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Re:	This is in response to the call for technical comments and contributions regarding IEEE Project 802.16j (80216j-07_xxx.pdf)
Abstract	This document proposes HARQ in multi-hop relay system.
Purpose	Add proposed spec changes in P802.16j Baseline Document (IEEE 802.16j-06/026r3).
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HARQ in Multi-hop Relay System

Introduction

In multi-hop relay system, one or more relay stations may involve in the traffic relaying along the relay path from MR-BS to MS or vice versa.

In relay system, the MAP generation and bandwidth allocation could be done in centralized or distributed manner. In centralized scheduling system, the MR-BS generates MAP and schedules bandwidth for all the links. In distributed scheduling system, the MR-BS and RS individually generates MAP and schedules bandwidth for the adjacent downstream link.

This contribution proposes five schemes for handling HARQ in an MR system under centralized scheduling: 1) the compact HARQ report channel, 2) the HARQ dummy pattern, 3) the multicast HARQ for transparent RS, 4) the dedicated HARQ report channel, and 5) the recovery HARQ report channel.

The proposed schemes will work on the chase combining HARQ (type I) and incremental-redundancy HARQ (type II).

Proposed Compact HARQ Report Channel

For saving the radio resource, MR-BS may allocate an ACK report channel shared by the RSs along a relay path. That is, no any ACK/NACK channel needs to be assigned any more to RSs. A HARQ status report is created by an RS only when the RS fails in decoding the packet. It needs report the hop number of failure link to MR-BS for indicating the retransmission requirement. The physical channel design for 6-bit CQICH can be reused for a new physical channel called as 6-bit compact HARQ report channel. A 6-bit HARQ report channel can be configured as 3 HARQ report channels for a less than 4-hop case or 2 HARQ report channels for up to 7-hop case.

If an erroneous reception occurs on a relay link, a HARQ status report is generated by the receiving RS to indicate the failure hop count away from MR-BS. The number of bits allocated for HARQ report channel depends on the number of hops of HARQ data channel. For an N-hop HARQ channel, 2-bit compact HARQ report channel is sufficient for N<4. The meanings of two coded bits are that: '00' indicates success transmission, and '01', '10' and '11' indicate the error incurring in the first hop, the second hop and the third hop, respectively. On the other hand, 3-bit compact HARQ report channel is allocated when 3<N<8. Similarly, code '000' indicates the success case and the decimal values of codes from '001' to '111' represent the hop count of failure link with regard to MR-BS.

DL HARQ with Compact HARQ Report Channel

In case of N-hop DL HARQ with centralized scheduling, the resources for N-hop DL data forwarding are assigned at the same time. MR-BS shall generate N DL_HARQ_Sub-burst_IEs, for which N-1 DL_HARQ_Sub-burst_IEs for R-link and one DL_HARQ_Sub-burst_IE for access link. For status reporting, the associated compact DL HARQ report channel is used to report the HARQ reception status at RS and MS.

A HARQ status report is created by an RS only when the RS fails in decoding the packet. For the last hop status report, a HARQ status report is created by the access RS only when the access RS received status report from the MS. If status report from the MS is ACK, access RS reports the success code (all zero) to MR-BS; otherwise, access RS reports the hop number of access link with regard to the MR-BS. Each HARQ status report shall be forwarded by intermediate RS to MR-BS. An RS forwards HARQ status report from its subordinate RS (if any) shall simply forward without modification. As an RS fails to decode data, it removes the related DL_HARQ_Sub-burst_IE to its subordinate RSs and MS and the RS may send the dummy pattern to its next hop and finally to the MS. The station which creates MAP IEs modifies the SPID according to the received HARQ status report.

Figure 1 and Figure 2 respectively illustrate flow diagrams of 2-hop and 3-hop DL HARQ with centralized scheduling and compact report channel.

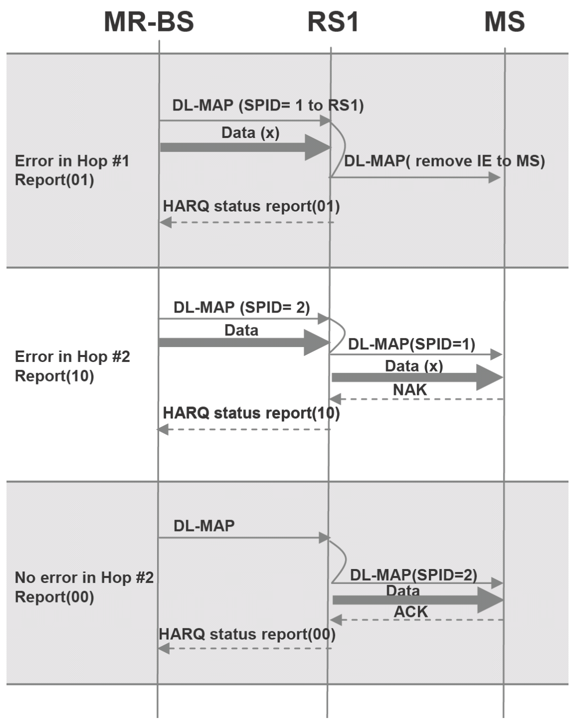

Figure 1. Flow diagram for 2-hop DL HARQ with centralized scheduling and compact HARQ report channel.

Figure 2. Flow diagram for 3-hop DL HARQ with centralized scheduling and compact report channel.

UL HARQ with Compact HARQ Report Channel

In case of N-hop UL HARQ with centralized scheduling, the resources for N-hop UL data forwarding and the compact UL HARQ report channel are assigned at the same time. For UL data forwarding, MR-BS shall generate N UL_HARQ_Sub-burst_IEs, for which N-1 UL_HARQ_Sub-burst_IEs for R-link and one UL_HARQ_Sub-burst_IE for access link. The associated compact UL HARQ report channel is used to report the HARQ reception status at RSs along the relaying path.

For UL HARQ channel, the HARQ report status is created only when an RS received an UL packet. If the decoding is success, the RS sends an ACK to the child RS (or MS) via HARQ_ACK_IE as in current 16e specification and at the same time, sends the UL HARQ status report (i.e. all 0s) to upstream station. If the decoding is not success, the RS sends a NACK to the child RS (or MS) via HARQ_ACK_IE as in current 16e specification, at the same time, sends the UL HARQ status report (i.e. hop number) to upstream station. And the RS may send dummy pattern to its upstream station, and finally to the MR-BS. An RS only needs to forward a non-all-zero status report from its child to the MR-BS to indicate error happens in the correponding link. The RS uses assigned compact HARQ report channel to carry its child's report. Moreover, RS will try to decode the received HARQ data only when the status report from its child is all-zero. The station which creates MAP-IE modifies the SPID according to the HARQ status report received.

Figure 3 and Figure 4 respectively illustrate flow diagrams of 2-hop and 3-hop UL HARQ with centralized scheduling and compact report channel.

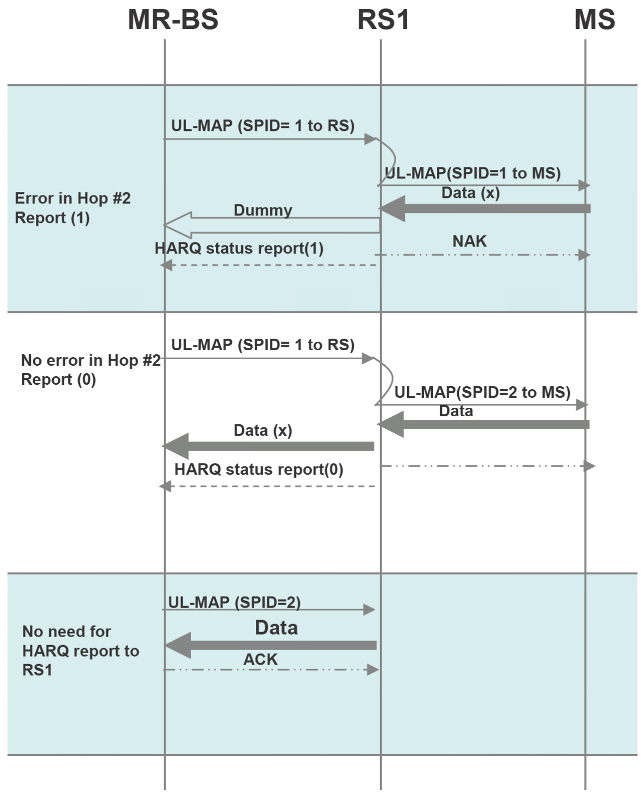

Figure 3. Flow diagram for 2-hop UL HARQ with centralized scheduling and compact report channel

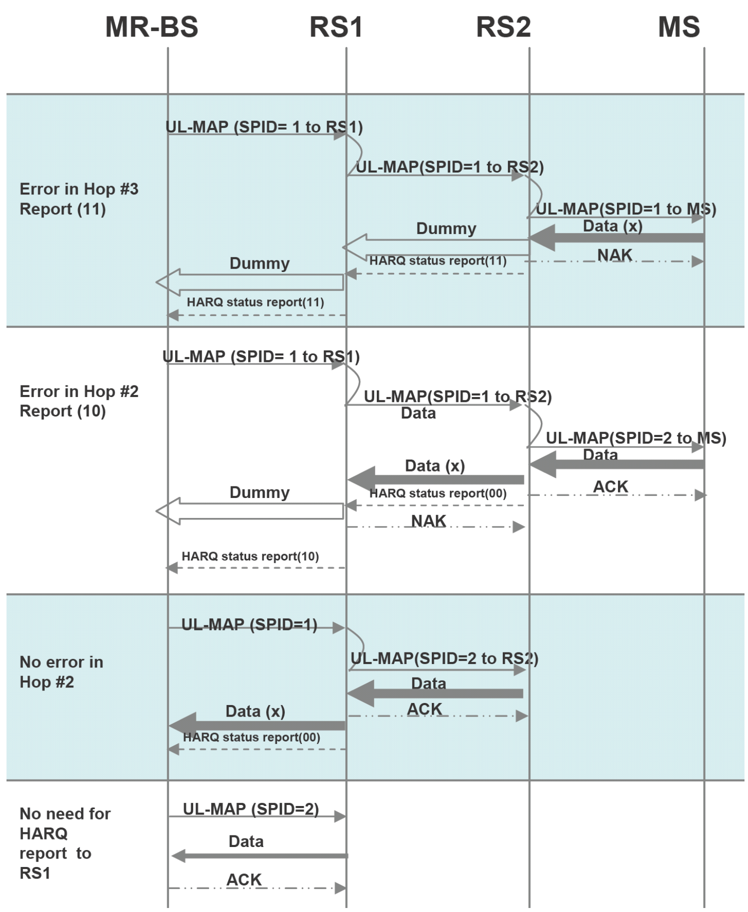

Figure 4. Flow diagram for 3-hop UL HARQ with centralized scheduling and compact report channel.

Proposed HARQ Dummy Pattern

For each UL/DL multi-hop HARQ channel, MR-BS may pre-allocate bandwidth for links on relay path. When HARQ burst is corrupted by interference and noise, RS should not forward erroneous HARQ burst to the next hop. Instead, RS may send none by modifying the MAP sent by it. However, it is impossible to change the MAP for transparent RSs. So, a station is expecting to receive data from the superordinate station. To resolve the issue, we propose a dummy HARQ pattern which is used for the pre-allocated transmissions when an RS cannot correctly decode HARQ packet. The dummy HARQ pattern is designed for facilitating receiver to perform channel quality measurement. The dummy HARQ pattern shall not cause any performance degradation on HARQ reception and no impact on the behavior in receiver.

The dummy HARQ pattern for an OFDMA symbol may be one of two kinds of formations. One formation is the stuff data with pilot. The stuff data indicates a specific pattern which will result in an invalid CRC check at the receiver. The other formation is null data with pilot. It is used for the CQI measurement.

Proposed Multicast HARQ for Transparent RS

An efficient method for supporting UL/DL HARQ in multi-hop relay system with transparent relays is making multiple transparent RSs to involve in the HARQ process. With centralized control of MR-BS, bursts for transparent RSs could be easily assigned to multiple RSs with MAP_IEs describing the same burst. Its behavior somewhat likes multicasting. For each hop, MR-BS virtually groups a number of transparent RSs, called MHARQ group which may be a subgroup of virtual RS group. Each UL/DL HARQ packet is sent to the MHARQ group and each RS in the MHARQ group may send an ACK to MR-BS if the received data is correct. Otherwise, the RS may send a NACK to MR-BS. Any RS shall forward the received ACK/NACK to the next hop. Forwarding data should be started from an RS, which has correctly received the HARQ packet, to the MHARQ group of next hop or to the destination station directly. RSs should free their HARQ buffers if no free command/message within timer is received, free command/message is received, or new data is received (by toggled AI_SN).

With hop-by-hop scheduling, HARQ data is scheduled and forwarded to the next hop when MR-BS receives at least one ACK from RS in MHARQ group. If none of ACK is received by MR-BS, MR-BS shall retransmit a HARQ packet to the MHARQ group. On the other hand, if any ACK is received by MR-BS, MR-BS shall schedule one or more RSs which sent ACK to forward data to the next hop. In general, hop-by-hop scheduling will cause long end-to-end transfer latency.

With end-to-end prescheduling, MR-BS pre-schedules one or more designated RSs of the corresponding MHARQ group in each hop to forward data. If one designated RS failed to decode data correctly, then it shall send a NACK to MR-BS. In such case, the RS will not send data to next hop or send dummy pattern to next hop. If one designated RS in a hop has correctly received HARQ data, it could forward the received HARQ data to the next hop. On the other hand, if none of ACK is received by MR-BS in a MHARQ group, MR-BS shall retransmit a HARQ packet to the MHARQ group.

Figure 5 illustrates the flow diagram of 2-hop DL multicast HARQ with centralized hop-by-hop scheduling. Figure 6 illustrates the flow diagram of 2-hop DL multicast HARQ with centralized end-to-end pre-scheduling. Figure 7 illustrates the flow diagram of 2-hop UL multicast HARQ with centralized hop-by-hop scheduling. Figure 8 illustrates the flow diagram of 2-hop UL multicast HARQ with centralized end-to-end pre-scheduling.

In figures, notation 'Data*' indicates data packet is failed during transmission, notation 'Data' indicates data packet is successfully transmitted, notation 'MData' indicates data packet is successfully received by the RS in an MHARQ group, and notation 'MData*' indicates data is unsuccessfully received by a RS in an MHARQ group.

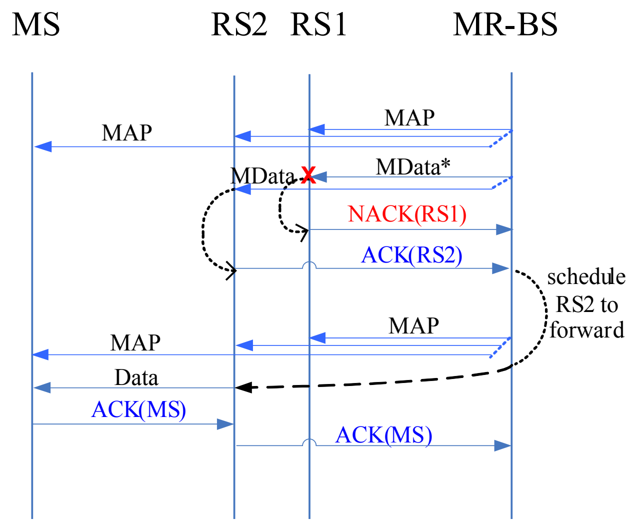

Figure 5. Flow diagram for 2-hop DL multicast HARQ with centralized hop-by-hop scheduling.

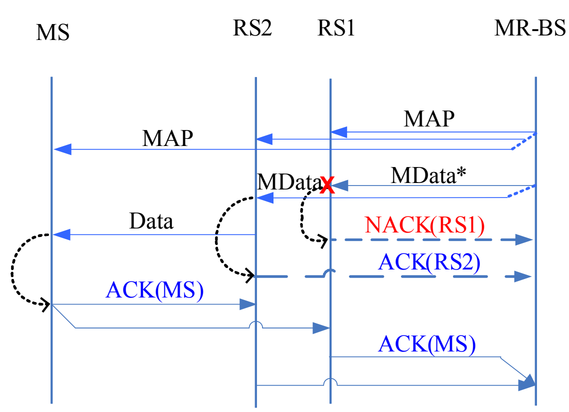

Figure 6. Flow diagram for 2-hop DL multicast HARQ with centralized end-to-end pre-scheduling.

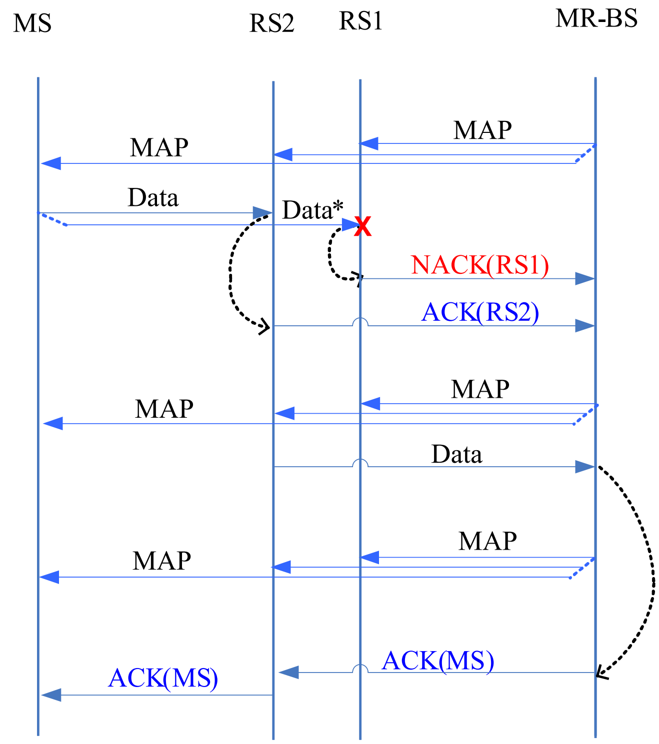

Figure 7. Flow diagram for 2-hop UL multicast HARQ with centralized hop-by-hop scheduling.

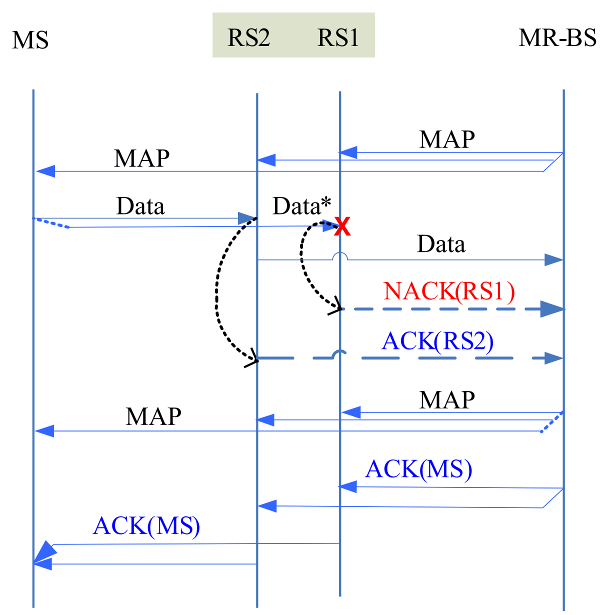

Figure 8. Flow diagram for 2-hop UL multicast HARQ with centralized end-to-end pre-scheduling.

Proposed Dedicated HARQ Report Channel for RS

For each DL HARQ channel, MR-BS may allocate one dedicated HARQ report channel for the designated RS along relay path, such that MR-BS can speed up the re-transmission of HARQ packet instead of waiting for full round-trip delay. The dedicated HARQ report channel could be selectively assigned to an RS whose air link quality is below a threshold. Figure 9 shows the flow diagram of 3-hop DL HARQ with dedicated HARQ report channels. In this figure, MR-BS allocates individual HARQ status report channel for each RS along the path. As the error unfortunately incurs at the first hop, MR-BS is able to quickly detect such error and then it can early start retransmission.

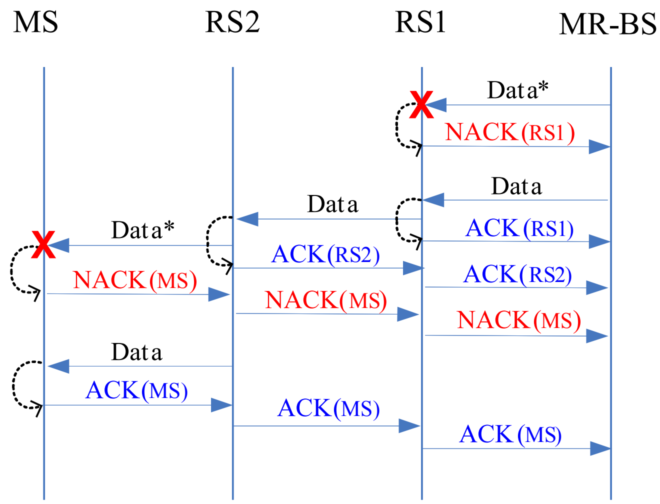

Figure 9. Flow diagram for 3-hop DL HARQ with dedicated HARQ report channels.

Proposed Recovery HARQ Report Channel

Generally, ACK/NACK sent from RS to MR-BS may be interfered by channel noise, if error occurs on ACK (i.e. ACK is decoded as NACK), it will cause unnecessary retransmissions but not cause system deadlock. However, if error occurs on NACK (i.e. NACK is decoded as ACK), it will cause inconsequent retransmission from the RS which does not have correct HARQ packet, and will cause system deadlock. To resolve the inconsequent retransmission problem, it is required to allocate a recovery ACK channel for the RS, which is arranged to retransmit HARQ packet, so that the inconsequent retransmission could be detected and eliminated at MR-BS by receiving a NACK from the RS. For saving resource requirement, the recovery channel may be embedded in the standard ACK channel or the compact HARQ report channel.

Figure 10 shows an example that MR-BS incorrectly decodes the NACK signal from RS and MR-BS does not allocate a recovery report channel for the RS arranged to retransmit HARQ data. In such case, MR-BS will repeatedly schedule inconsequent retransmission from RS to MS. Figure 11 shows an example that MR-BS incorrectly decodes the NACK signal from RS and MR-BS automatically allocate a recovery report channel for the sender RS arranged to retransmit HARQ data. As a result, MR-BS will detect inconsequent retransmission situation and prevent system from deadlock situation.

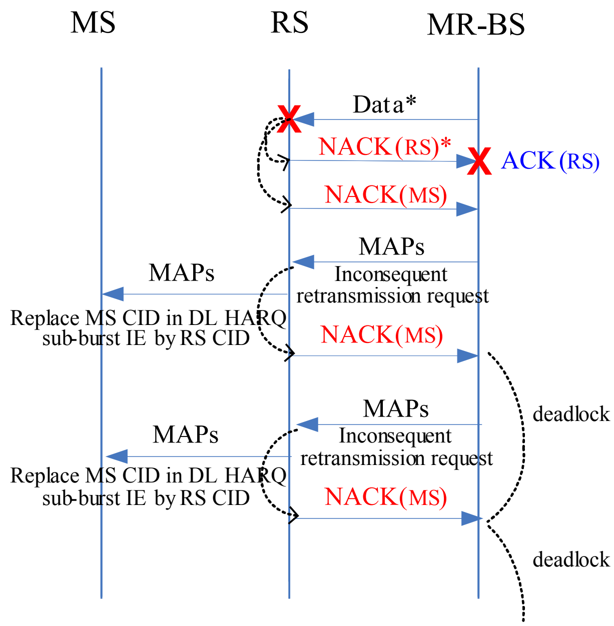

Figure 10. Flow diagram for 2-hop DL HARQ without recovery ACK channel for retransmission.

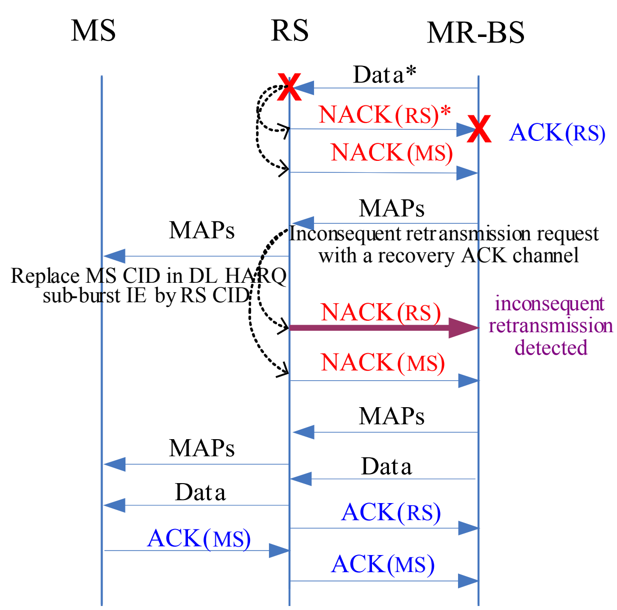

Figure 11. Flow diagram for 2-hop DL HARQ with recovery ACK channel for retransmission.

Conclusions

A multi-hop relay system reusing 6-bit CQICH as compact HARQ report channel has three benefits: 1) it avoids demanding the new orthogonal codes for UL HARQ report channel, 2) it utilizes radio resource in a more efficient way and 3) it can precisely determine the affected hop required for retransmissions. For ecah HARQ data channel, MR-BS should allocate one UL HARQ report channel to designated RS along the path, or one HARQ report channel to every HARQ channel, or combination of both schemes. Transparent RSs could be grouped for assisting HARQ data forwarding, hop by hop. Dedicated report channel allocated for intermediate RS is helpful for MR-BS to early detect the error occurrence and start retransmission as well. For each scheduled retransmission from an RS, MR-BS may allocate one recovery ACK channel to the RS in order to eliminate any inconsequent retransmission arrangement caused by erroneously decoded ACK/NACK which introduces inconsistent HARQ state between MR-BS and RS. In multi-hop relay system with pre-scheduling, RS should relay either correct HARQ burst or dummy HARQ pattern to the next hop,

Proposed text changes

Insert new sub-clause 6.3.17.5

6.3.17.5 RS supporting multi-hop HARQ in centralized scheduling

Each RS on the relaying path from MR-BS to MS or vice versa should:

- buffer all received HARQ packets until it receives the explicit ACK indication to it
- forward either correctly decoded packets from its predecessor to its successor or dummy information to its successor if the decoded packet is incorrect
- resend correctly decoded packets to the successor and report the status of retransmission arrangement to the MR-BS if it is scheduled to retransmit
- report the ACK/NACK to the MR-BS according to the status of decoding the received packet
- relay the ACK/NACK to the next station
- stop forwarding packets and release buffer if it receives the explicit ACK

6.3.17.5.1 HARQ report channel support for multi-hop HARQ in centralized scheduling

For saving the radio resource, MR-BS may allocate one ACK report channel shared by the RSs along a relay path. A HARQ status report of relay link is created by an RS only when the RS fails in decoding the received HARQ packet. It needs report the hop number of failure link to MR-BS for indicating the retransmission requirement. The physical channel design for 6-bit CQICH (see 8.4.5.4.10.5) can be reused for a new physical channel called as 6-bit compact HARQ report channel. A 6-bit compact HARQ report channel can be configured as 3 HARQ report channels for a less than 4-hop case or 2 HARQ report channels for up to 7-hop case.

If an erroneous reception occurs on a relay link, the HARQ status report is generated by the receiving RS to indicate the hop count of failure link with regard to MR-BS. The number of bits allocated for HARQ report channel depends on the number of hops of associated HARQ data channel. For N-hop HARQ channel, 2-bit compact HARQ report channel is sufficient for $N<4$. The meanings of two coded bits are that: '00' indicates success transmission and '01', '10' and '11' indicate the error incurring in the first hop, the second hop and the third hop, respectively. On the other hand, 3-bit HARQ report channel is allocated when $3<N<8$. Similarly, code '000' indicates the success case and the decimal values of codes from '001' to '111' represent the hop count of failure link with regard to MR-BS.

6.3.17.5.2 HARQ dummy pattern

For each UL/DL multi-hop HARQ channel, MR-BS may pre-allocate bandwidth for links on relay path. When HARQ burst is corrupted by interference or noise, RS should not forward erroneous HARQ burst to the next hop in order to avoid error propagation. Instead, RS may send none by modifying the MAP sent by it.

However, it is impossible to change the MAP for transparent RSs and a station is expecting to receive data from the superordinate station. The dummy HARQ pattern is used for the pre-allocated transmissions when an RS cannot correctly decode HARQ packet. The dummy HARQ pattern is designed for facilitating receiver to perform channel quality measurement. The dummy HARQ pattern shall not cause any performance degradation on HARQ reception and no impact on the behavior in receiver.

The dummy HARQ pattern for an OFDMA symbol may be one of two kinds of formations. One formation is the stuff data with pilot. The stuff data indicates a specific pattern which will result in an invalid CRC check at the receiver. The other formation is null data with pilot. It is used for the CQI measurement.

6.3.17.5.3 Multi-hop DL HARQ with centralized scheduling

MR-BS schedules the bandwidth for relaying a HARQ packet on all the multi-hop links along the relay path from MR-BS to MS. It also allocates the bandwidth for relaying ACK/NACK from RS and MS towards MR-BS.

If RS failed to decode the received HARQ-burst correctly, it replies a NACK (i.e. the hop number) to its upstream station and it de-allocates the DL_HARQ_Sub-burst_IE in the DL-MAP such that its subordinate station does not receive the erroneous HARQ burst. In this case, the ACKCH_Region_IE shall be de-allocated also. For the last hop status report, a HARQ status report is created by an access RS if the access RS forwarded a packet to MS and receives status report from MS. If status report is ACK, access RS reports the success code (all zero) to MR-BS; otherwise, access RS reports the hop number of access link to the MR-BS. Each HARQ status report shall be forwarded by intermediate RS to MR-BS. A RS forwards HARQ status report from its subordinate RS (if any) shall simply forward without modification. The station which creates MAP IEs modifies the SPID according to the received HARQ status report.

As a response to a successful reception of the HARQ sub-burst, RS shall forward the HARQ packet to the next hop and reply ACK to notify MR-BS to stop HARQ retransmission from its predecessor.

The event of ACK/NACK timeout for an MS or RS at MR-BS represents the reception of implicit NACK from related MS or RS. The ACK/NACK timeout is defined in the parameter HARQ_ACK_Delay_for_DL_Burst broadcast by UCD message.

MR-BS identifies the multi-hop link(s) of DL transmission failure by checking the received NACK which is encoded as the hop number and then schedules the retransmission only for the affected link(s) that didn't transmit packet successfully in the last attempt.

6.3.17.5.3.1 ACK/NACK channel support for multi-hop DL HARQ in centralized scheduling

The ACK/NACK channel construction is the same as specified in 8.4.5.4.13.

6.3.17.5.4 Multi-hop UL HARQ with centralized scheduling

MR-BS schedules the bandwidth for relaying a HARQ packet on all the links along the relay path from MS to MR-BS. It also schedules the bandwidth for relaying upstream ACK/NACK on UL ACK channel from RS to MR-BS and the bandwidth for relaying individual downstream ACK/NACK from MR-BS to the subordinate RS, RS to the subordinate RS, and from access RS to MS.

For UL HARQ channel, the HARQ report status is created only when a RS received an UL packet. If the decoding is success, the RS sends an ACK to the child RS (or MS) via HARQ_ACK_IE as in current 16e specification and at the same time, sends the UL HARQ status report (i.e. all 0s) to upstream station. If the decoding is not success, the RS sends a NACK to the child RS (or MS) via HARQ_ACK_IE as in current 16e specification, at the same time, sends the UL HARQ status report (i.e. hop number) to upstream station. And the RS may send dummy pattern to its upstream station, and finally to the MR-BS. A RS only needs to forward a non-all-zero status report from its child (some error happens already in the path). The RS uses assigned compact HARQ report channel to carry its child's report. Moreover, RS will try to decode the received HARQ data only when the status report from its child is not zero. The station which creates MAP-IE modifies the SPID according to the HARQ status report received

Every ACK/NACK on UL ACK channel is forwarded by upstream RS(s) and finally to the MR-BS. Every ACK/NACK carried in HARQ_ACK_IE is forwarded by RS(s) and finally to the destination RS or MS.

The ACK/NACK timeout event for an MS or RS at MR-BS represents the reception of implicit NACK from related MS or RS. The ACK/NACK timeout is defined in the parameter HARQ ACK Delay for UL Burst broadcast by DCD message.

MR-BS identifies the multi-hop link(s) of UL transmission failure by checking the received NACK which is encoded as the hop number and then schedules the retransmission only for the affected link(s) that didn't transmit packet successfully in the last attempt.

6.3.17.5.4.1 HARQ_ACK_IE support for multi-hop UL HARQ in centralized scheduling

The HARQ_ACK_IE is defined in 8.4.5.3.22.

6.3.17.5.4.2 ACK/NACK channel support for multi-hop UL HARQ in centralized scheduling

The ACK/NACK channel construction is the same as specified in 8.4.5.4.13.

6.3.17.5.5 Dedicated HARQ ACK/NACK channel

For each DL HARQ channel, MR-BS may allocate one dedicated HARQ report channel for the designated RS along relay path, such that MR-BS can speed up the re-transmission of HARQ packet instead of waiting for full round-trip delay. The dedicated HARQ report channel could be selectively assigned to an RS whose air link quality is below a threshold.

Upon the MR-BS detects the first NACK signal, the retransmission from MR-BS could be scheduled prior MR-BS collects all NACKs from MS and RS(s) on the path, This enables early fault detection at MR-BS. The time period required for MR-BS to collect all NACKs from MS and RS(s) depends on the packet processing delay at each RS and the ACK delay defined by the "HARQ_ACK_Delay_for_DL_Burst" field in the UCD message. The retransmission scheduling at MR-BS will not rely on the pending NACK(s) from downstream RS(s), the bandwidth required for relaying such NACK could be further conserved by just skipping the bandwidth allocation(s) in ACK Region IE carried in the following UL-MAPs.

6.3.17.5.6 Multicast HARQ for transparent RS

An efficient method of supporting UL/DL HARQ in multi-hop relay system with transparent relays is making multiple transparent RSs to involve in the HARQ process. With centralized control of MR-BS, bursts for transparent RSs could be easily assigned to multiple RSs with MAP_IEs describing the same burst. Its behavior somewhat likes multicasting. For each hop, MR-BS virtually groups a number of transparent RSs, called MHARQ group which may be a subgroup of virtual RS group. Each UL/DL HARQ packet is sent to the MHARQ group and each RS in the MHARQ group may send an ACK to MR-BS if the received data is correct. Otherwise, the RS may send a NACK to MR-BS. Any RS shall forward the received ACK/NACK to the next hop. Forwarding data should be started from an RS, which has correctly received the HARQ packet, to the MHARQ group of next hop or to the destination station directly. RSs should free their HARQ buffers if no free command/message within timer is received, free command/message is received, or new data is received (by toggled AI_SN).

With hop-by-hop scheduling, HARQ data is scheduled and forwarded to the next hop when MR-BS receives at least one ACK from RS in MHARQ group. If none of ACK is received by MR-BS, MR-BS shall retransmit a HARQ packet to the MHARQ group. On the other hand, if any ACK is received by MR-BS, MR-BS shall schedule one or more RSs which sent ACK to forward data to the next hop. In general, hop-by-hop scheduling will cause long end-to-end transfer latency.

With end-to-end prescheduling, MR-BS pre-schedules one or more designated RSs of the corresponding MHARQ group in each hop to forward data. If one designated RS failed to decode data correctly, then it shall send a NACK to MR-BS. In such case, the RS will not send data to next hop or send dummy pattern to next hop. If one designated RS in a hop has correctly received HARQ data, it could forward the received HARQ data to the next hop. On the other hand, if none of ACK is received by MR-BS in a MHARQ group, MR-BS shall retransmit a HARQ packet to the MHARQ group.

6.3.17.5.7 Recovery HARQ channel

Generally, ACK/NACK sent from RS to MR-BS may be interfered by channel noise, if error occurs on ACK (i.e. ACK is decoded as NACK), it will cause unnecessary retransmissions but not cause system deadlock. However, if error occurs on NACK (i.e. NACK is decoded as ACK), it will cause inconsequent retransmission from the RS which does not have correct HARQ packet, and will cause system deadlock. To resolve the inconsequent retransmission problem, it is required to allocate a recovery ACK channel for the RS, which is arranged to retransmit HARQ packet, so that the inconsequent retransmission could be detected and eliminated at MR-BS by receiving a NACK from the RS. For saving resource requirement, the recovery channel may be embedded in the standard ACK channel or the compact HARQ report channel.