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Title	Pipeline HARQ for multi-relay system
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Re:	This is in response to the call for technical comments and contributions regarding IEEE Project 802.16j (80216j-07_007r2.pdf)
Abstract	This document proposes a method for shortening the end-to-end HARQ data transfer latency along the relay path in a relay system.
Purpose	Add proposed spec changes in P802.16j Baseline Document (IEEE 802.16j-06/026r2).
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Procedures	include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

Pipeline HARQ with Relay

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. Considering the procedure of handling retransmission of HARQ failure attempt in multi-hop scenario, the logical HARQ channel between MR-BS and MS could be performed in either the end-to-end or the hop-by-hop manner depending on which station generating the ACK indication. Generally, in the fashion of end-to-end HARQ, the ACK messages are only generated from either the MR-BS or the MS according to the direction of data flow. On the other hand, the MR-BS, MS and RS are able to generate ACK indications in the fashion of hop-by-hop HARQ.

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 link. For end-to-end HARQ channel in centralized scheduling system, the bandwidth required for relaying the HARQ data packet could be pre-allocated for all the links along the relay path between MR-BS and MS. If any HARQ packet transmission failure occurs on a link, then the failure shall be reported to the MR-BS in order to request bandwidth for retransmission on the effected links. For hop-by-hop HARQ channel in centralized scheduling system, the bandwidth required for relaying the HARQ data packet could be sequentially allocated for the links along the relay path, one by one. From above descriptions, if the HARQ packet is received incorrectly at an RS, it will not forward the incorrectly received packet to next hop RS. Therefore, a longer HARQ packet transfer latency between MR-BS and MS is inevitable in a multi-hop relay system no matter either the end-to-end or hop-by-hop approach is adopted.

This contribution is mainly aimed at efficient HARQ retransmissions in multi-hop relay system with centralized control and scheduling approach. Moreover, it suggests the mechanism that will work on the chase combining HARQ (type I) and incremental-redundancy HARQ (type II).

Proposed Pipeline HARQ

This contribution introduces a pipeline HARQ method in multi-hop relay system with centralized scheduling to minimize the unnecessary retransmissions on links along the relay path. The feature of minimal unnecessary retransmissions on links on relay path is essential for providing high system performance.

RS supporting pipeline HARQ

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 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 indication to it

In both cases of UL HARQ channel and DL HARQ channel, RS always reports MR-BS the status of decoding the received packet. To provide fault tolerance on ACK/NACK indications, each RS sends separate ACK/NACK to MR-BS. Each time RS receives an ACK/NACK sent from the successor, the RS shall forward the received ACK/NACK to the predecessor, finally to the destination such as MR-BS or MS. Upon MR-BS receiving the NACK indication from an RS or MS, it schedules the bandwidth for retransmissions on all effected links related to the RS or MS. To avoid error propagation causes from RS forwarding erroneous HARQ packet to the next station, RS should not forward erroneous HARQ packet on the pre-allocated HARQ sub-burst. Instead, RS excluding the access RS could send dummy information to the next station to indicate error occurrence on some link(s). Moreover, the dummy pattern is predefined in mutli-hop relay system and it shall be specific for RS to distinguish it from all possibly encoded data patterns. The design of dummy pattern is not the scope of this contribution.

Proposed DL pipeline HARQ in centralized scheduling

In DL HARQ scenario, the data packets may be sent from MR-BS to MS via RS. As shown in Figure 1, HARQ data packet will be sent from MR-BS to RS1, and is forwarded to RS2 and finally to MS. In Figure 1, notation 'Data' indicates the HARQ packet is successfully transmitted, notation 'Data*' indicates the HARQ packet is disturbed by noise during transmission, and notation 'Dummy' indicates the allocated HARQ sub-burst on relay link is replaced by dummy information. For the efficiency purpose, the bandwidth for relaying the HARQ packet and status report on all the links along relay path could be prescheduled by MR-BS. If RS1 failed to decode HARQ packet correctly, RS1 does not relay the erroneous packet to the next hop and it reports NACK signal back to MR-BS to indicate the retransmission request. In this case, RS sends dummy information on the allocated HARQ sub-burst to the next hop such that further downstream RS also fails to decode the HARQ burst correctly and replies separate NACK back to MR-BS consequently. If this situation occurs at access RS, the RS modifies the DL HARQ sub-burst IE in the DL-MAP such that the MS does not receive the erroneous HARQ burst. The RS replaces the CID in the corresponding HARQ sub-burst IE with its own basic CID. Moreover, the access RS represents MS to generate the NACK and send it to MR-BS through ACK channel in the ACKCH region at the designated frame.

The proposed scheme also provides the advantage of early fault detection by MR-BS. Considering Figure 2 for example again, assume the first transmission attempt is scheduled at the k-th frame and the packet processing delay at an RS plus the ACK delay defined by the field "HARQ ACK Delay for DL burst" field in the DCD message be one frame. Then, MR-BS will perceive the first NACK signal (from RS1) at the (k+1)-th frame and the first retransmission from MR-BS could be started at the (k+2)-th frame. It is definitely earlier than the timing after MR-BS collecting all NACKs from MS and RS(s) on the path. Furthermore, the NACK waiting to be sent from downstream RS(s) later shall become useless from the system-wise viewpoint and, consequently, the bandwidth required for relaying such NACK could be further conserved by just skipping the bandwidth allocation in ACK Region IE carried in the following UL-MAP(s) after the (k+2)-th frame. Such advantage will become more obvious as the growth of number of hops in a relay path.

As a response to a successful reception of the data at the MS or RS, MS or RS shall generate separate ACK indication to notify MR-BS the stopping of HARQ retransmissions from its predecessor to it.

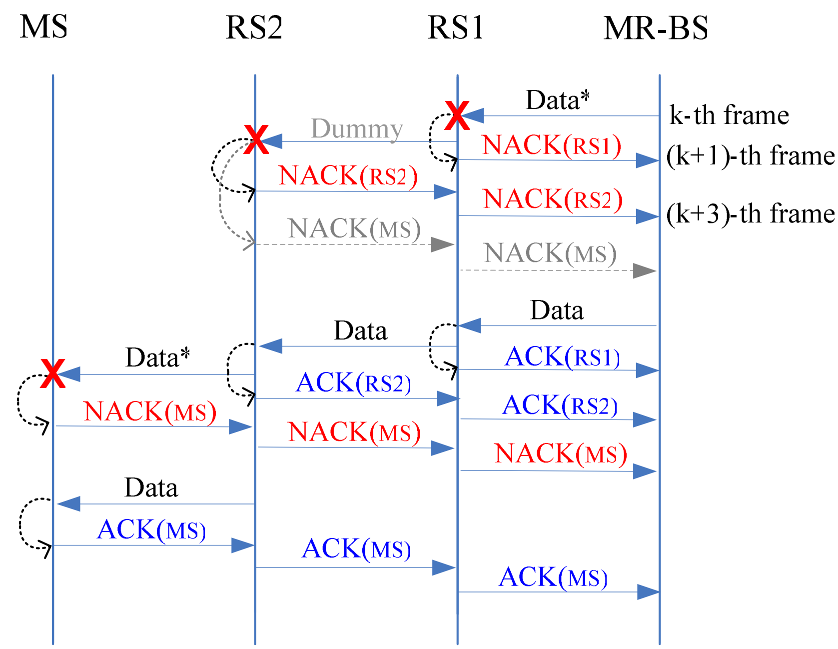

Figure 1. Message flow for 3-hop DL pipeline HARQ.

Proposed UL pipeline HARQ in centralized scheduling

The data flow of uplink HARQ is in the opposite direction as that illustrated in Figure. 1. System requires to setup two contra-directional ACK channels for an uplink pipeline HARQ channel : the UL ACK channel and the DL ACK channel. The ACK/NACK transmitted on UL ACK channel and DL ACK channel are denoted as UL ACK/NACK and DL ACK/NACK respectively. The DL ACK/NACK is carried in HARQ_ACK_IE as in current 16e spec, and HARQ_ACK_IE s could be generated by access RS or MR-BS. The followings list their requirements and purposes :

- DL ACK destining to MS shall be generated by access RS. It is used to stop retransmission at MS
- DL NACK destining to MS shall be generated by access RS. It is used to indicate the requirement of retransmission
- DL ACK destining to RS shall be generated by MR-BS. It is used to stop retransmission at RS
- DL NACK destining to RS may be generated by MR-BS. It is used to indicate the requirement of retransmission
- UL ACK shall be generated by RS and forwarded to MR-BS. It is used to trigger MR-BS to generate DL ACK to the successor of the intermediate RS sending the UL ACK
- UL NACK shall be generated by RS and forwarded to MR-BS. It is used to notify MR-BS that it needs receive packet from its successor again

Figure 2 illustrates the uplink pipeline HARQ with necessary UL ACK/NACK and DL ACK/NACK indications. Notations used in Figure 2 are the same to that shown in Figure 1. In Figure 2, as access RS RS2 failed to decode HARQ packet from MS correctly, it sending the dummy information to the next hop, RS1, and finally to the MR-BS. RS2 replies the DL NACK(MS) such that MS can receive ACK/NACK before ACK timeout. The UL NACK(RS1) and UL NACK(RS2) shall be separately sent from RS1 and RS2 for the purpose of notifying MR-BS the failed receptions at RS1 and RS2 respectively. In this case, MR-BS can not correctly decode the packet and there is no ACK indication sent from RS. Then, MR-BS schedules retransmission on all links from MS to MR-BS. For the first retransmission, data is assumed to be successful at the access link from MS to RS2 and at the relay link from RS2 to RS1, and to be failure at the last link. As a result, RS2 generates the DL ACK(MS) and replies it to MS. Moreover, RS2 and RS1 respectively send UL ACK(RS2) and UL ACK(RS1) to MR-BS and the latter will trigger MR-BS to generate the DL ACK(RS2) which is used to release the buffer at RS2. After then, retransmission on effected link from RS1 to MR-BS is repeated again. As the packet retransmission from RS1 to MR-BS is successful, DL ACK(RS1) is generated accordingly as shown in Figure 2.

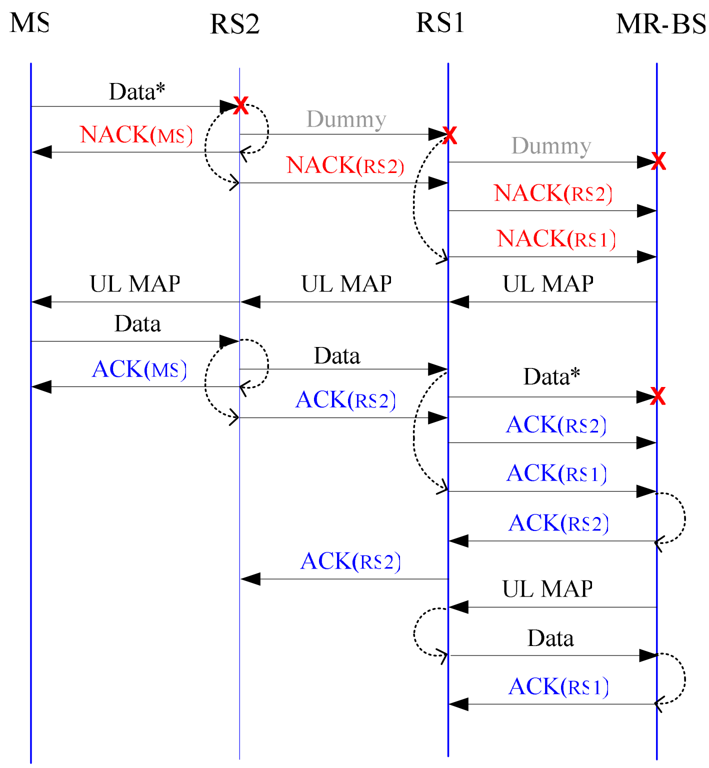

Figure 2. Message flow for 3-hop UL pipeline HARQ.

It is optional for a BS to send explicit NACK to RS to indicate the retransmission request because MR-BS controls all retransmissions by using HARQ-MAP IE. According to the aforementioned descriptions, when a system adopting the pipeline HARQ technique, HARQ packet is retransmitted from a station until it receives the explicit ACK indication. To minimize the unnecessary retransmissions caused from any loss ACK/NACK indication along the way to MR-BS, MR-BS should allocate one uplink and one downlink ACK channel for MS and every RS on the path.

Conclusion

In summary, a multi-hop relay system using pipeline HARQ technique can efficiently determined the effected links required for retransmissions and reduce the unnecessary retransmissions caused from the potential loss of ACK/NACK indication along the relay path to MR-BS.

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 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

For each UL HARQ channel or DL HARQ channel, MR-BS should allocate one ACK channel for every RS on the path. Each RS on the path is required to send individual ACK/NAK signal back to the MR-BS. RS shall forward every received ACK/NACK to the next station, and to the destination such as MR-BS or MS. The MS HARQ operation behavior is unchanged with the introduction of RS.

To avoid error propagation causes from RS forwarding erroneous HARQ packet to the next station, RS should not forward erroneous HARQ packet on the pre-allocated HARQ sub-burst. Instead, RS (excluding access RS) could send dummy information pattern to the next station to indicate error occurrence on predecessor link(s). Moreover, the specific dummy pattern is predefined in mutli-hop relay system with an erroneous CRC attachment.

6.3.17.5.1 Multi-hop DL HARQ in 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 each RS and MS towards MR-BS.

If RS or MS failed to decode the received HARQ-burst correctly, it replies a NACK to MR-BS, as in current 16e specification. In this case, RS (excluding the access RS) sends dummy pattern on the pre-allocated HARQ sub-burst to the next hop such that further downstream RS also fails to decode the HARQ burst correctly and then replies individual NACK back to MR-BS correspondingly. If this situation occurs at access RS, the RS modifies the DL_HARQ_Sub-burst_IE in the DL-MAP such that the MS does not receive the erroneous HARQ burst. The RS replaces the CID in the corresponding DL_HARQ_Sub-burst_IE with its own basic CID, in this case, the ACKCH_Region_IE shall be de-allocated. Moreover, the access RS represents MS to generate the NACK and send it to MR-BS through ACK channel in the ACKCH region at the designated frame.

As a response to a successful reception of the HARQ sub-burst, MS or RS shall forward the HARQ packet to the next hop and reply ACK to notify MR-BS to stop HARQ retransmission from its predecessor. Every ACK/NACK sent from MS or RS is forwarded by upstream RS(s) and ultimately to the MR-BS.

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 to all received ACK/NACK signals and then schedules the retransmission only for the affected link(s) that didn’t transmit packet successfully in the last attempt.

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.

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

Since each RS on the path is required to send individual ACK/NAK signal back to the MR-BS, for each DL HARQ channel, MR-BS should allocate one ACK channel for each RS on the path. RS shall forward every received ACK/NACK to the next station, and to the destination MR-BS. The ACK/NACK channel construction is the same as specified in 8.4.5.4.13.

6.3.17.5.2 Multi-hop UL HARQ in 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 individual 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 RS and from access RS to MS.

An RS shall send NACK to MR-BS if the decoded HARQ-burst is incorrect. In this case, RS sends dummy pattern on the pre-allocated HARQ sub-burst to the next hop such that further upstream RS also fails to decode the HARQ burst correctly and sends individual NACK to MR-BS consequently. If access RS failed to decode HARQ-burst correctly, it shall reply NACK to MS via HARQ_ACK_IE as in current 16e specification.

As a response to a successful reception of the data, RS shall forward the HARQ packet to the next hop and generate ACK to notify MR-BS to stop HARQ retransmissions from its next downstream station. Such ACK, which is sent from intermediate RS, arriving MR-BS will trigger MR-BS to send an ACK, which is carried in HARQ_ACK_IE, to the RS which is the next downstream station of the RS sending the ACK signal. If access RS decodes the HARQ-burst correctly, it shall reply ACK to MS via HARQ_ACK_IE as in current 16e specification.

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 determines the links of DL transmission failure by referring to all received ACK/NACK signals and then schedules the retransmission only for the effected links that didn't transmit packet successfully in the last attempt.

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

Since each RS on the path is required to send individual ACK/NAK signal back to the RS(s) and MS, for each HARQ_ACK_IE, MR-BS should allocate one ACK channel for each RS on the path. RS shall forward every received ACK/NACK to the next station, and to the destination MS. The HARQ_ACK_IE is defined in 8.4.5.3.22.

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

Since each RS on the path is required to send individual ACK/NAK signal back to the MR-BS, for each UL HARQ channel, MR-BS should allocate one ACK channel for each RS on the path. RS shall forward every received ACK/NACK to the next station, and to the destination MR-BS. The ACK/NACK channel construction is the same as specified in 8.4.5.4.13.