Project	IEEE 802.16 Broadband Wireless Access Working Group **<http://ieee802.org/16>**
Title	HARQ in Multi-hop Relay System
Date Submitted	~~2007-05-04~~

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Re:	This is in response to IEEE 802.16j-07/013: “Call for Technical Comments Regarding IEEE Project 802.16j”
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 MAPs and schedules bandwidth for all the links. In distributed scheduling system, the MR-BS and RS individually generates MAPs and schedules bandwidth for the adjacent downstream link.

This contribution proposes six 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 DL RS-assisted relaying, 5) the dedicated HARQ report channel and 6) the HARQ recovery report channel.

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

Proposed 6-bit 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 for 3-bit HARQ report channel is the same as fast-feedback channel sub-carrier modulation defined in Table 298c in 8.4.5.4.10.5 and is called as 3-bit compact HARQ report channel. The physical channel design for 6-bit CQICH in 802.16e specification can be reused for a new physical channel called as 6-bit compact HARQ report channel. A 3-bit compact HARQ report channel could be used for either one 3-bit HARQ report channel for up to 7-hop case or one 2-bit HARQ report channel for a less than 4-hop case. A 6-bit compact HARQ report channel can be flexibly configured as three 2-bit HARQ report channels for a less than 4-hop case, two 3-bit HARQ report channels for up to 7-hop case or one 2-bit HARQ report channel for a less than 4-hop case and one 3-bit HARQ report channel 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 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 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.

The failure decoding of forwarding DL data packet and UL data packet at the kth hop is encoded for the specific hop number and the associated compact HARQ report channel is generated by the kth RS node and the (k-1)th RS respectively.

DL HARQ with 6-bit Compact HARQ Report Channel

In centralized scheduling system, the resources for N-hop DL HARQ data forwarding are assigned at the same time. MR-BS shall generate N DL_HARQ_Sub-burst_IEs, in 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 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 (i.e. all 0s) 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 forwarding HARQ status report from its subordinate RS (if any) shall simply forward it 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 insert a Skip_IE with the mode set to 0 prior to the associated HARQ_DL_MAP_IE and insert another Skip_IE with the mode set to 0 post to the associated HARQ_DL_MAP_IE. The RS may send the dummy pattern to its next hop and finally to the MS. In other words, the RS may transmit pilots only to the subordinate station, or the RS may perform amplify and forward of the erroneous packet with dedicated pilot to the subordinate station and forward the pre-allocated MAP_IE; for the DL transparent relay case; the RS should not transmit the erroneous packet to the subordinate station, but only transmit pilot. 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 HARQ report channel.

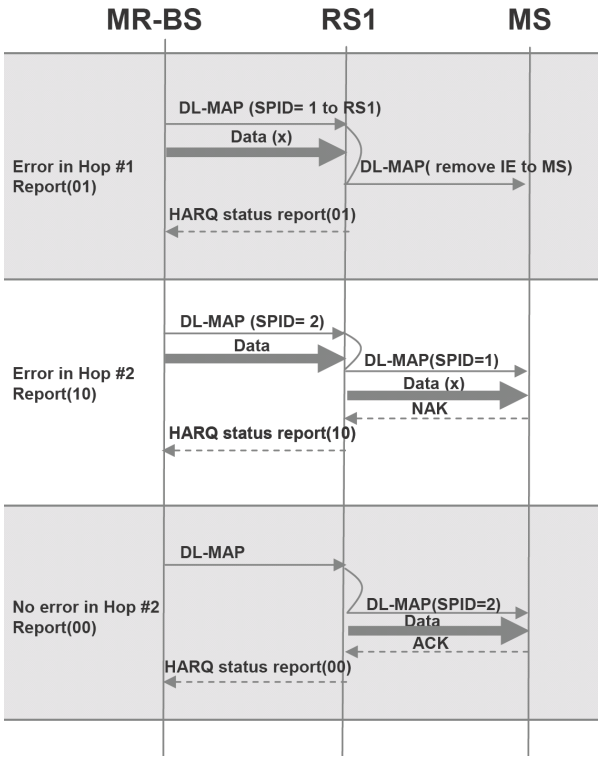

Figure 1. Flow diagram for 2-hop DL HARQ with centralized scheduling and compact HARQ report channel.

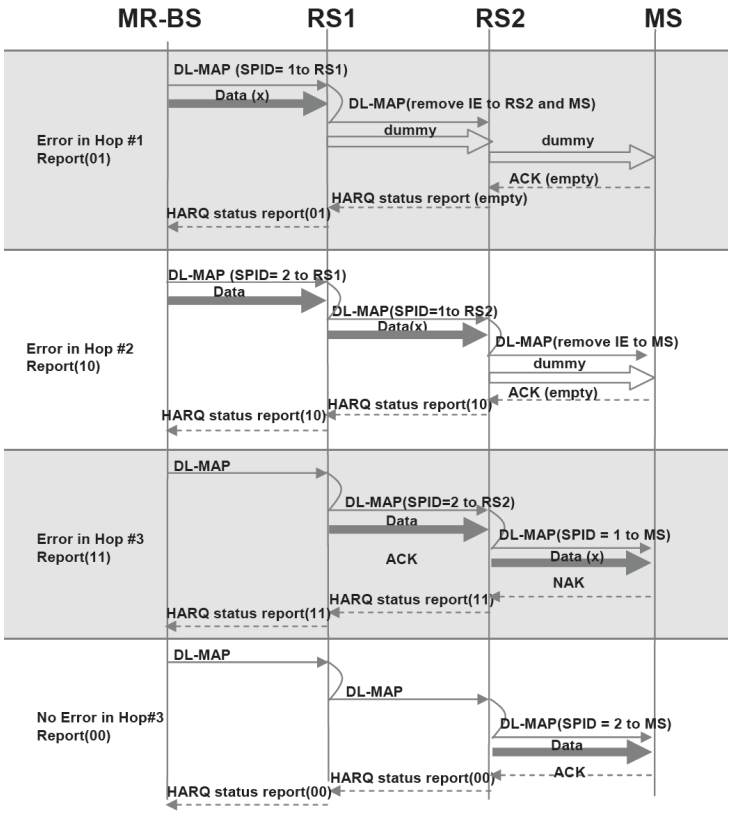

Figure 2. Flow diagram for 3-hop DL HARQ with centralized scheduling and compact HARQ report channel.

UL HARQ with Compact HARQ Report Channel

In centralized scheduling system, the resources for N-hop UL HARQ data forwarding and the compact UL HARQ report channel are assigned at the same time. For UL HARQ data forwarding, MR-BS shall generate N UL_HARQ_Sub-burst_IEs, in 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 and, at the same time, sends the UL HARQ status report (i.e. hop number) to upstream station. Moreover, 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 corresponding link. That is, 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 HARQ report channel.

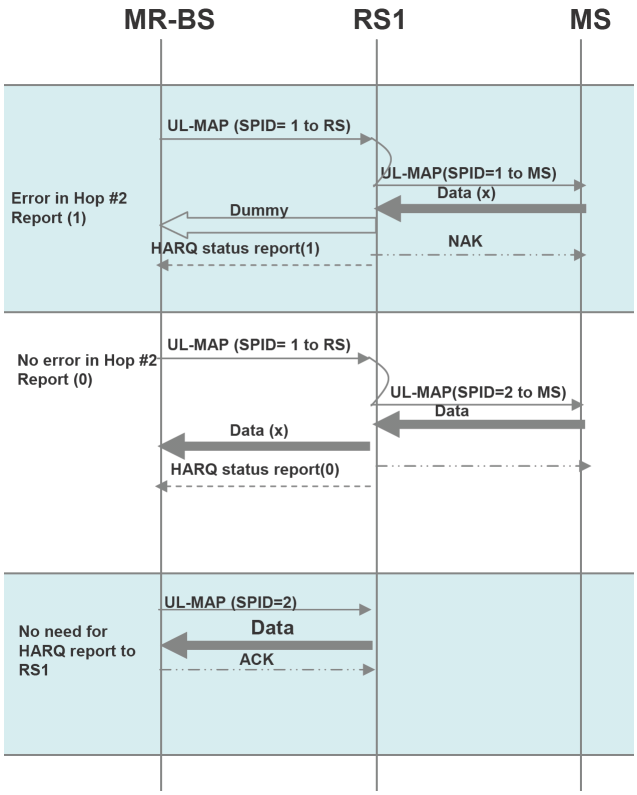

Figure 3. Flow diagram for 2-hop UL HARQ with centralized scheduling and compact HARQ report channel

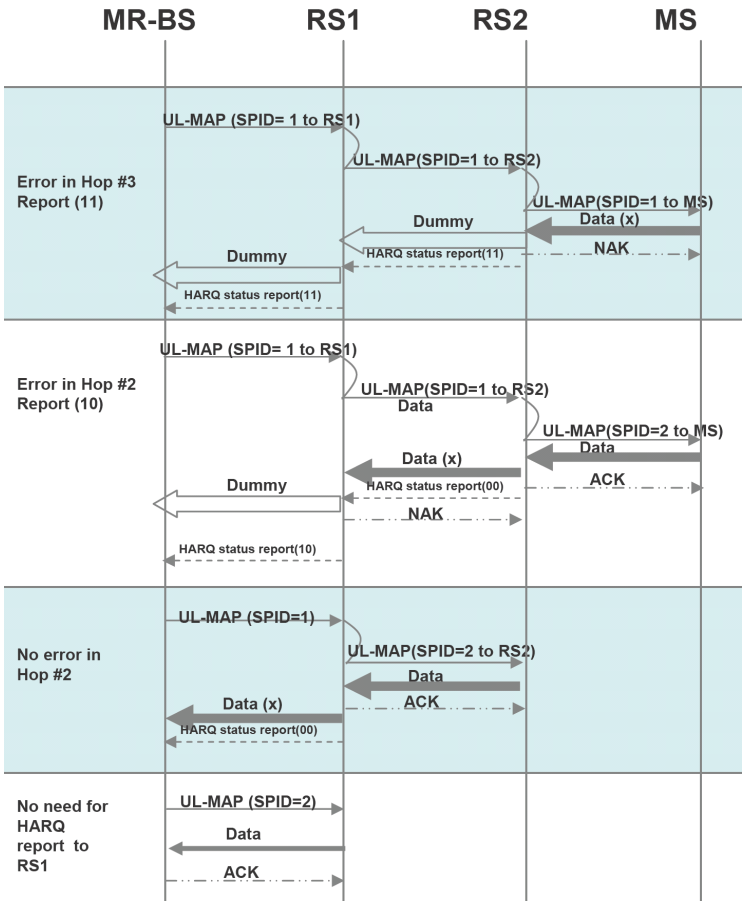

Figure 4. Flow diagram for 3-hop UL HARQ with centralized scheduling and compact HARQ report channel.

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 null data with pilot. The other formation is the erroneous data with dedicated pilot. The latter is used for amplify-and-forward purpose.

Proposed Multicast HARQ for Transparent RS

An efficient method for supporting UL/DL HARQ in multi-hop relay system with transparent relays is to make multiple transparent RSs to involve in the HARQ process. In centralized scheduling system, the schedule of

source transmitting a burst to multiple transparent RSs can be easily achieved by using MAP_IEs which describe the same burst to be received by those RSs. 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 command/message within timer is received, command/message is received within timer, or new data is received (by toggled AI_SN). Because the relay link can support 16 HARQ channels at most and the total number of HARQ channels in associated MSs may be larger than 16, it requires that RS needs to automatically replace some HARQ buffer for accommodating new HARQ data. The HARQ buffer replacement algorithm in RS is beyond the scope of this contribution.

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 the 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 and it shall amplify and forward the erroneous data with dedicated pilots to the next hop. If one designated RS in a hop has correctly received HARQ data, it shall send an ACK to MR-BS and forward the received HARQ data to the next hop. If MR-BS can not receive any ACK from the receiving MHARQ group at a certain hop, MR-BS shall arrange retransmission for the receiving MHARQ group and one or more RSs, which have correct data, will be scheduled to retransmit data.

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 7 and 8, both RS1 and RS2 are scheduled to receive data but only RS2 is scheduled to relay data. Figure 9 illustrates the flow diagram of 2-hop DL multicast HARQ with centralized end-to-end prescheduling where RS1 and RS2 are scheduled to relay data at the same time. Assume that RS2 decodes data successfully but RS2 fails to decode data. In such case, RS2 transmits the correct data and RS1 applies the amply-and-forward method to send the erroneous data. 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, notation ‘MData*’ indicates data is unsuccessfully received by a RS in an MHARQ group.

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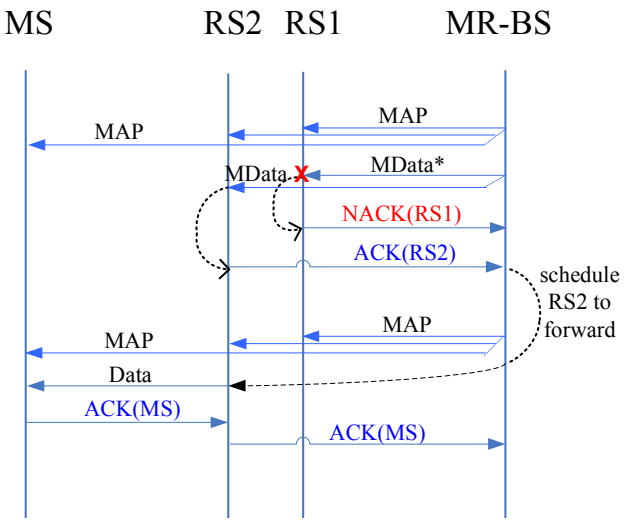

Figure 5. Flow diagram for 2-hop DL multicast HARQ with centralized hop-by-hop scheduling.

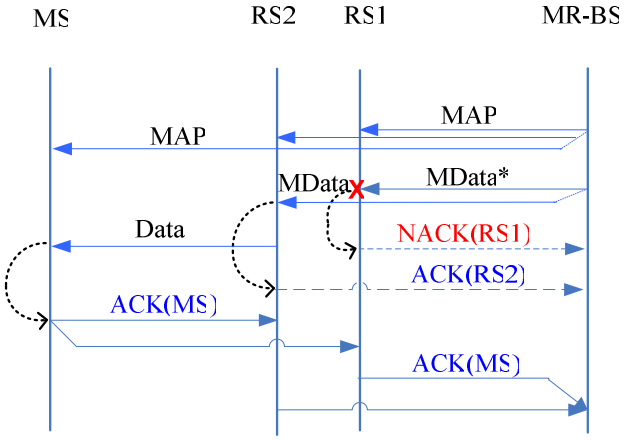

Figure 6. Flow diagram for 2-hop DL multicast HARQ with centralized end-to-end pre-scheduling where RS2 is scheduled to forward data to MS.

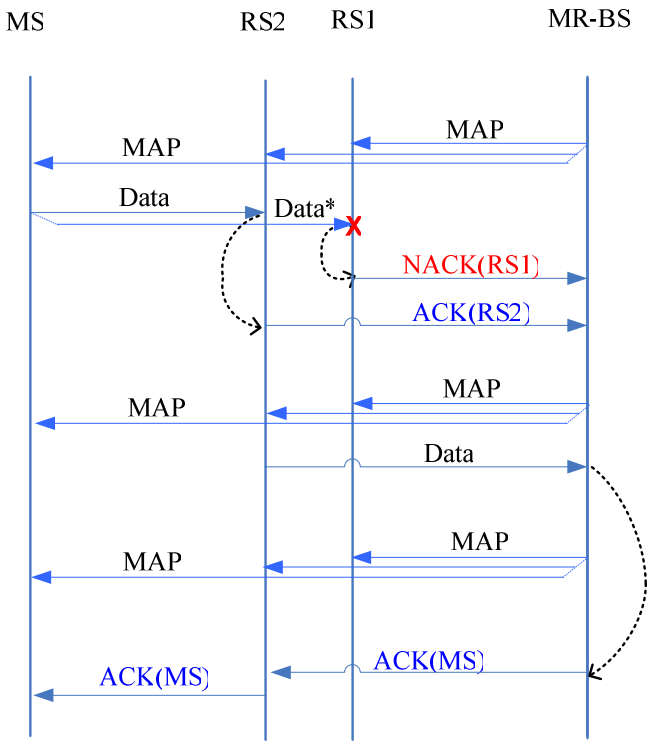

Figure 7. Flow diagram for 2-hop UL multicast HARQ with centralized hop-by-hop scheduling.

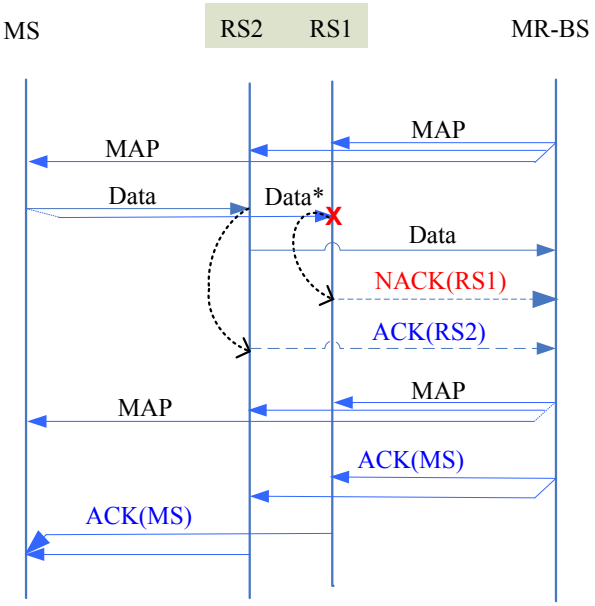

Figure 8. Flow diagram for 2-hop UL multicast HARQ with centralized end-to-end pre-scheduling where RS2 is scheduled to forward data to MR-BS.

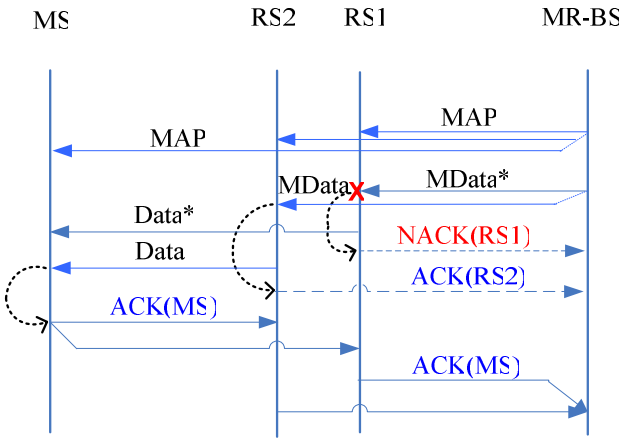

Figure 9. Flow diagram for 2-hop DL multicast HARQ with centralized end-to-end pre-scheduling where both RS1 and RS2 are scheduled to forward data to MS.

Proposed RS-assisted Relaying

Based on the concept RS-assisted proposed in C802.16j-07_232, the proposed multicast RS can be extended to support both UL and DL RS-assisted relaying without introducing new IE messages. In the case of RS-assisted relaying, RS monitors the HARQ burst transmitted by MR-BS to MS. If RS can decode the HARQ burst correctly and MS fails to receive the HARQ burst, the RS retransmits it to MS.

Figure 10 shows the example of DL RS-assisted relaying procedure. In this case, MR-BS receives ACK/NAK signal from RS and MS separately. If MR-BS receives NAK signal from both RS and MS, the MR-BS transmits the HARQ burst to RS and MS again. If MR-BS receives ACK signal from RS and NAK signal from MS, the MR-BS makes RS retransmits the HARQ burst to MS.

Figure 11 shows another ACK/NACK feedback method for DL RS-assisted relay. In this case, the encoded ACK/NACK in compact HARQ report channel is used on relay-link and RS replies the encoded ACK/NACK signal after receiving ACK/NACK signal from MS. If RS, which decoded the HARQ burst correctly, receives NACK from MS, RS replies the new encoded NACK in compact HARQ report channel to MR-BS. Then MR-BS makes RS retransmits the HARQ burst to MS.

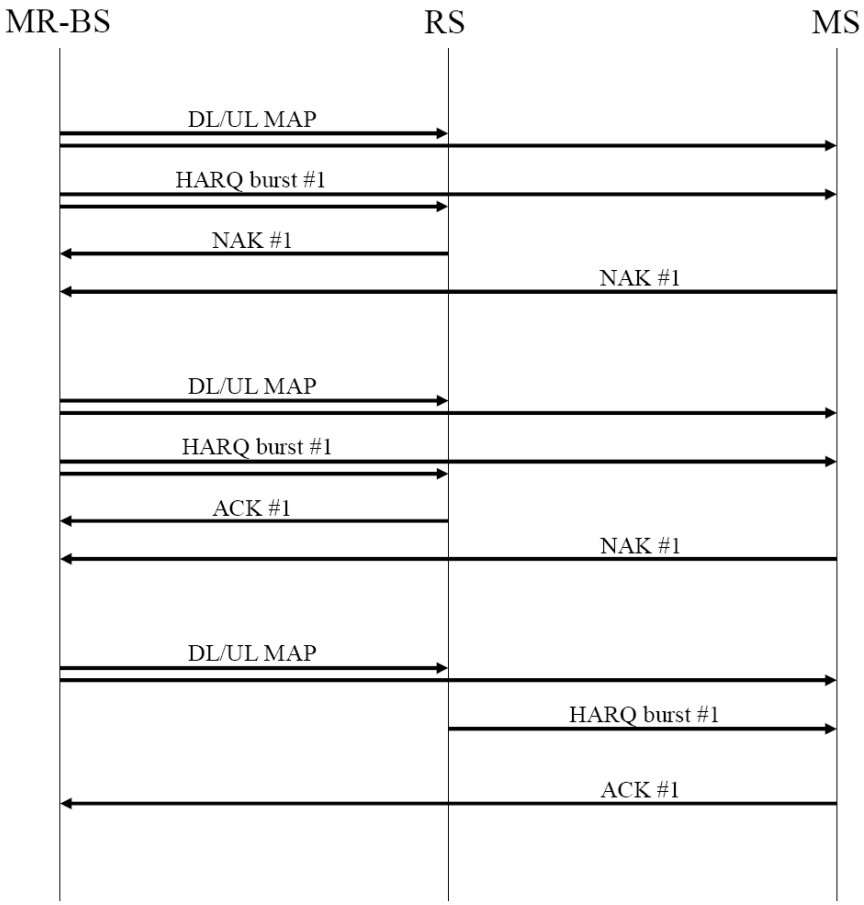

Figure 10. Flow diagram of RS-assisted relaying for data sub-burst.

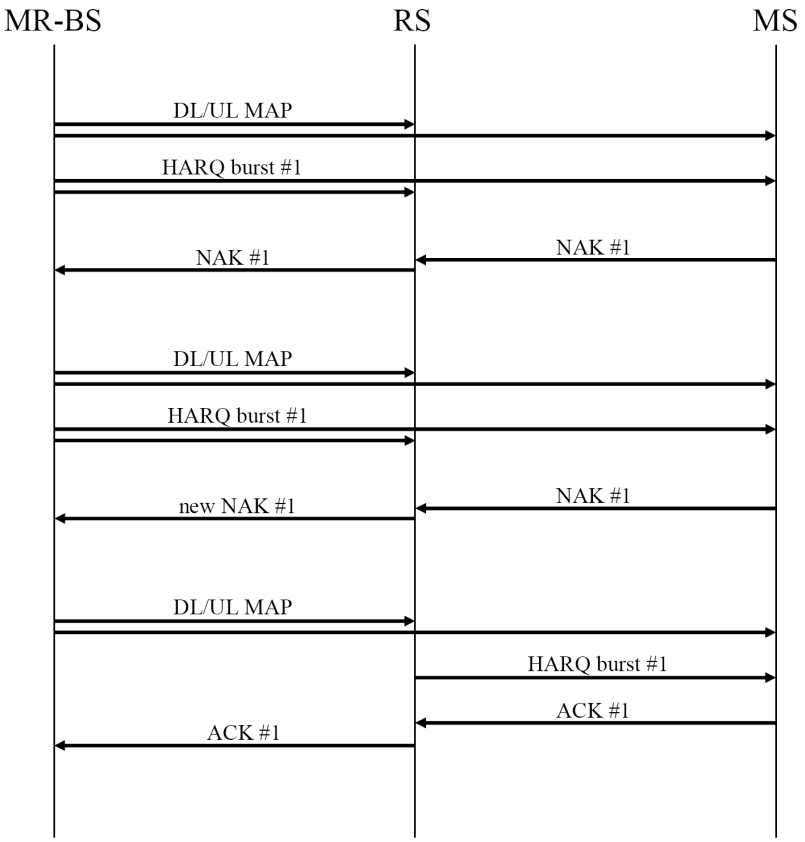

Figure 11. Flow diagram of RS-assisted relaying for data sub-burst and ACK/NACK signals.

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 12 shows the flow diagram of 3-hop DL HARQ with dedicated HARQ report channels. In this figure, MR-BS allocates individual HARQ 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.

The dedicated HARQ report channel only occupies one bit which is a flag used for indicating the MR-BS about the failure occurs at the designated RS. To accommodate the 1-bit dedicated HARQ report channel into the 3-bit or 6-bit compact HARQ report channel, the configuration of 3-bit or 6-bit compact HARQ report channel becomes more versatile. For example, a 3-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case and one 1-bit dedicated HARQ report channel. The 6-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case, one 3-bit HARQ report channel for up to 7-hop case and one 1-bit dedicated HARQ report channel. Another configuration example is that a 6-bit compact HARQ report channel can be configured as two 2-bit HARQ report channels for a less than 4-hop case and two 1-bit dedicated HARQ report channels.

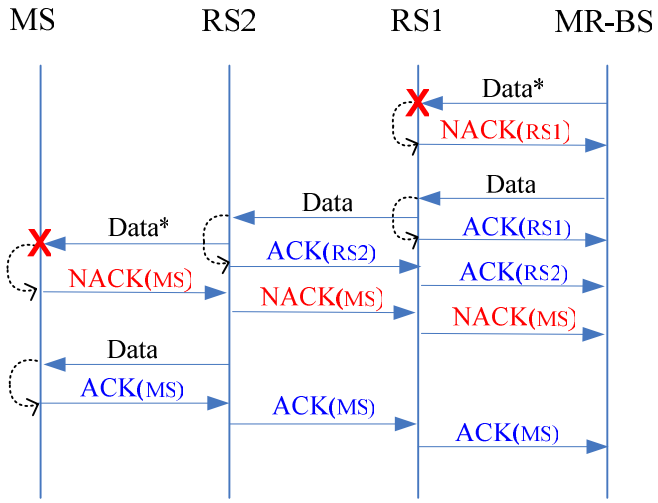

Figure 12. Flow diagram for 3-hop DL HARQ with dedicated HARQ report channels.

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 or NACK(x^{th} hop) is decoded as NACK(y^{th} hop) where x>y in DL case and x<y in UL case), it will cause unnecessary retransmissions but not cause system deadlock. However, if error occurs on NACK (i.e. NACK(x^{th} hop) is decoded as ACK or NACK(y^{th} hop) where x<y in DL case and x>y in UL case), 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 HARQ report 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. Considering the resource usage, the recovery report channel may be allocated in two ways: the dedicated recovery HARQ report channel scheme and the shared recovery HARQ report channel scheme.

Dedicated Recovery HARQ Report Channel Scheme

For DL HARQ data, MR-BS with dedicated recovery HARQ report channel scheme could allocate a recovery HARQ report channel for the RS which is going to start the retransmission. Such RS reports a NACK to MR-BS if it does not have correct data; Otherwise, it reports the ACK. For DL HARQ channel, recovery HARQ report channel provides the benefit of fast recovery. For UL HARQ channel, the recovery HARQ report channel for the RS to retransmit data shall be allocated.

A dedicated recovery HARQ report channel only occupies one bit which is a flag used for indicating the MR-BS about the correct or incorrect retransmission schedule. If RS does not have correct data, it sends a NACK to MR-BS; otherwise, it sends an ACK to MR-BS.

The way of accommodating the 1-bit recovery HARQ report channel into the 3-bit or 6-bit compact HARQ report channel is the same as that for dealing with 1-bit dedicated HARQ report channel. For example, a 6-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case, one 3-bit HARQ report channel for up to 7-hop case and one 1-bit recovery HARQ report channel. Another configuration example is that a 6-bit compact HARQ report channel can be configured as two 2-bit HARQ report channels for a less than 4-hop case, one 1-bit dedicated HARQ report channel and one 1-bit recovery HARQ report channel..

Shared Recovery HARQ Report Channel Scheme

With shared recovery HARQ report channel scheme, the recovery HARQ report channel and regular ACK/NACK channel share the HARQ report channel. When it is applied for the DL HARQ channel, there is no extra resource dedicated for recovery mechanisms. However, it takes full round trip delay to detect and recover. For the UL HARQ channel, the recovery HARQ report channel shall be allocated to the designated RS and it could along with the regular HARQ report channel back to MR-BS. That is, MR-BS shall allocate the regular HARQ report channel from the RS which is arranged to retransmit HARQ data. If the designated RS does not have correct data, it will send a NACK to MR-BS with the hop number of the adjacent downstream link of it.

Figure 13 shows an example that MR-BS incorrectly decodes the NACK signal with the failure hop number (=2) from RS as NACK signal with the failure hop number (=1) and MR-BS does not allocate a recovery HARQ report channel for the RS1 which is arranged to retransmit UL HARQ data. In such case, MR-BS will repeatedly schedule inconsequent retransmission from RS1 to MR-BS. Figure 14 shows an example that MR-BS incorrectly decodes the NACK signal with the failure hop number (=2) as NACK signal with the failure hop number (=1) from RS and MR-BS automatically allocates a recovery HARQ report channel for the sender RS1. As a result, MR-BS detects the inconsequent retransmission situation and prevent system from deadlock situation.

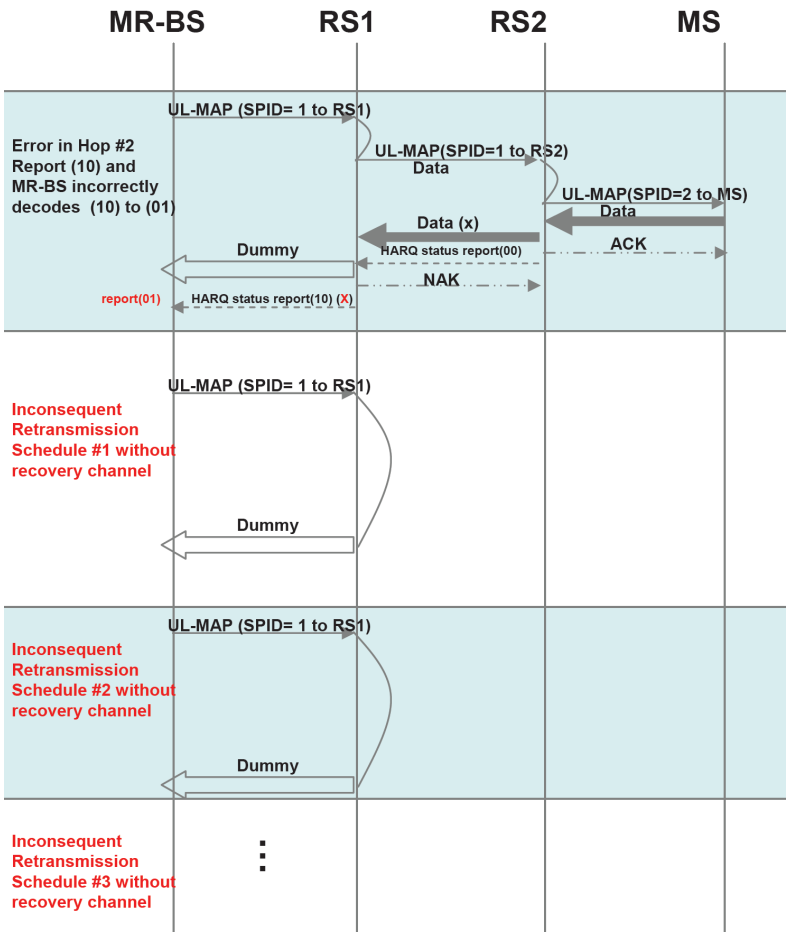

Figure 13. Flow diagram for 3-hop UL HARQ retransmission without recovery HARQ report channel..

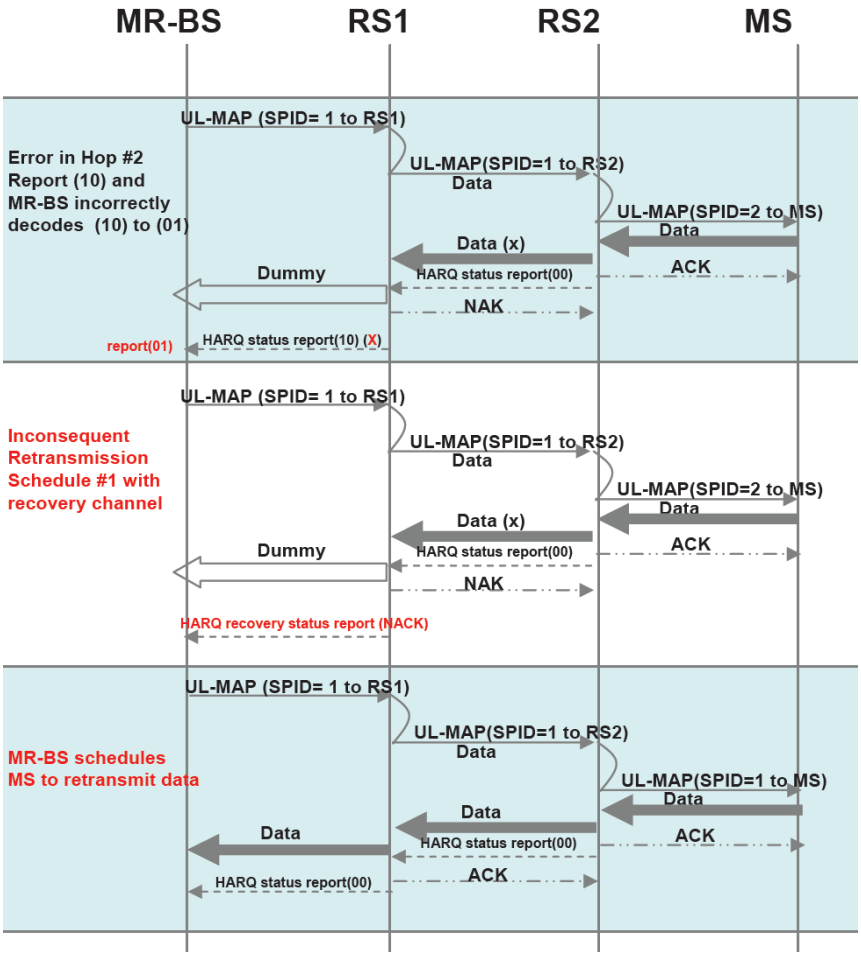

Figure 14. Flow diagram for 3-hop UL HARQ retransmission with recovery HARQ report channel.

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 each 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 particularly grouped for assisting HARQ data forwarding. For DL HARQ channel, dedicated HARQ 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 HARQ report 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. The compact HARQ report channel is versatile for accommodating the normal HARQ report channel, the dedicated HSRQ report channel and the dedicated recovery HARQ report channel. In multi-hop relay system with end-to-end pre-scheduling, RS should relay either correct HARQ burst or dummy HARQ pattern to the next hop.

Reference :

[1] C802.16j-07_232, “Downlink HARQ for Transparent RS”

Proposed text changes

Insert new sub-clause 6.3.17.5

6.3.17.5 RS supporting multi-hop HARQ in centralized scheduling

In an N-hop relaying path with centralized scheduling, the resource allocation for the data forwarding is assigned by MR-BS at the same time on a per-HARQ channel basis. All HARQ retransmissions shall be scheduled at the MR-BS. Burst allocations for DL HARQ retransmissions shall be signaled to the intermediate RSs on the N-hop path between the MR-BS and a destination MS in the HARQ DL MAP IE defined in Section 8.4.5.3.21. Burst allocations for UL HARQ retransmissions shall be signaled to the intermediate RSs on the N-hop path between a source MS and the MR-BS in the HARQ UL MAP IE defined in Section 8.4.5.4.24.

Each RS on the N-hop relaying path from MR-BS to MS or vice versa, on a per-HARQ channel basis, 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, and apply the erroneous packet handling procedure if the decoded packet is incorrect
- re-transmit 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

A DL HARQ status report channel, on a per-HARQ channel basis, is assigned to each RS to report the HARQ forwarding status to indicate the failure hop number and the ACK/NACK channel allocation to the RS(s) is not required. An UL HARQ status report channel, on a per-HARQ channel basis, is assigned to each RS to report the HARQ forwarding status to indicate the failure hop number if any. Such a HARQ status report channel is signaled by a physical channel called as UL HARQ report channel.

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 for 3-bit HARQ report channel is the same as fast-feedback channel sub-carrier modulation defined in Table 298c in 8.4.5.4.10.5 and is called as 3-bit compact HARQ report channel. The physical channel for 6-bit HARQ report channel is the same as enhanced fast-feedback channel sub-carrier modulation defined in Table 298d in 8.4.5.4.10.5 and is called as 6-bit compact HARQ report channel. The basic configuration of compact HARQ report channel is listed in Table aaa, the failure decoding of forwarding DL data packet and UL data packet at the k^{th} hop is encoded for the specific hop number and the associated compact HARQ report channel is generated by the k^{th} RS node and the $(k-1)^{th}$ RS respectively. The intermediate relaying RS(s) should decode and forward the compact HARQ report channel without modification of the encoding if the compact HARQ channel is allocated for the downstream RS(s). Contrarily, the intermediate relaying RS(s) should decode, encode and forward the new compact HARQ report channel if it is scheduled to report its status to MR-BS in this compact HARQ report channel.

Table aaa - Encoding of Compact HARQ Report Channel for normal UL HARQ report channel

Compact HARQ Report Channel		3-bit		6-bit			6-bit	
		HARQ_CH#1		HARQ_CH#1	HARQ_CH#2	HARQ_CH#3	HARQ_CH#1	HARQ_CH#2
Success		x00	000	xxxx00	xx00xx	00xxxx	xxx000	000xxx
Failure Hop Number	1	x01	001	xxxx01	xx01xx	01xxxx	xxx001	001xxx
	2	x10	010	xxxx10	xx10xx	10xxxx	xxx010	010xxx
	3	x11	011	xxxx11	xx11xx	11xxxx	xxx011	011xxx
	4		100				xxx100	100xxx
	5		101				xxx101	101xxx
	6		110				xxx110	110xxx
	7		111				xxx111	111xxx

6.3.17.5.2 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 generates UL HARQ report channel with an encoding of the hop number to its upstream station. 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 0s) 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. The station which creates MAP-IE modifies the SPID according to the HARQ status report received.

6.3.17.5.2.1 DL Erroneous HARQ Decoding Packet Handling in RS

For each 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, for the DL non-transparent relay case, the RS may insert a Skip_IE with the mode set to 0 prior to the associated HARQ_DL_MAP_IE and insert a Skip_IE with the mode set to 0 post to the associated HARQ_DL_MAP_IE. The RS does not transmit the erroneous packet and only transmit pilot to the subordinate station, or the RS may perform amplify and forward of the erroneous packet with dedicated pilot to the subordinate station and forward the pre-allocated MAP_IE; for the DL transparent relay case; the RS should not transmit the erroneous packet to the subordinate station, but only transmit pilot.

6.3.17.5.3 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 channel 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 report channel with the hop number to upstream station. 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. RS will try to decode the received HARQ data only when the status report from its child is 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 AK 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.

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

The HARQ_ACK_IE is defined in 8.4.5.3.22.

6.3.17.5.3.2 UL Erroneous HARQ Decoding Packet Handling in RS

For the UL transparent and non-transparent relay cases; the RS should not transmit the erroneous packet to upstream stations, but only transmit pilot. The presence of the HARQ report channel in the child station will indicate the forwarding packet is in erroneous.

6.3.17.5.4 Dedicated HARQ Report 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.

The dedicated HARQ report channel only occupies one bit which is a flag used for indicating the MR-BS about the failure occurs at the designated RS. For saving resource requirement, the dedicated HARQ report channel may be embedded in the compact HARQ report channel. For example, a 3-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case and one 1-bit dedicated HARQ report channel. The 6-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case, one 3-bit HARQ report channel for up to 7-hop case and one 1-bit dedicated HARQ report channel. Another configuration example is that a 6-bit compact HARQ report channel can be configured as two 2-bit HARQ report channels for a less than 4-hop case and two 1-bit dedicated HARQ report channels.

6.3.17.5.5 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). Because the relay link can support 16 HARQ channels at most and the total number of HARQ channels in associated MSs may be larger than 16, it requires that RS needs to automatically replace some HARQ buffer for accommodating new HARQ data. The HARQ buffer replacement algorithm in RS is beyond the scope of this contribution.

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 and it shall amplify and forward the erroneous data with dedicated pilots to the next hop. If one designated RS in a hop has correctly received HARQ data, it shall send an ACK to MR-BS and forward the received HARQ data to the next hop. If MR-BS can not receive any ACK from the receiving MHARQ group at a certain hop, MR-BS shall arrange retransmission for the receiving MHARQ group and one or more RSs, which have correct data, will be scheduled to retransmit data.

6.3.17.5.6 DL RS-Assisted Relaying

In a case where the MR-BS sends a HARQ sub-burst to the MS directly, the MR-BS informs the RS that it needs to monitor that particular transmission by properly generating the DL-MAP and also allocates HARQ ACK region allocation IE on the relay link for sending report from RS. The RS, having information on the downlink resource allocations sent in the DL-MAP for the MS, monitors the HARQ sub-burst transmission sent

to MS by MR-BS directly and attempts to decode it. When the RS receives the HARQ sub-burst correctly, the RS saves it for a possible retransmission.

When MR-BS receives ACK/NAK from MS directly, MR-BS informs RS to reply ACK/NAK signal after RS receives the HARQ sub-burst. In this case, MR-BS receives ACK/NAK from RS and MS separately. When MR-BS receives NAK from both RS and MS, MR-BS retransmits the HARQ sub-burst. If MR-BS receives ACK from RS and NAK from MS, MS-BS makes the RS retransmits the HARQ sub-burst.

MR-BS may also configure RS to listen the ACK/NACK from the MS using DL-MAP. After the RS receives ACK/NACK from the MS, the RS replies using an encoded ACK/NAK defined in Table aaa through compact HARQ report channel prepared by MR-BS. RS shall clear the HARQ sub-burst depending upon the ACK/NACK information received from MS. If the RS received the HARQ sub-burst correctly and receives a NACK from MS, the RS replies the NACK with failure hop number to MR-BS. In this case, the MR-BS requests the RS to retransmit the HARQ sub-burst saved at the RS. When the RS fails to receive the HARQ sub-burst and receives a NACK from the MS, the RS sends a NACK to the MR-BS. Then the MR-BS retransmits the burst by itself. When the RS receives an ACK from MS then irrespective of whether RS receives the HARQ sub-burst correctly or not, the RS replies ACK to the MR-BS. RS will send the encoded ACK/NAK in the UL ACKCH according to the order of CID in the DL-MAP.

6.3.17.5.7 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 or NACK(x^{th} hop) is decoded as NACK(y^{th} hop) where $x>y$ in DL case and $x<y$ in UL case), it will cause unnecessary retransmissions but not cause system deadlock. However, if error occurs on NACK (i.e. NACK(x^{th} hop) is decoded as ACK or NACK(y^{th} hop) where $x<y$ in DL case and $x>y$ in UL case), 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 HARQ report 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. Considering the resource usage, the recovery report channel may be allocated in two ways: the dedicated recovery HARQ report channel scheme and the shared recovery HARQ report channel scheme.

6.3.17.5.7.1 Dedicated Recovery HARQ Report Channel Scheme

For DL HARQ data, MR-BS with dedicated recovery HARQ channel scheme could allocate a recovery HARQ report channel for the RS which is going to start the retransmission. Such RS reports a NACK to MR-BS if it does not have correct data; Otherwise, it reports the ACK. For DL HARQ channel, recovery HARQ report channel provides the benefit of fast recovery. For UL HARQ channel, the recovery HARQ report channel for the RS to retransmit data shall be allocated.

A dedicated recovery HARQ report channel only occupies one bit which is a flag used for indicating the MR-BS about the correct or incorrect retransmission schedule. If RS does not have correct data, it sends a NACK to MR-BS; otherwise, it sends an ACK to MR-BS.

The way of accommodating the 1-bit recovery HARQ report channel into the 3-bit or 6-bit compact HARQ report channel is the same as that for dealing with 1-bit dedicated HARQ report channel. For example, a 6-bit compact HARQ report channel can be configured as one 2-bit HARQ report channel for a less than 4-hop case, one 3-bit HARQ report channel for up to 7-hop case and one 1-bit recovery HARQ report channel. Another configuration example is that a 6-bit compact HARQ report channel can be configured as two 2-bit HARQ

report channels for a less than 4-hop case, one 1-bit dedicated HARQ report channel and one 1-bit recovery HARQ report channel.

6.3.17.5.7.2 Shared Recovery HARQ Report Channel Scheme

With shared recovery HARQ channel scheme, the recovery HARQ report channel and regular ACK/NACK channel share the HARQ report channel. When it is applied for the DL HARQ channel, there is no extra resource dedicated for recovery mechanisms. However, it takes full round trip delay to detect and recover. For the UL HARQ channel, the recovery HARQ report channel shall be allocated to the designated RS and it could along with the regular HARQ report channel back to MR-BS. That is, MR-BS shall allocate the regular HARQ report channel from the RS which is arranged to retransmit HARQ data. If the designated RS does not have correct data, it will send a NACK to MR-BS with the hop number of the adjacent downstream link of it.

6.3.17.5.8 Hybrid Compact HARQ Report Channel Encoding

For saving resource requirement, the dedicated HARQ report channel and recovery HARQ report channel may be embedded in the compact HARQ report channel.

For the compact HARQ report channel, there are three possible types of HARQ report channels : normal HARQ report channel, dedicated HARQ report channel and recovery HARQ report channel. For a L-bit compact HARQ report channel, let N denote the number of bits used for normal HARQ report channels, D denote the number of bits used for dedicated HARQ report channels, R denote the number of bits used for recovery HARQ report channel, and U denote the number of unused bits. Then, the summation of values of N, D and R is equal to L-U. Let C=<D, R, n(1), n(2),…, n(m)> denote the detailed configuration of a L-bit compact HARQ report channel, where n(i) is the number of bits allocated for the i-th normal HARQ report channel associated with a HARQ channel. Notice that the summation of all n(i) ($1 \le i \le m$) is equal to N. One 2-bit normal HARQ report channel (i.e. n(i)=2) can handle 3-hop HARQ channel at most and one 3-bit normal HARQ report channel (i.e. n(i)=3) can handle HARQ channel up to 7-hop. Tables bbb and ccc respectively illustrate the example of 3-bit and 6-bit hybrid compact HARQ report channel encodings.

Table bbb Example of 3-bit hybrid compact HARQ report channel encoding

Compact HARQ Report Channel		3-bit	
Configuration		<1,0,2>	
HARQ_Channel		HARQ_CH#1	HARQ_CH#2
Type		Dedicated	Normal
	Success	0xx	x00
Failure Hop Number	1	1xx	x01
	2	1xx	x10
	3	1xx	x11

Table ccc Example of 6-bit hybrid compact HARQ report channel encoding

Compact HARQ Report Channel	6-bit			
Configuration	<1,1,2,2>			
HARQ_Channel	HARQ_CH#1	HARQ_CH#2	HARQ_CH#3	HARQ_CH#4

Type		Dedicated	Recovery	Normal	Normal
	Success	0xxxxx	x0xxxx	xx00xx	xxxx00
Failure Hop Number	1	1xxxxx	x1xxxx	xx01xx	xxxx01
	2	1xxxxx	x1xxxx	xx10xx	xxxx10
	3	1xxxxx	x1xxxx	xx11xx	xxxx11