor, field programmable gate array, or application specific integrated circuit.

Each transceiver 1752 includes any suitable structure for generating signals for wireless or wired transmission to one or more EDs or other devices. Each transceiver 1752 further includes any suitable structure for processing signals received wirelessly or by wire from one or more EDs or other devices. Although shown combined as a transceiver 1752, a transmitter and a receiver could be separate components. Each antenna 1756 includes any suitable structure for transmitting or receiving wireless or wired signals. While a common antenna 1756 is shown here as being coupled to the transceiver 1752, one or more antennas 1756 could be coupled to the transceiver(s) 1752, allowing separate antennas 1756 to be coupled to the transmitter and the receiver if equipped as separate components. Each memory 1758 includes any suitable volatile or non-volatile storage and retrieval device(s). Each input/output device 1766 facilitates interaction with a user or other devices (network communications) in the network. Each input/output device 1766 includes any suitable structure for providing information to or receiving/providing information from a user, including network interface communications.

Figure 18 is a block diagram of a computing system 1800 that may be used for implementing the devices and methods disclosed herein. For example, the computing system can be any entity of UE, access network (AN), mobility management (MM), session management (SM), user plane gateway (UPGW), or access stratum (AS). Specific devices may utilize all of the components shown or only a subset of the components, and levels of integration may vary from device to device. Furthermore, a device may contain multiple instances of a component, such as multiple processing units, processors, memories, transmitters, receivers, etc. The computing system 1800 includes a processing unit 1802. The processing unit includes a central processing unit (CPU) 1814, memory 1808, and may further include a mass storage device 1804, a video adapter 1810, and an I/O interface 1812 connected to a bus 1820.

The bus 1820 may be one or more of any type of several bus architectures including a memory bus or memory controller, a peripheral bus, or a video bus. The CPU 1814 may comprise any type of electronic data processor. The memory 1808 may comprise any type of non-transitory system memory such as static random access memory (SRAM), dynamic random access memory (DRAM), synchronous DRAM (SDRAM), read-only memory (ROM), or a combination thereof. In an embodiment, the memory 1808 may include ROM for use at boot-up, and DRAM for program and data storage for use while executing programs.

The mass storage 1804 may comprise any type of non-transitory storage device configured to store data, programs, and other information and to make the data, programs, and other information accessible via the bus 1820. The mass storage 1804 may comprise, for example, one or more of a solid state drive, hard disk drive, a magnetic disk drive, or an optical disk drive.

The video adapter 1810 and the I/O interface 1812 provide interfaces to couple external input and output devices to the processing unit 1802. As illustrated, examples of input and output devices include a display 1818 coupled to the video adapter 1810 and a mouse, keyboard, or printer 1816 coupled to the I/O interface 1812. Other devices may be coupled to the processing unit 1802, and additional or fewer interface cards may be utilized. For example, a serial interface such as Universal Serial Bus (USB) (not shown) may be used to provide an interface for an external device.

The processing unit 1802 also includes one or more network interfaces 1806, which may comprise wired links, such as an Ethernet cable, or wireless links to access nodes or different networks. The network interfaces 1806 allow the processing unit 1802 to communicate with remote units via the networks. For example, the network interfaces 1806 may provide wireless communication via one or more transmitters/transmit antennas and one or more receivers/receive antennas. In an embodiment, the processing unit 1802 is coupled to a local-area network 1822 or a wide-area network for data processing and communications with remote devices, such as other processing units, the Internet, or remote storage facilities.

It should be appreciated that one or more steps of the embodiment methods provided herein may be performed by corresponding units or modules. For example, a signal may be transmitted by a transmitting unit or a transmitting module. A signal may be received by a receiving unit or a receiving module. A signal may be processed by a processing unit or a processing module. Other steps may be performed by a determining unit or module. The respective units or modules may be hardware, software, or a combination thereof. For instance, one or more of the units or modules may be an integrated circuit, such as field programmable gate arrays (FPGAs) or application-specific integrated circuits (ASICs).

Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the scope of the disclosure as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A method for operating a first device, the method comprising:

receiving, by the first device from a second device, a first scheduling information in a first slot, the first scheduling information including a first assignment for reception of a first transport block (TB) and a first communication priority for transmission of a first hybrid automatic repeat request (HARQ) feedback message associated with the reception of the first TB, the first HARQ feedback message being scheduled for transmission in a first resource of a feedback slot;

transmitting, by the first device to a third device, a second scheduling information in a second slot, the second scheduling information including a second assignment for transmission of a second TB and a second communication priority for transmission of a second HARQ feedback message associated with the transmission of the second TB, the second HARQ feedback message being scheduled for transmission in a second resource of the feedback slot; and

communicating, by the first device, the first HARQ feedback message and the second HARQ feedback message in accordance with a comparison of the first communication priority with the second communication priority.

2. The method of claim 1, the first HARQ feedback message being transmitted by the first device to the second device.

3. The method of any one of claims 1-2, the second HARQ feedback message being received from the third device.

4. The method of any one of claims 1-3, the first resource being determined in accordance with a first time assignment and a periodicity of feedback resource pools for transmission of HARQ feedback messages, and the second resource being determined in accordance with a second time assignment and the periodicity of feedback resource pools for transmission of HARQ feedback messages.

5. The method of any one of claims 1-4, communicating the first and second HARQ feedback messages comprising transmitting, by the first device, the first HARQ feedback message when the first communication priority exceeds the second communication priority.

6. The method of any one of claims 1-4, communicating the first and second HARQ feedback messages comprising receiving, by the first device, the second HARQ feedback message when the second communication priority exceeds the first communication priority.

7. The method of any one of claims 1-6, the first slot and the second slot being different slots.

8. The method of any one of claims 1-7, a number of slots between the first slot and the feedback slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the feedback slot.

9. The method of any one of claims 1-8, the first and second communication priority comprising one of a transmission or a reception priority, a quality of service (QoS) requirement, or a number of retransmissions of the first HARQ feedback message and the second HARQ feedback message.

10. A method for operating a first device, the method comprising:

transmitting, by the first device, to a second device, a scheduling information in a first slot including an assignment for a transmission of a transport block (TB) in a first slot, and an instruction for a transmission of a first hybrid automatic repeat request (HARQ) feedback message associated with the transmission of the TB, the first HARQ feedback message being scheduled for transmission in a first resource of a second slot configured for feedback transmission, a first number of slots between the first slot and the second slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the second slot;

monitoring, by the first device, the first resource of the second slot for the transmission of the first HARQ feedback message; and

monitoring, by the first device, a second resource of a third slot configured for feedback transmission for a transmission of a second HARQ feedback message, the second HARQ feedback message comprising the first HARQ feedback message, and a second number of slots between the second slot and the third slot being at least equal to the periodicity of slots configured for feedback transmission.

11. The method of claim 10, further comprising determining, by the first device, a status of the TB in accordance with a reception of the first HARQ feedback message and a reception of the second HARQ feedback message.

12. The method of claim 11, determining the status of the TB comprising determining that the transmission being successful when the first HARQ feedback message comprises an acknowledgement.

13. The method of any one of claims 10-12, the second HARQ feedback message being received from a third device.

14. The method of any one of claims 10-12, the first HARQ feedback message being received from the second device.

15. The method of any one of claims 10-14, the first number of slots comprising a sum of a minimum time gap between the slot associated with the decoding of the first TB and the first second slot, and the periodicity of slots configured for feedback transmission.

16. The method of any one of claims 10-15, the second number of slots comprising a sum of the minimum time gap between the slot associated with the decoding of the first TB and the second slot, the number of slots between the first slot and the second slot, and a number of slots between the second slot and the third slot.

17. The method of any one of claims 10-16, the TB comprising a sidelink data transmission.

18. A first device comprising:

one or more processors; and

a non-transitory memory storage comprising instructions that, when executed by the one or more processors, cause the first device to:

receive, from a second device, a first scheduling information in a first slot, the first scheduling information including a first assignment for a reception of a first transport block (TB), and a first communication priority for a transmission of a first HARQ feedback message associated with the reception of the first TB, the first HARQ feedback message being scheduled for transmission in a first resource of a feedback slot;

transmit, to a third device, a second scheduling information in a second slot, the second scheduling information including a second assignment for a transmission of a second TB, and a second communication priority for a transmission of a second HARQ feedback message associated with the transmission of the second TB, the second HARQ feedback message being scheduled for transmission in a second resource of the feedback slot; and

communicate the first HARQ feedback message and the second HARQ feedback message in accordance with a comparison of the first communication priority with the second communication priority.

19. The first device of claim 18, the first HARQ feedback message being transmitted by the first device to the second device.

20. The first device of any one of claims 18-19, the second HARQ feedback message being received from the third device.

21. The first device of any one of claims 18-20, the first resource being determined in accordance with a first time assignment and a periodicity of feedback resource pools for transmission of HARQ feedback messages, and the second resource being determined in accordance with a second time assignment and the periodicity of feedback resource pools for transmission of HARQ feedback messages.

22. The first device of any one of claims 18-21, wherein the instructions are further executed by the one or more processors to cause the first device to: receive the second HARQ feedback message when the second communication priority exceeds the first communication priority.

23. The first device of any one of claims 18-21, wherein the instructions are further executed by the one or more processors to cause the first device to: transmit the first HARQ feedback message when the first communication priority exceeds the second communication priority.

24. The first device of any one of claims 18-23, the first slot and the second slot being different slots.

25. The first device of any one of claims 18-24, a number of slots between the first slot and the feedback slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the feedback slot.

26. The first device of any one of claims 18-25, the first and second communication priority comprising one of a transmission or a reception priority, a quality of service (QoS) requirement, or a number of retransmissions of the first HARQ feedback message and the second HARQ feedback message.

27. A first device comprising:

one or more processors; and

a non-transitory memory storage comprising instructions that, when executed by the one or more processors, cause the first device to:

transmit, to a second device, a scheduling information in a first slot including an assignment for a transmission of a transport block (TB) in a first slot, and an instruction for a transmission of a first HARQ feedback message associated with the transmission of the TB, the first HARQ feedback message being scheduled for transmission in a first resource of a second slot configured for feedback transmission, a first number of slots between the first slot and the second slot being at least a minimum number of slots between a slot associated with a decoding of the first TB and the second slot;

monitor the first resource of the second slot for the transmission of the first HARQ feedback message; and

monitor a second resource of a third slot configured for feedback transmission for a transmission of a second HARQ feedback message, the second HARQ feedback message comprising the first HARQ feedback message, and a second number of slots between the second slot and the third slot being at least equal to the periodicity of slots configured for feedback transmission.

28. The first device of claim 27, wherein the instructions are further executed by the one or more processors to cause the first device to: determine a status of the TB in accordance with a reception of the first HARQ feedback message and a reception of the second HARQ feedback message.

29. The first device of claim 28, wherein the instructions are further executed by the one or more processors to cause the first device to: determine that the transmission being successful when the first HARQ feedback message comprises an acknowledgement.

30. The first device of any one of claims 27-29, the second HARQ feedback message being received from a third device.

31. The first device of any one of claims 27-29, the first HARQ feedback message being received from the second device.

32. The first device of any one of claims 27-31, the first number of slots comprising a sum of a minimum time gap between the slot associated with the decoding of the first TB and the first second slot, and the periodicity of slots configured for feedback transmission.

33. The first device of any one of claims 27-32, the second number of slots comprising a sum of the minimum time gap between the slot associated with the decoding of the first TB and the second slot, the number of slots between the first slot and the second slot, and a number of slots between the second slot and the third slot.

34. The first device of any one of claims 27-33, the TB comprising a sidelink data transmission.

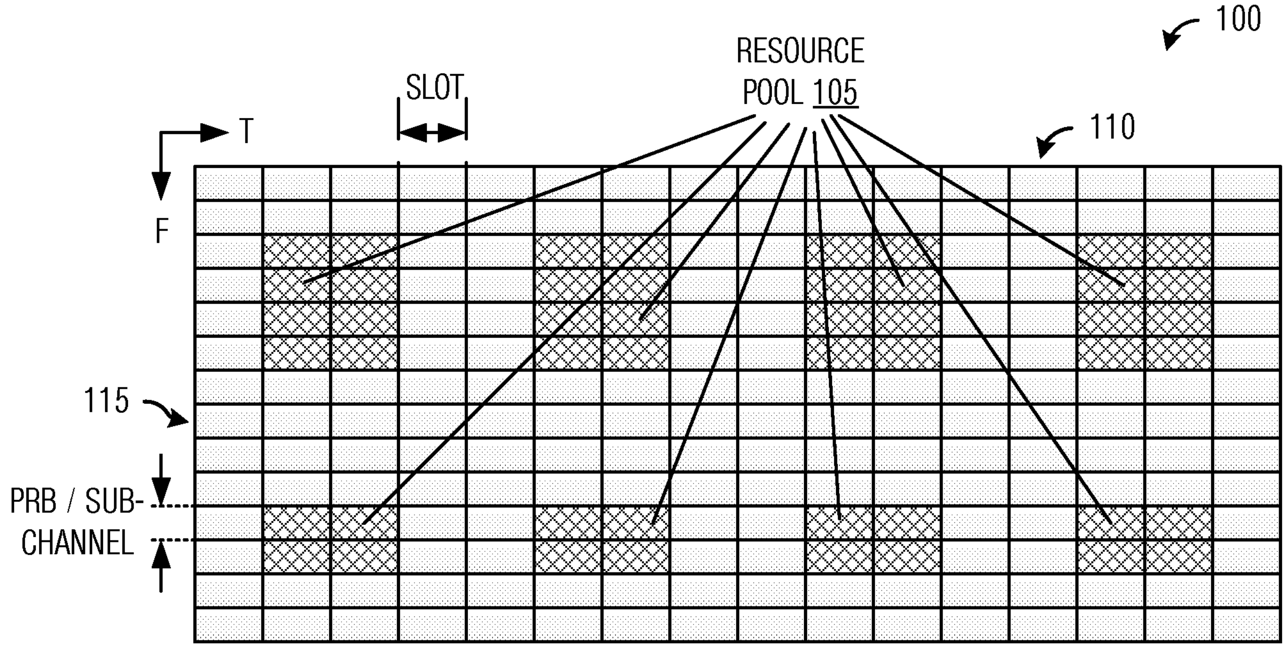
100
RESOURCE POOL 105
SLOT
T
110
F
115
PRB / SUB-CHANNEL

Fig. 1

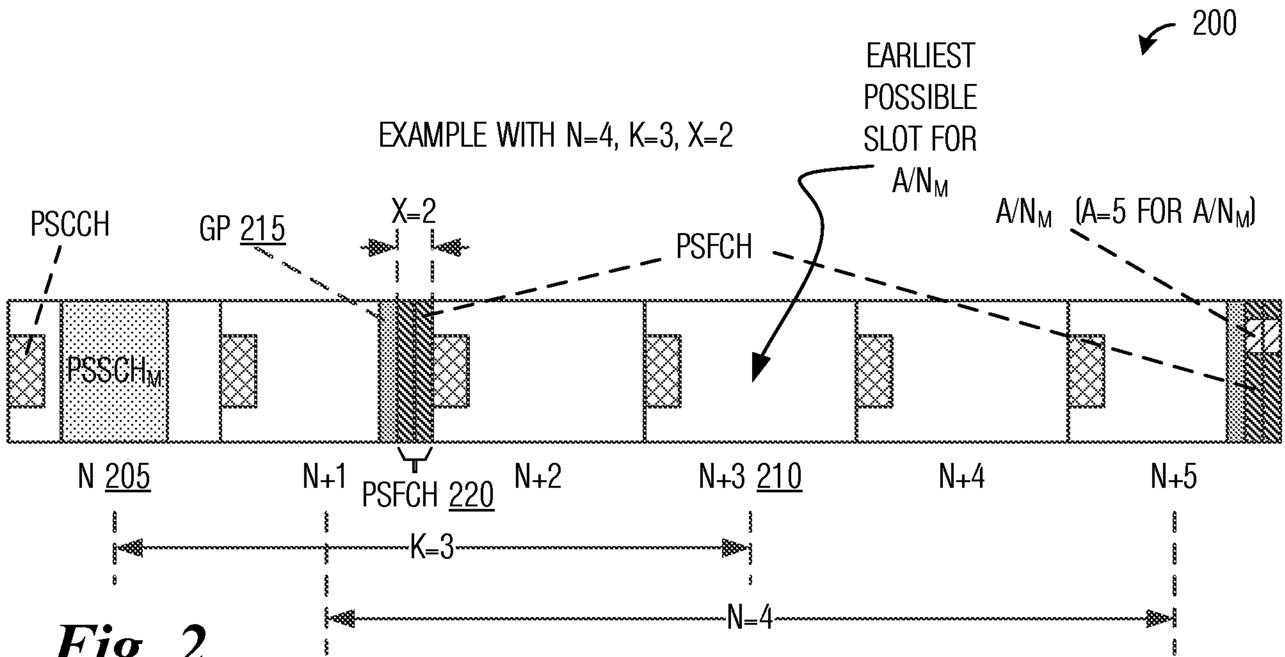
200
EARLIEST POSSIBLE SLOT FOR A/N$_M$
EXAMPLE WITH N=4, K=3, X=2
X=2
PSCCH
GP 215
PSFCH
A/N$_M$ (A=5 FOR A/N$_M$)
PSSCH$_M$
N 205
N+1
PSFCH 220
N+2
N+3 210
N+4
N+5
K=3
N=4

Fig. 2

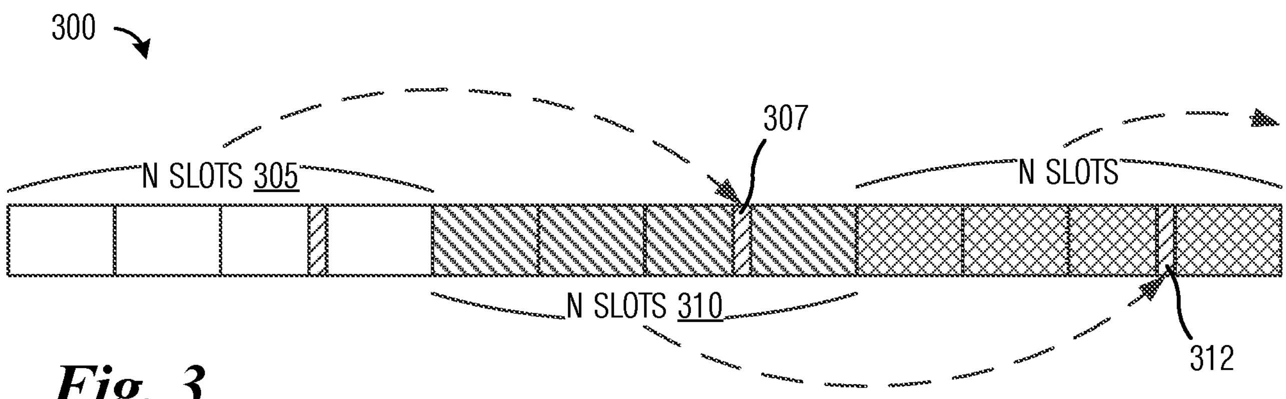
300
N SLOTS 305
307
N SLOTS
N SLOTS 310
312

Fig. 3

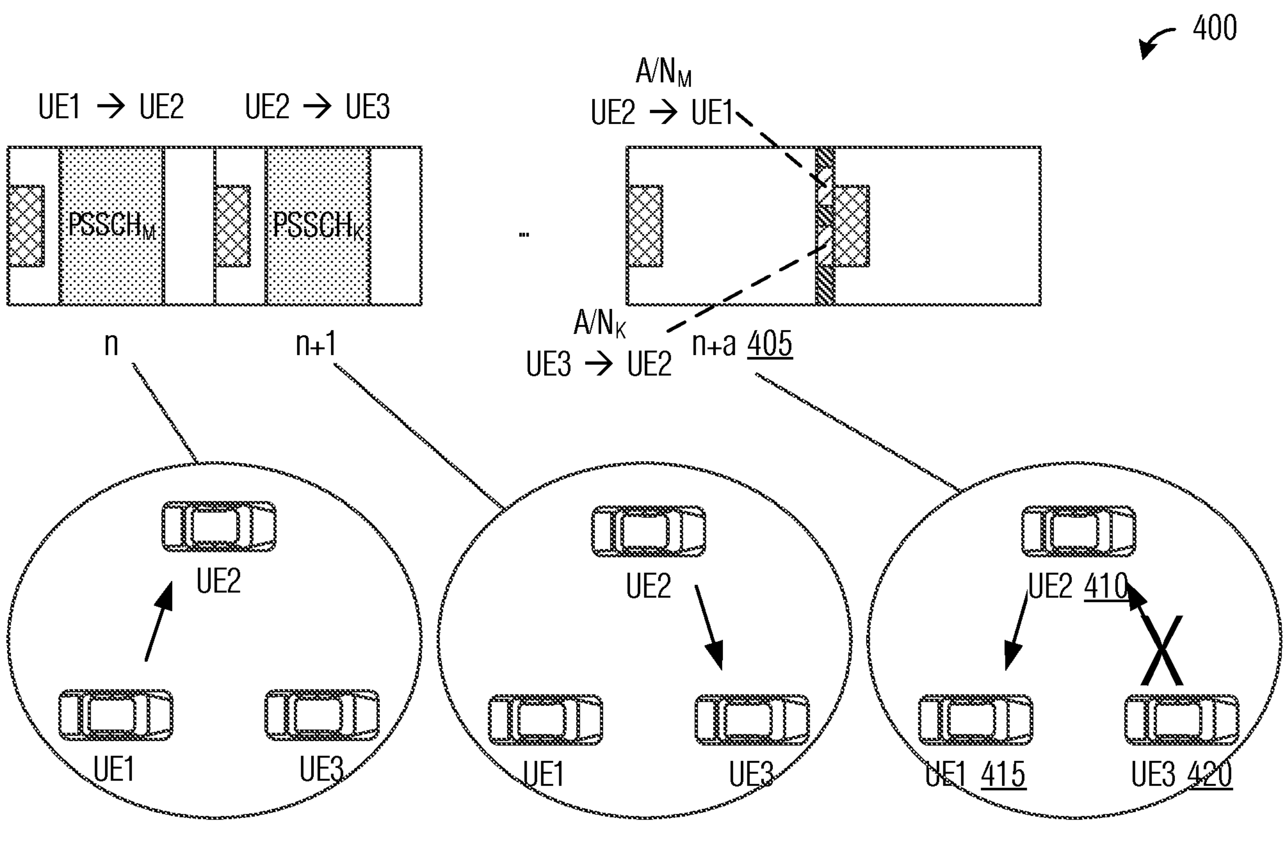
400
A/N$_M$
UE2 → UE1
UE1 → UE2
UE2 → UE3
PSSCH$_M$
PSSCH$_K$
A/N$_K$
UE3 → UE2
n
n+1
n+a 405
UE2
UE1
UE3
UE2
UE1
UE3
UE2 410
UE1 415
UE3 420

Fig. 4

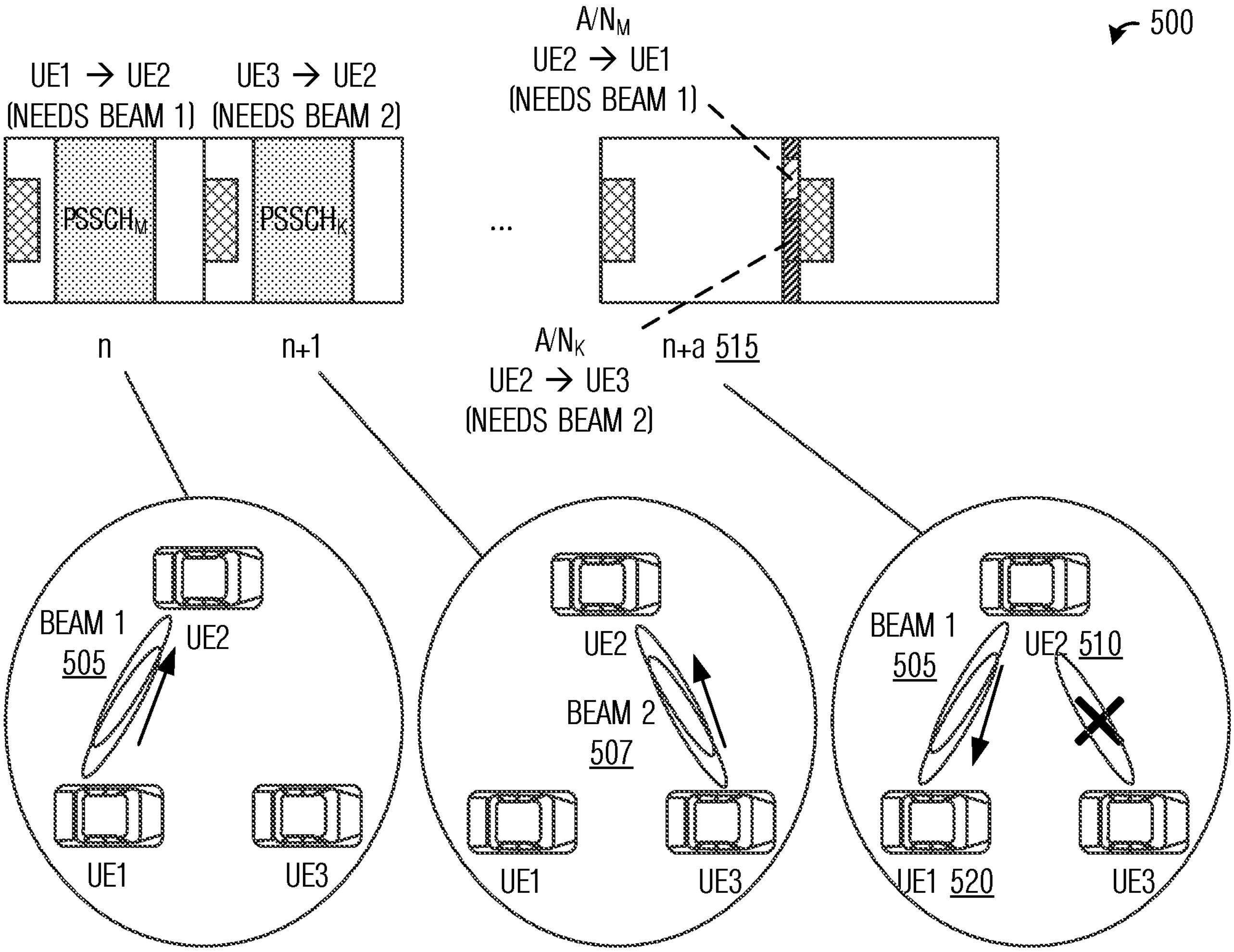
500
A/N$_M$
UE2 → UE1
(NEEDS BEAM 1)
UE1 → UE2
(NEEDS BEAM 1)
UE3 → UE2
(NEEDS BEAM 2)
PSSCH$_M$
PSSCH$_K$
...
n
n+1
A/N$_K$
UE2 → UE3
(NEEDS BEAM 2)
n+a 515
BEAM 1
505
UE2
UE1
UE3
UE2
BEAM 2
507
UE1
UE3
BEAM 1
505
UE2 510
UE1 520
UE3

Fig. 5

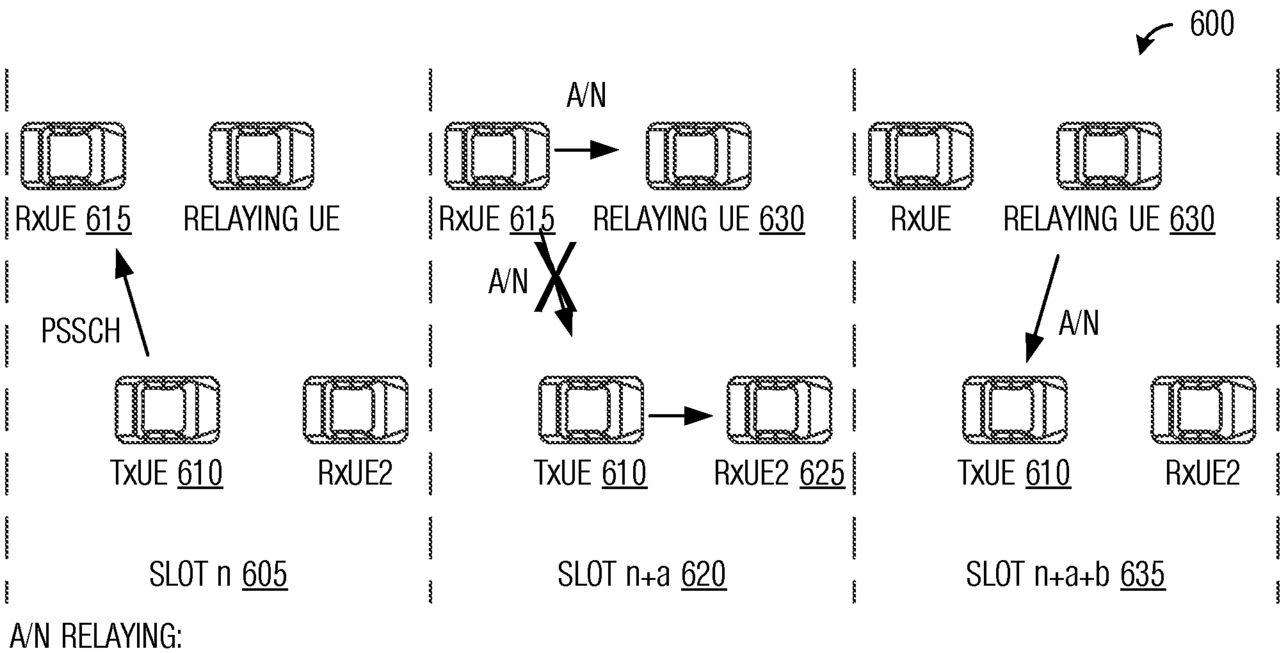
600
RxUE 615
RELAYING UE
PSSCH
TxUE 610
RxUE2
A/N
RxUE 615
RELAYING UE 630
A/N
TxUE 610
RxUE2 625
RxUE
RELAYING UE 630
A/N
TxUE 610
RxUE2
SLOT n 605
SLOT n+a 620
SLOT n+a+b 635
A/N RELAYING:

Fig. 6

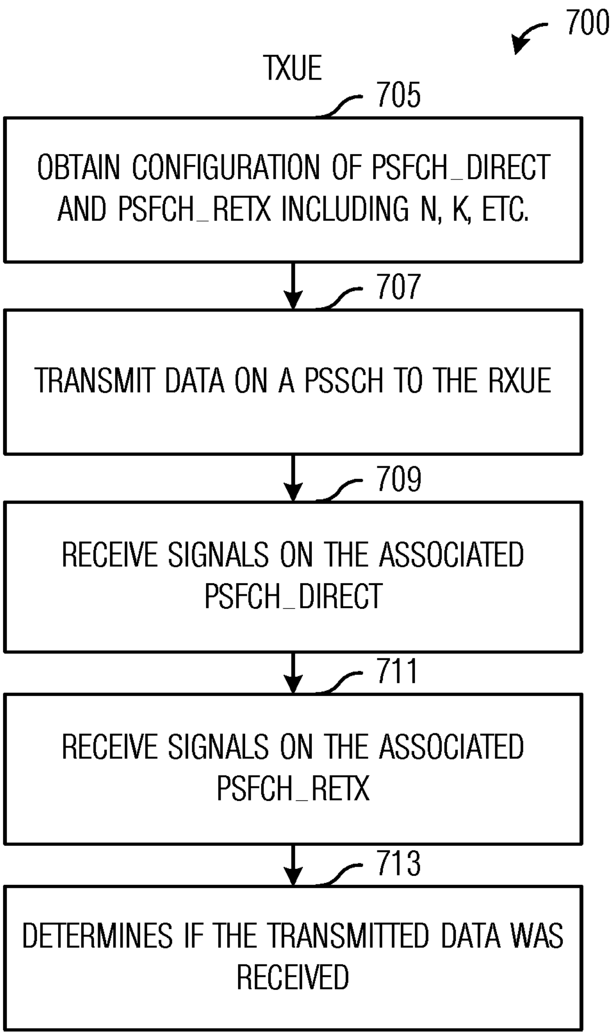
700
TXUE
705
OBTAIN CONFIGURATION OF PSFCH_DIRECT AND PSFCH_RETX INCLUDING N, K, ETC.
707
TRANSMIT DATA ON A PSSCH TO THE RXUE
709
RECEIVE SIGNALS ON THE ASSOCIATED PSFCH_DIRECT
711
RECEIVE SIGNALS ON THE ASSOCIATED PSFCH_RETX
713
DETERMINES IF THE TRANSMITTED DATA WAS RECEIVED

Fig. 7A

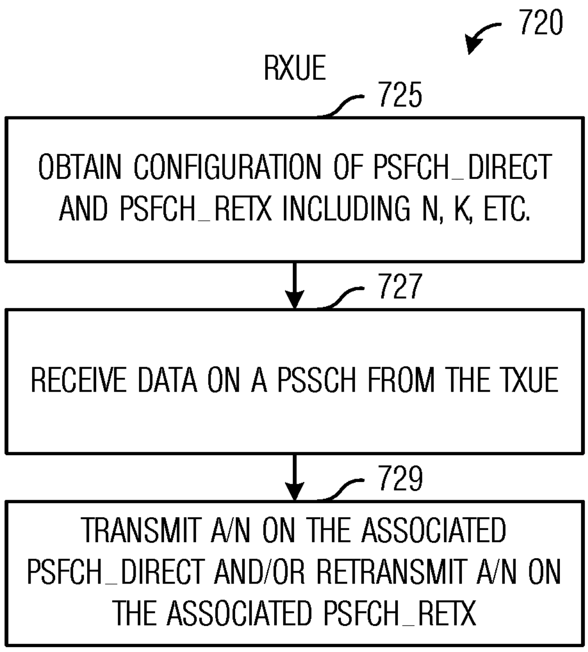
720
RXUE
725
OBTAIN CONFIGURATION OF PSFCH_DIRECT AND PSFCH_RETX INCLUDING N, K, ETC.
727
RECEIVE DATA ON A PSSCH FROM THE TXUE
729
TRANSMIT A/N ON THE ASSOCIATED PSFCH_DIRECT AND/OR RETRANSMIT A/N ON THE ASSOCIATED PSFCH_RETX

Fig. 7B

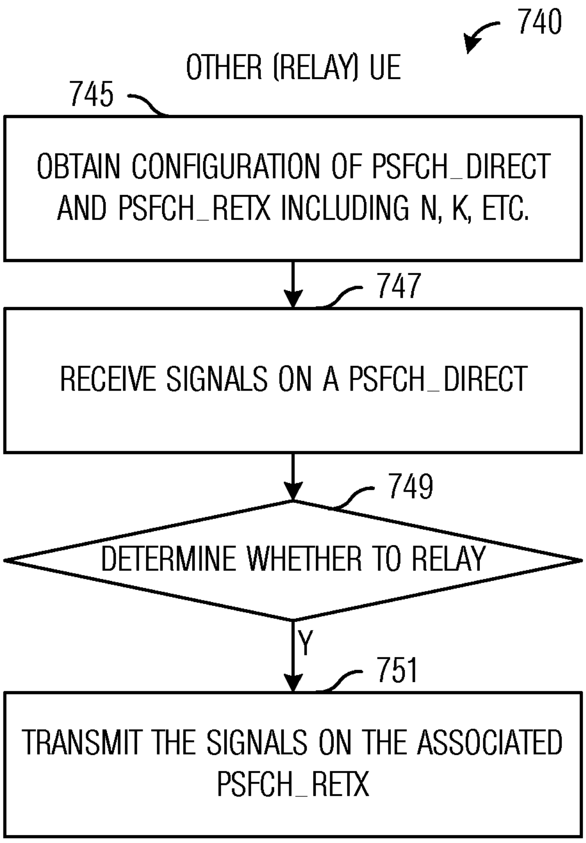
740
OTHER (RELAY) UE
745
OBTAIN CONFIGURATION OF PSFCH_DIRECT AND PSFCH_RETX INCLUDING N, K, ETC.
747
RECEIVE SIGNALS ON A PSFCH_DIRECT
749
DETERMINE WHETHER TO RELAY
Y
751
TRANSMIT THE SIGNALS ON THE ASSOCIATED PSFCH_RETX

Fig. 7C

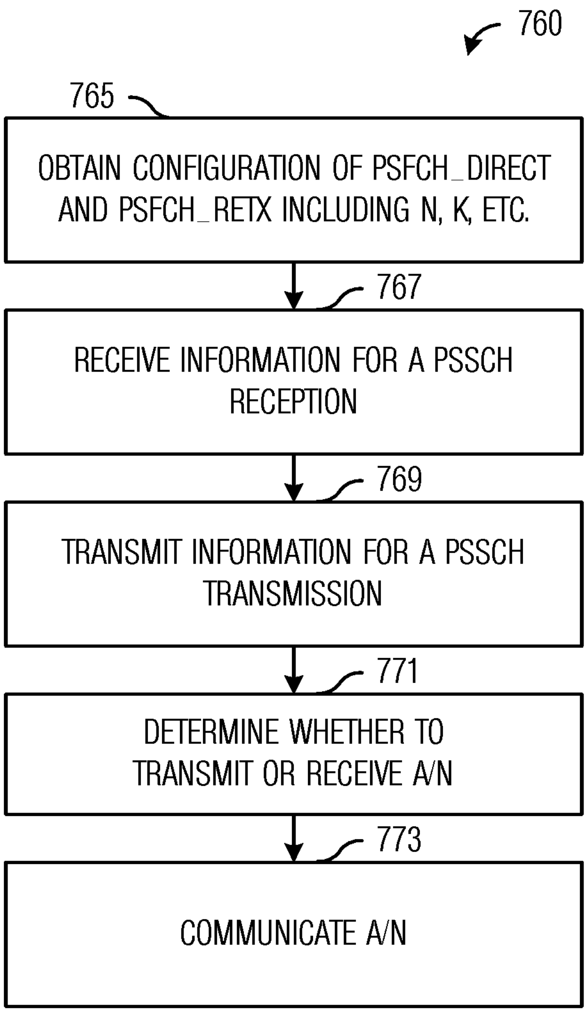
760
765
OBTAIN CONFIGURATION OF PSFCH_DIRECT AND PSFCH_RETX INCLUDING N, K, ETC.
767
RECEIVE INFORMATION FOR A PSSCH RECEPTION
769
TRANSMIT INFORMATION FOR A PSSCH TRANSMISSION
771
DETERMINE WHETHER TO TRANSMIT OR RECEIVE A/N
773
COMMUNICATE A/N

Fig. 7D

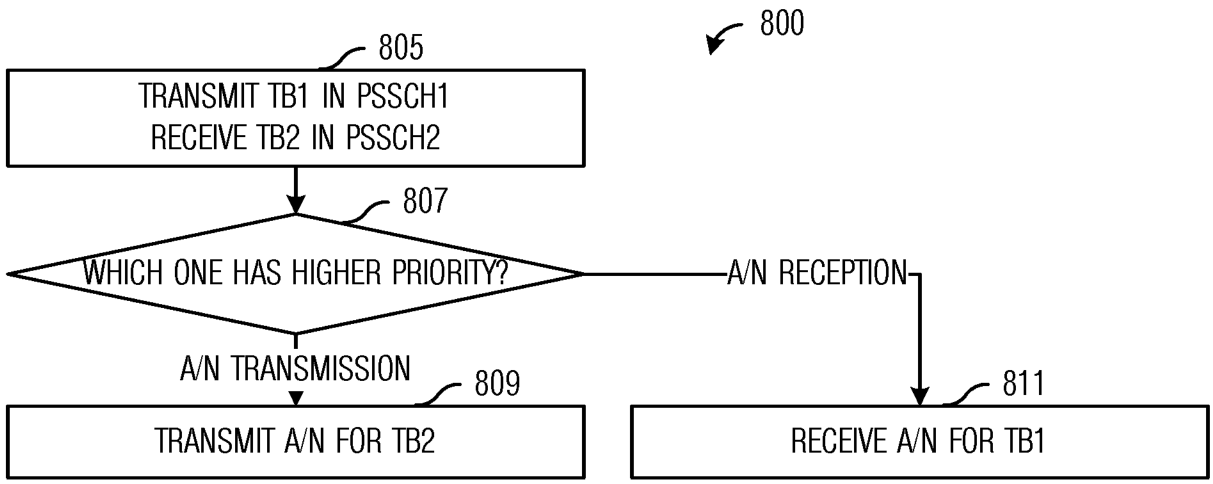

Fig. 8A

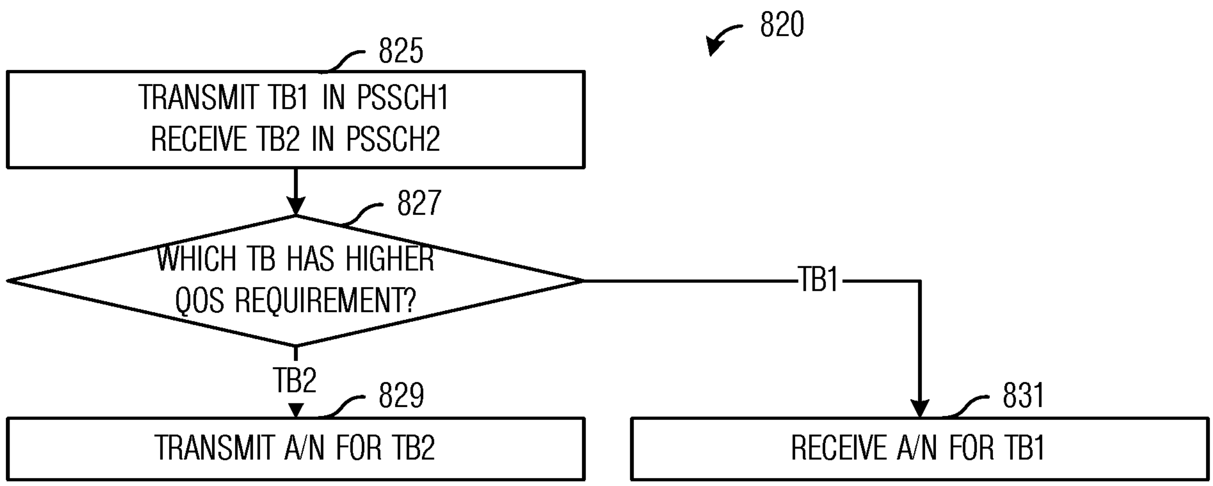

Fig. 8B

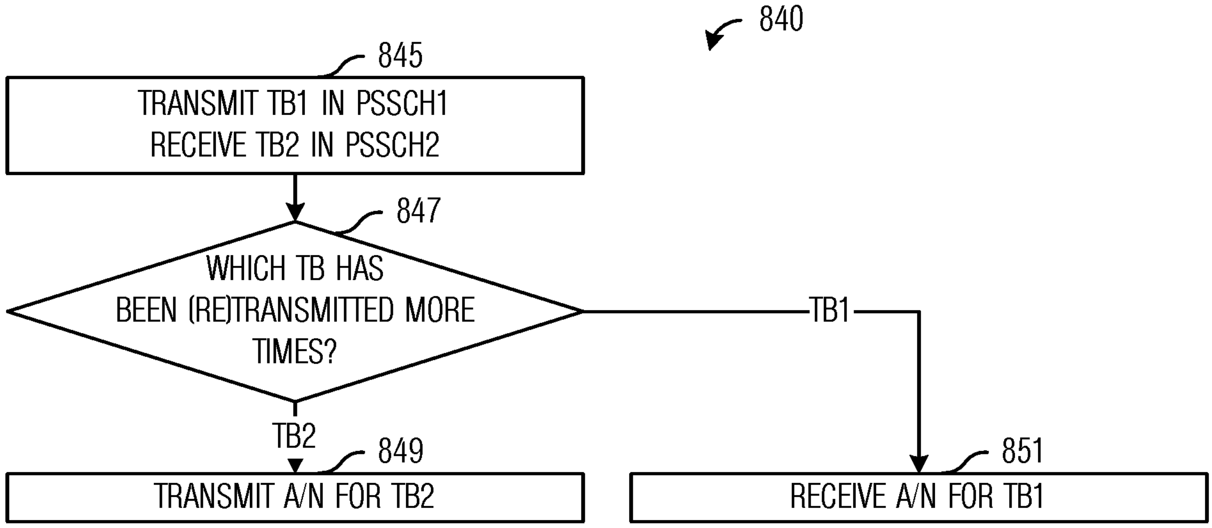

Fig. 8C

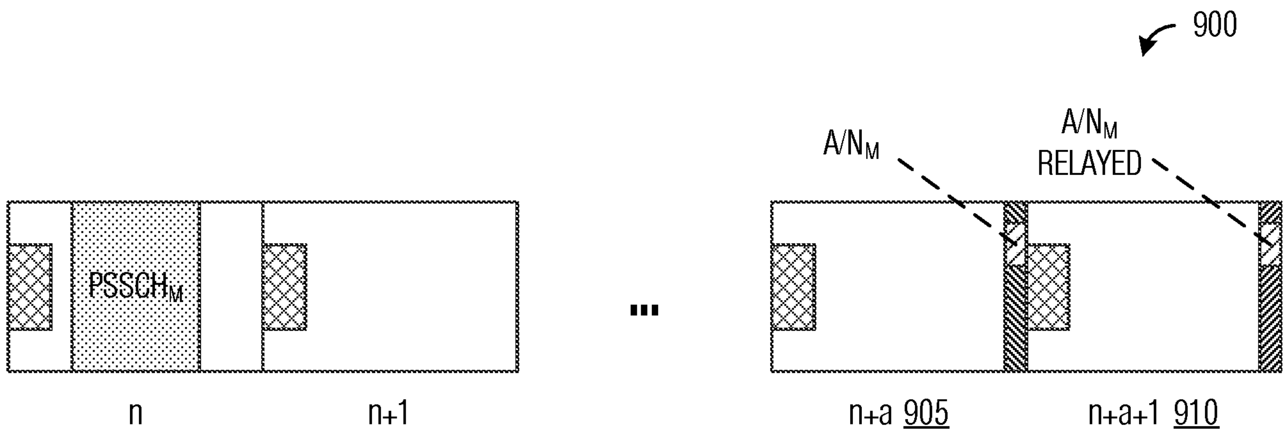

Fig. 9

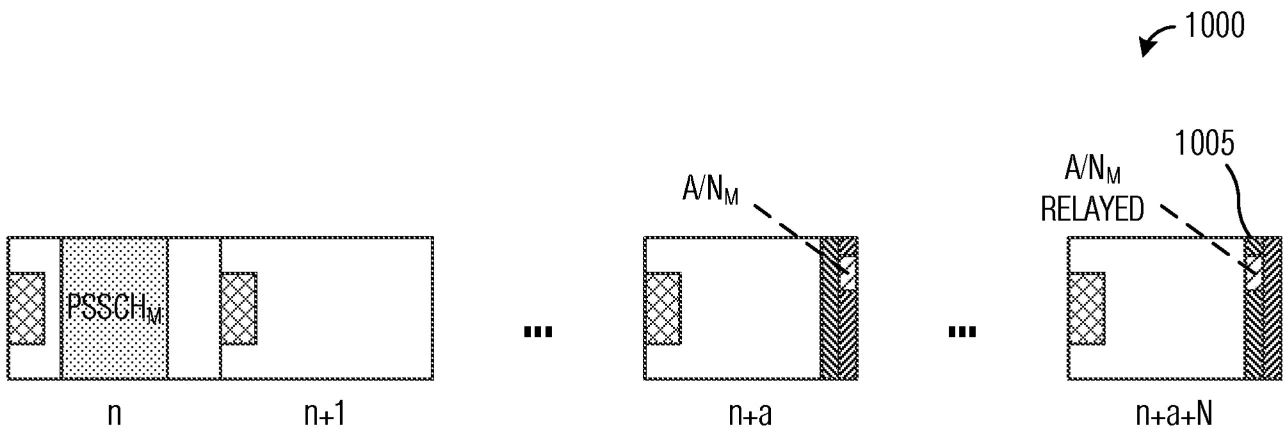

Fig. 10

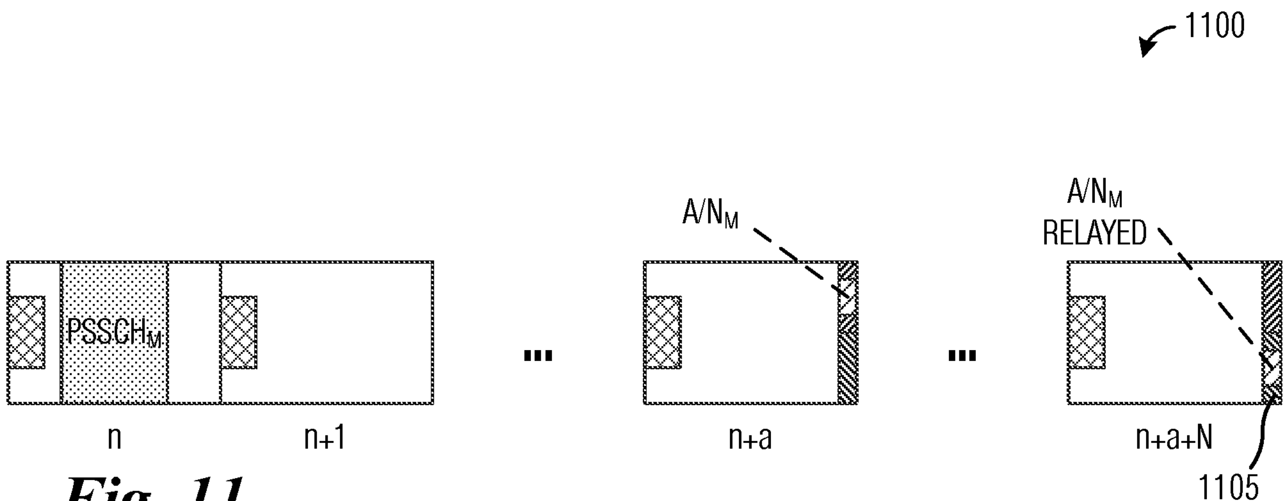

Fig. 11

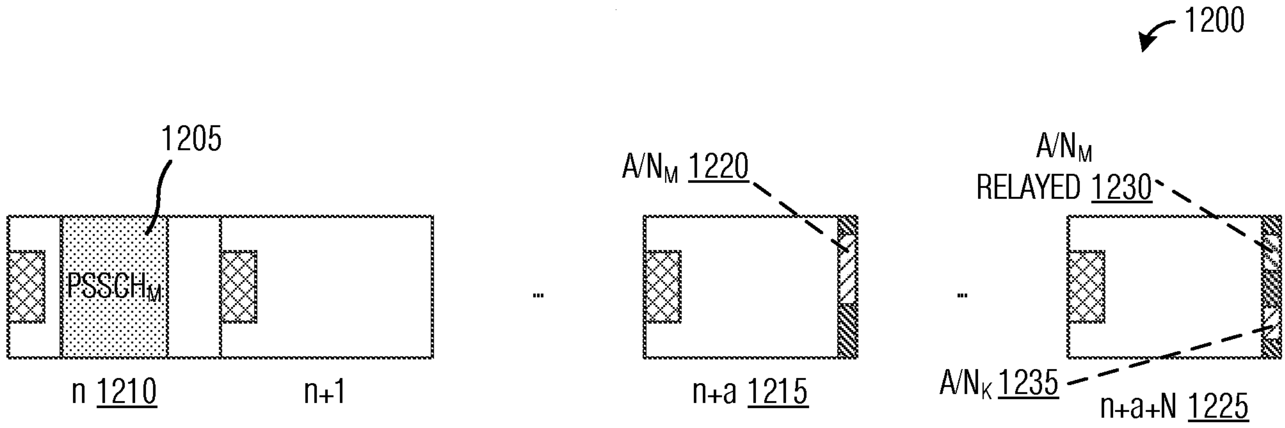

Fig. 12

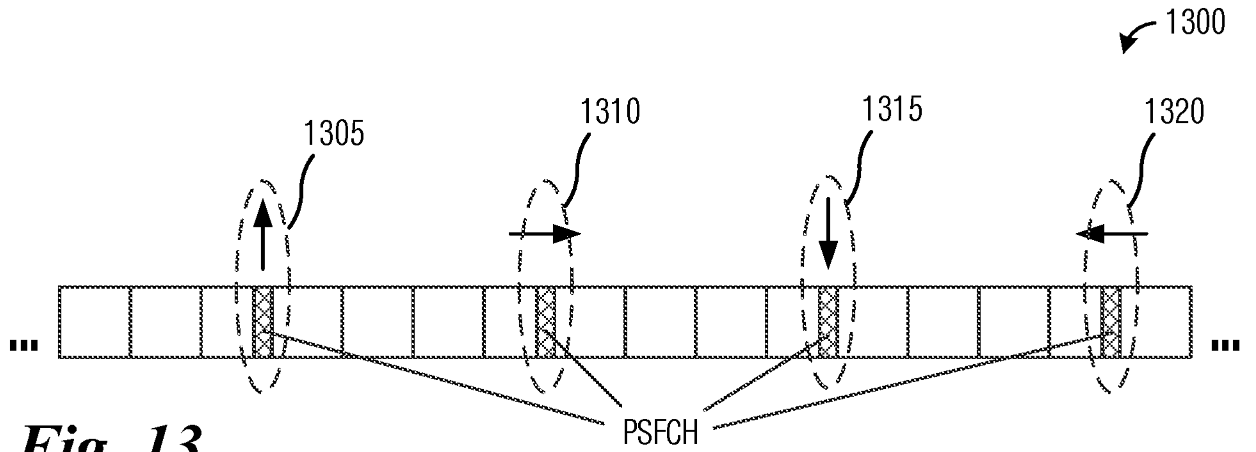

Fig. 13

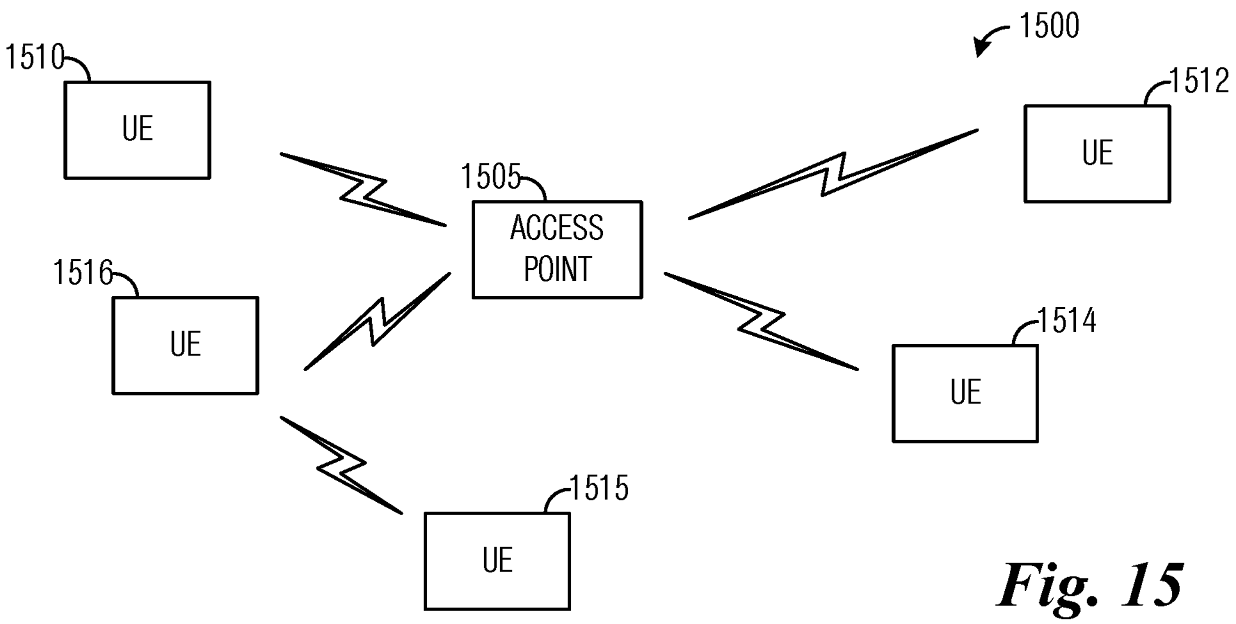

Fig. 15

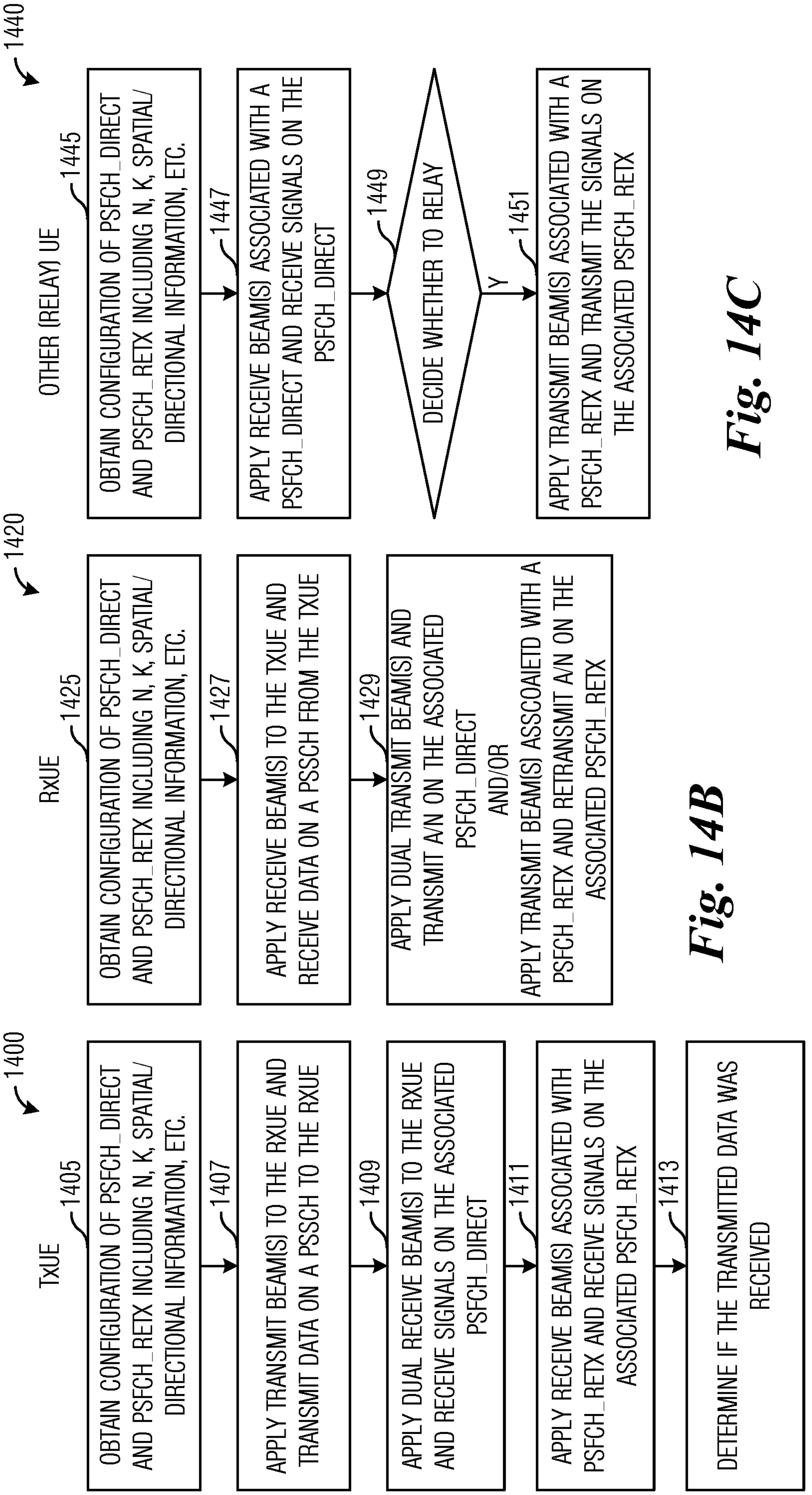

Fig. 14A

Fig. 14B

Fig. 14C

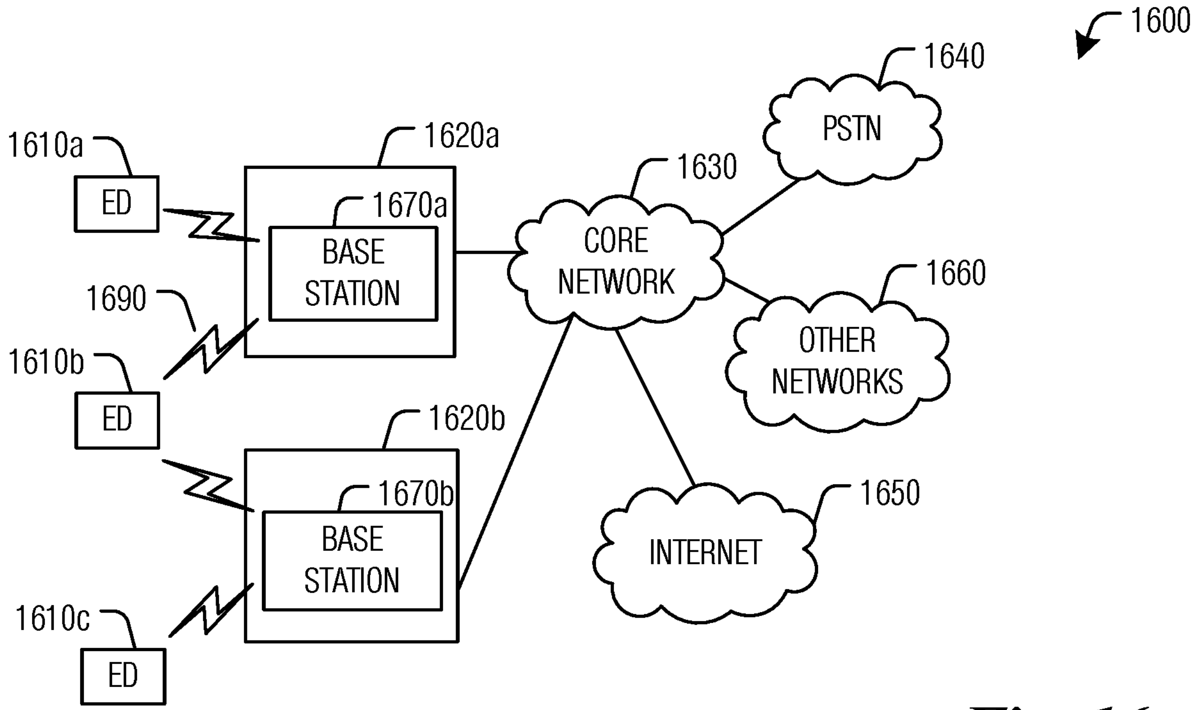
1600
1640
PSTN
1610a
ED
1620a
1670a
BASE
STATION
1630
CORE
NETWORK
1690
1660
OTHER
NETWORKS
1610b
ED
1620b
1670b
BASE
STATION
1650
INTERNET
1610c
ED

Fig. 16

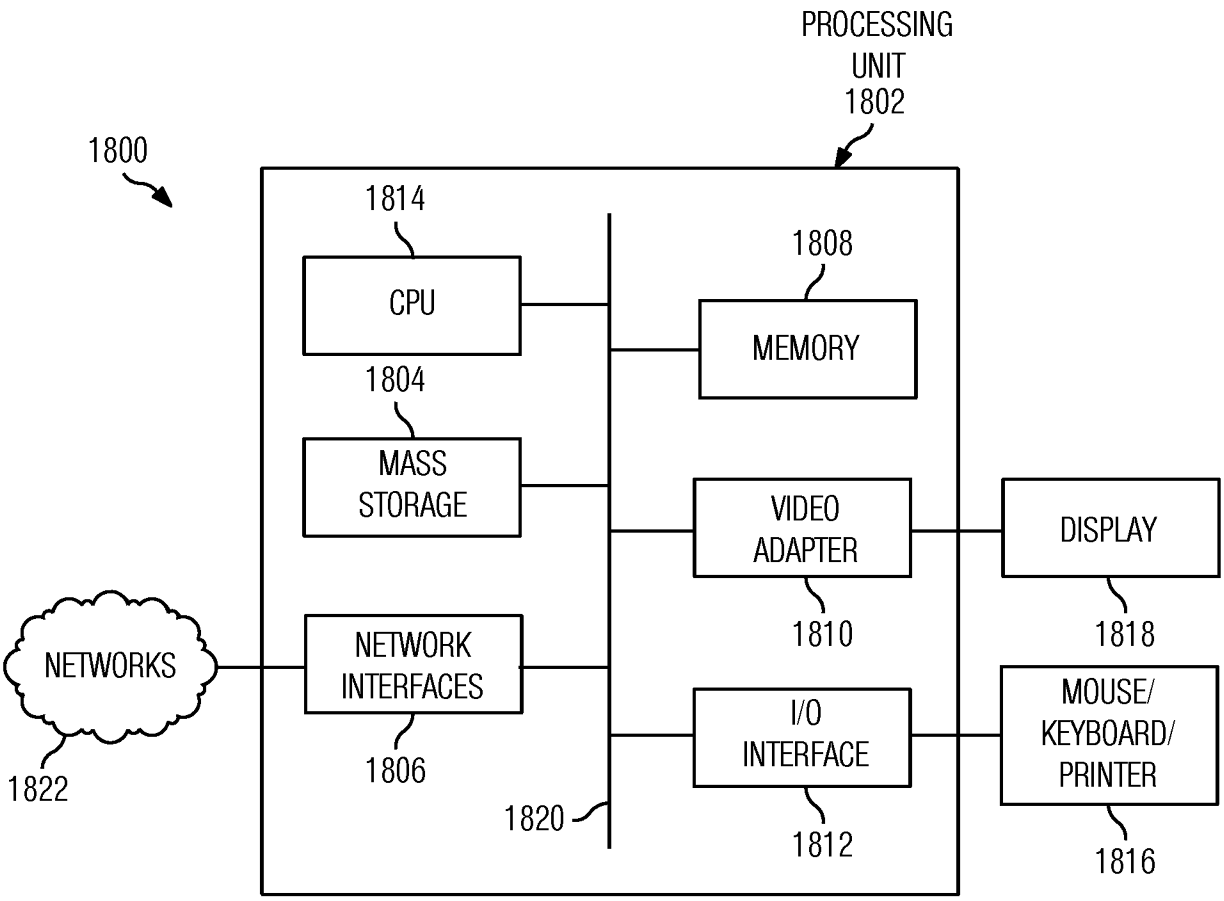
PROCESSING
UNIT
1802
1800
1814
CPU
1808
MEMORY
1804
MASS
STORAGE
VIDEO
ADAPTER
DISPLAY
1810
1818
NETWORKS
NETWORK
INTERFACES
I/O
INTERFACE
MOUSE/
KEYBOARD/
PRINTER
1806
1822
1820
1812
1816

Fig. 18

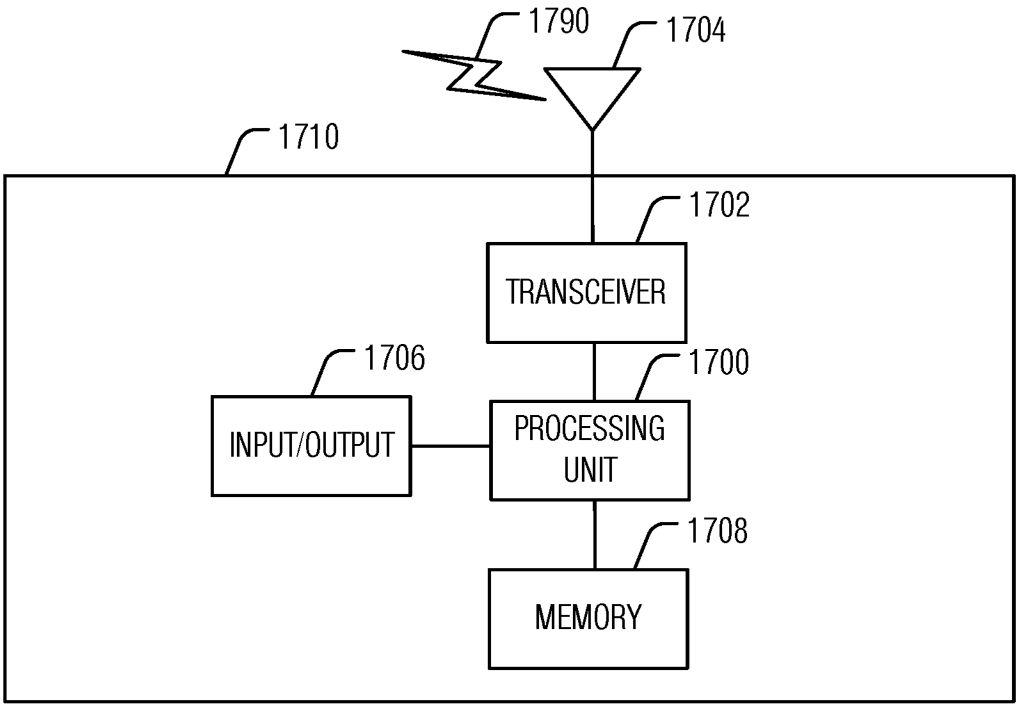

Fig. 17A

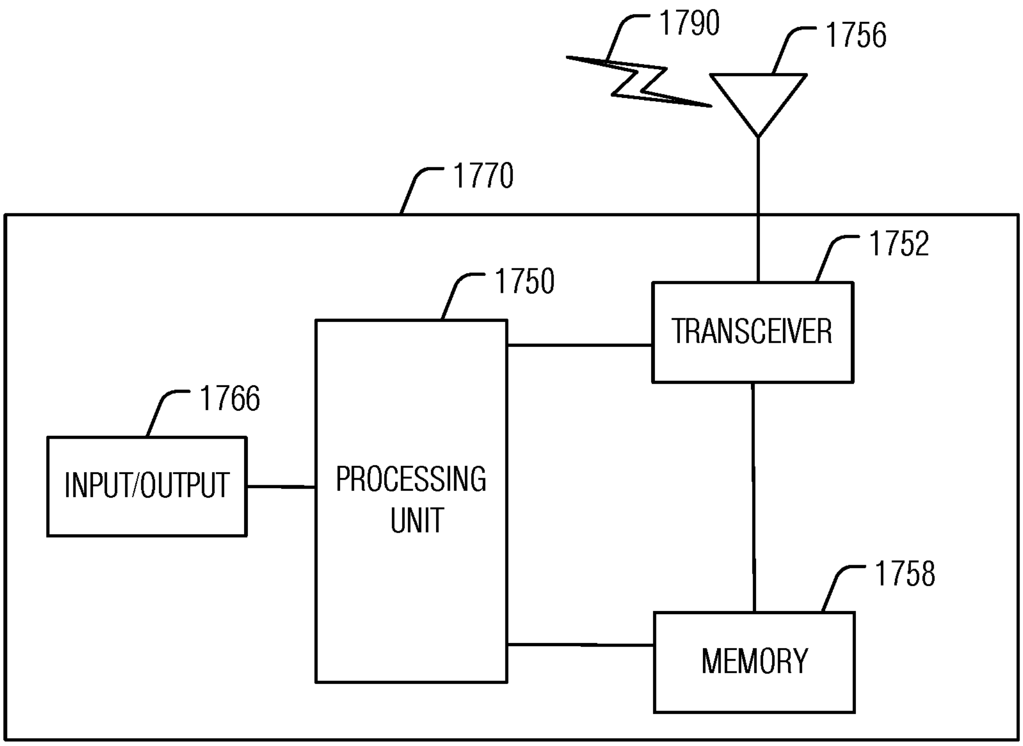

Fig. 17B