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Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Reliable Multicasting with Selective Acknowledgement for IEEE802.16j**
Date Submitted	**2007-03-14**
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Re:	A response to the call for technical proposals for the Relay TG, see IEEE 80216j-07/007r2.pdf
Abstract	The relay-based IEEE 802.16j network topology has some unique aspects and by allowing ARQ for some critical RSs in certain restricted cases may considerably improve the reliability. The proposed contribution presents an optional reliable multicast mode for IEEE 802.16j systems and specifies the changes needed in the ARQ mechanism for realization of such a mode. An example mechanism for the selection of critical RSs is also outlined.
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Reliable Multicasting with Selective Acknowledgement for IEEE 802.16j

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I. Introduction

ARQ is not applicable to multicast/broadcast connections in IEEE 802.16-2004 and IEEE 802.16e standards. However, the relay-based IEEE 802.16j network topology has some unique aspects in which, by allowing ARQ for a subset of relay stations (RSs) in certain restricted cases may considerably improve the reliability of multicast transmissions for a large number of subscriber stations (SSs).

The proposed contribution provides a reliable layer-2 multicasting for a subset of intended receivers in a selective fashion. Broadcast/multicast connections provide a mode of operation, where the messages transmitted by one sender over the shared wireless medium can be received simultaneously by a plurality of distinct receivers. The reliability in this context amounts to link layer retransmissions in broadcast/multicast connections after receiving a negative acknowledgement (NACK) or not receiving a positive acknowledgement (ACK) within a time-out period from an a-priori selected subset of intended RSs. These RSs are named as *critical RSs* and can be determined by the BS.

II. Purpose

Deleted: The method presented in this proposal determines which subset of the receivers over each multicast/broadcast connection in a wireless relay network is responsible for sending ACKs/NACKs back to the original sender. The method also resolves the scheduling of ACKs/NACKs, i.e., the subset of nodes that send ACKs/NACKs are informed about this decision as well as the particular channel and time slot, where each member of the subset is eligible for sending its ACKs/NACKs.¶
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The purpose of the contribution is

- To improve the reliability of the information transmitted to the critical RSs by allowing ACK/NACK messages in the link layer multicasting in a selective fashion.
- To specify the changes required in the ARQ mechanism for implementing reliable multicasting.
- To provide an example mechanism for the selection of critical RSs for implementing reliable multicasting (implementation dependent).

III. Proposal for Reliable Multicasting

a) Default Multicast Mode of Operation in IEEE 802.16

Link layer multicasting is used to avoid duplicate transmissions of the same packet over the same network interface. Unlike unicast transmissions where a packet is transmitted per link, i.e., point-to-point, in multicast transmissions, a packet is transmitted per connection over a broadcast medium where more than one node listening to this multicast connection is allowed to receive the packet. Link layer multicasting is important for spectrum efficiency in order to deliver broadcast/multicast applications over the air. In IEEE 802.16-2004 and IEEE 802.16e standards, link layer multicasting is performed without using retransmissions (i.e., the success or the failure of the transmission over a multicast connection is not reported by any receiver back to the BS), and hence multicast transmissions are unreliable at the link layer level. This mode of multicast transmission will be referred to as the "D*efault Multicast Mode*" (DMM).

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The lack of protection against losses at the MAC layer may have serious implications when some of the receivers of the multicast connection are RSs that forward the packets to other RSs or SSs. Some of these RSs can be serving many SSs and loss of a packet at these RSs result in packet loss at all the SSs being served by these RSs.

The network in Figure 1 illustrates the operation of DMM over one of the interesting scenarios. This example network has one wireless BS (node A), six RSs (nodes B,C,D,E,F,G), and sixteen SSs (nodes 1 through 16) which are subscribed to the same multicast service, e.g., streaming from the same video source. BS-A creates a DMM and allocates a common channel (labeled DMM-1 in Figure 1) for this connection. Similarly the RSs create distinct multicast connections (each of which is allocated a unique channel), to forward the packets received from their upstream nodes to their downstream nodes. Under ideal circumstances, each packet of the multicast service is transmitted exactly once by the BS and each RS over their respective multicast connections, and all SSs correctly receive it.

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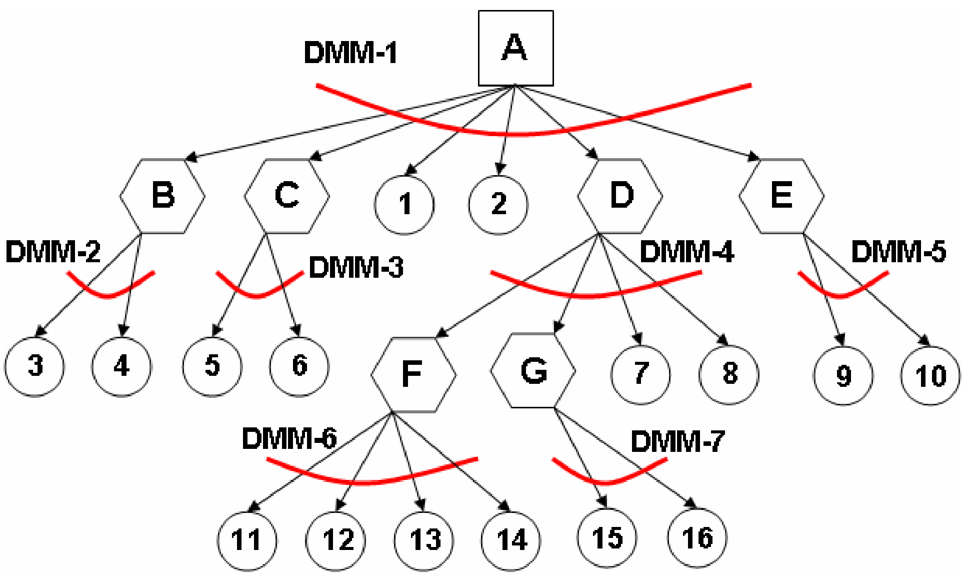

Figure 1: An example of a multicast routing over shared medium through broadcast/multicast channels.

However, this ideal mode of operation where each downstream node receives the information at the first time when information is transmitted by its upstream node is not a realistic assessment especially when the broadcast medium is a wireless radio channel, where the channel is time-varying. Indeed, the successful reception of a packet becomes a probabilistic event which varies from one receiver to another. Therefore, while some of the downstream nodes can successfully receive a particular multicast packet, the remaining downstream nodes may not receive it successfully. As an extreme solution, one can implement multicast connection with ARQ support. However, since there may be a large number of receivers, it is not desirable to have each receiver to notify back the sender about the successful transmissions by sending an ACK message. ACK based approach can significantly drain the bandwidth resources considering the fact that under good channel conditions, most of the receivers will receive and send back an ACK message. With this consideration, a NACK based system can be utilized. However, this time there is ambiguity in terms of which receivers are going to send a NACK message in case more than one receiver did not received the packet correctly. One way to overcome such ambiguity is to allocate a slot (or sub-channel, sub-carrier, etc.) for each receiver, which may result in many unused bandwidth resources. Many systems therefore utilize a random back-off procedure to resolve any conflicts, which makes NACK based approaches more efficient than ACK based approaches when fewer nodes have unsuccessful reception. One problem with NACK-based solutions is that the receiver node must be able to decode the MAC header correctly.

In order to avoid such complications, many broadband wireless standards such as IEEE 802.11 or IEEE 802.16 do not impose a reliable multicast or broadcast transmission and no link layer (LL) retransmission mechanism (neither with ACK nor NACK) is supported in those modes of operation. They leave the reliability of transmission either to the physical layer (PHY) or to the higher layer protocols (e.g., transport layer, application layer, multicast routing layer, etc.) that utilize some form of forward error correction (FEC) or retransmissions. For popular broadcast/multicast content such as multi-media, higher layer solutions may generally result in higher delays that can be critical for media quality and they can also lead to less optimal use of the wireless resources at the edge. PHY solutions on the other hand might be insufficient in long enough error bursts and they may not differentiate between the receivers.

b) Proposed Solution for Reliable Multicast in IEEE 802.16j

As a compromise between completely reliable and completely unreliable layer-2 multicast modes, this contribution proposes a LL solution in order to improve the reliability of multicasting via retransmissions using the ACK/NACK feedback from a targeted subset of receivers in a particular multicast connection. Such mode of multicast transmission will be referred to as the "*Reliable Multicast Mode*" (RMM) and is outlined next.

RMM provides a solution that satisfies partial reliability for LL multicast/broadcast transmissions by a-priori selecting a set of nodes which are responsible for sending ACK/NACK messages. The main assumption used in this contribution is that the downstream RSs effectively serve many SSs and they are more important than the individual end users that are at the same depth in a multicast tree. For instance in Figure 1, BS-A is the root of the multicast tree. RS-B, RS-C, RS-D, RS-E as well as SS-1, SS-2 constitute the nodes that are 1-hop away from the root (hence they are depth-1 nodes). While SS-1 and SS-2 do not serve any other nodes, the RSs must retransmit the multicast packets so that other RSs and SSs can receive it. Thus, RS-D effectively serves 8 SSs. Similarly RS-B, RS-C, and RS-E each serve 2 SSs. Clearly in this setting, RS-D becomes the most critical downstream node; if RS-D does not receive a multicast packet, the failure propagates up to 8 SSs. On the other hand RS-B, RS-C, and RS-E are not as much critical, since a failure in their reception only impedes the quality of service (QoS) observed at only 2 SSs.

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Accordingly what we propose in this proposal is to employ a selective reliable multicasting, where at each hop only the relays with significant number of downstream SSs are designated as critical RSs. Any RS (or BS) which has at least one critical RS on its next hop waits for ACK (or NACK depending on which method is used by the unicast transmissions) from those nodes. If ACK stage fails, the unacknowledged packet is retransmitted until it is successful or a preset number of retransmissions fail. Alternatively our proposal also allows more complex criterion that considers both the channel qualities observed at the receiving nodes and the serving capacities. Accordingly, this process provides reliable multicasting in certain routing directions that serve significant number of SSs or that has weaker channel conditions.

In the default mode of operation, multicast/broadcast packets are not acknowledged hence they are not retransmitted by the last sender. In the enhanced mode of operation (i.e., in RMM), a subset of

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receivers is selected, the members of which are to provide feedback about whether the packet has been successfully recovered at those locations. Figure 2 depicts the scenario where network can be represented as a tree topology. Suppose RS-D, RS-E, RS-F, and RS-G declared that they can support RMM, while RS-B and RS-C have no support of RMM. Among capable RSs, suppose BS-A designated RS-D and RS-F as RMM critical RSs (RMM-CRS), communicated this designation with them, also allocated them the schedule for sending back feedback information (ACK/NACK). On the other hand, RS-E and RS-G are RMM non-critical RSs (NCRSs). While RMM-NCRSs do not have to send acknowledgements, they are capable of doing duplicate packet detection, and they keep track of ARQ_RX_WINDOW_START. Keeping track of the ARQ_RX_WINDOW_START is needed for a smooth transition to RMM-CRS mode when required in the case of changes in the topology, channel qualities, serving capacities etc.

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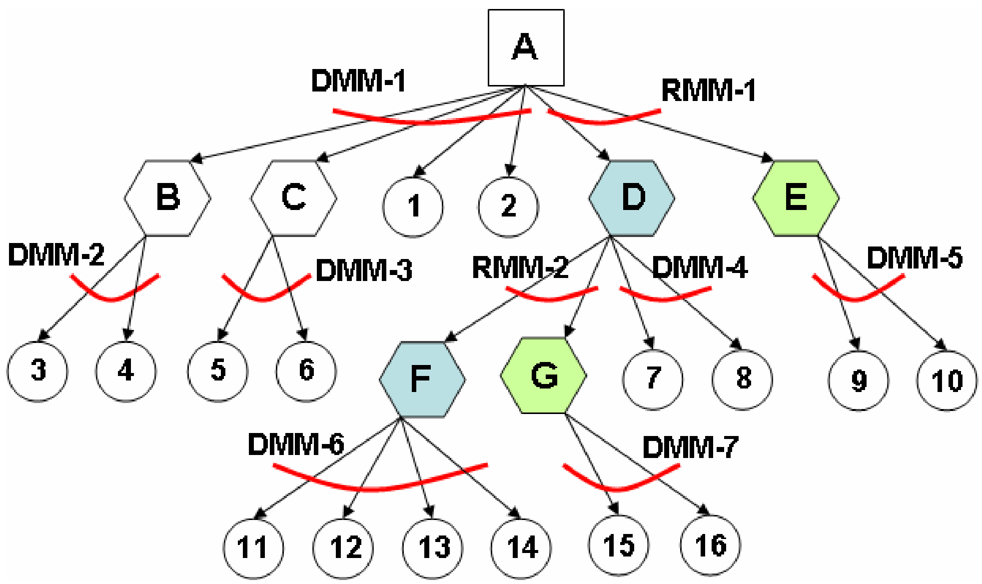

Figure 2: An example network of "selective reliable" link layer multicasting. RS-B and RS-D are designated as critical RSs.

Under these settings, as illustrated in Figure 2, two RMM connections can be initiated with RMM capable RSs in addition to existing DMM connections. This will improve the overall reliability of the system since critical RSs serve a large number of SSs. For example, when BS-A sends a multicast packet over the RMM-1 connection, the packet is received by RS-D and RS-E. The RS-E discards the packet if it is a duplicate packet, and otherwise increments its ARQ_RX_WINDOW_START variable. Since RS-D is designated as the critical RS, if it recovers the packet, it sends back an ACK message. If the packet is not recovered successfully at RS-D, no ACK is sent back and BS-A retransmits the multicast packet. Retransmissions end after a time-out period or when an ACK is received back from RS-D. When the packet is successfully recovered at RS-D, it re-transmits the packet in RMM-2 to RSs F and G, and in DMM-4 to SSs 7 and 8. Since only RS-F is designated as the RMM-CRS, it ACKs the packet using the advertised UL schedule by BS-A. RS-D retransmits the packet in RMM-2 unless an ACK is received from RS-F or a time-out occurred. In another possible implementation, a NACK mechanism is used instead of an ACK-based feedback mechanism to support retransmissions.

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Note that it may also be possible that SSs and RSs that do not support RMM may operate under RMM without knowing it. When duplicate packets are received, they are agnostic that the packet is duplicate, and pass the packet to upper layers which will handle it. In this way, it may be possible to use a single RMM connection rather than simultaneous RMM and DMM connections, which will improve the utilization of the channel resources.

c) An Example Methodology for the Selection of Critical Relay Stations

Selection of the critical RSs is implementation dependent and it is outside the scope of the standard. In here, we will provide a simple example for the selection of critical RSs as a possible option which uses a three-step algorithm.

The first step checks for each node **x** in the wireless network whether they are serving a critical number of end users by comparing the service capacity N(ST(**x**)) (i.e., the number of SSs under the subtree rooted at the node of interest) with the service capacity threshold C_{th}. For instance in Figure 1, N(ST(**A**)) = 16, N(ST(**B**)) = 2, N(ST(**C**)) = 2, N(ST(**D**)) = 8, N(ST(**E**)) = 2, N(ST(**F**)) = 4, and N(ST(**G**)) = 2. C_{th} represents a configuration parameter that can be set beforehand by the network operator. If C_{th} is set to 3, decision metric eliminates RS-B, RS-C, RS-E, and RS-G, and only BS-A, RS-D, and RS-F are eligible as critical RSs.

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The second step verifies the relative importance of the service capacity N(ST(**x**)) with respect to its parent node P_x by comparing the ratio γ = N(ST(**x**))/N(ST($P_{\mathbf{x}}$)) with threshold γ_{th}. The ratio is a number between 0 and 1, and it represents the relative service capacity. This criterion is useful to avoid unnecessary slow downs in the system due to retransmissions to a designated node with bad channel conditions. For instance RS-D has relative service capacity of γ=8/10 under RMM-1, serving most of the end users. It is more acceptable for RS-D to slow down the other users served by BS-A but not by RS-D, as it has larger relative service capacity. Again γ_{th} here is a parameter of choice by the network operator.

The third step checks whether any of the nodes that passed the first two steps have critical channel conditions, e.g., the channel quality for the transmissions to node **x** from its parent node P_x on the routing tree is below the desired level (e.g., Q_{th} in the figure) to achieve a target bit error rate performance. A simple quality measure can be the signal to interference and noise ratio (SINR). If there are nodes that cannot achieve SINR target through coding, link layer retransmissions must accompany the channel coding. Therefore, the nodes that have service capacity above C_{th} and relative service capacity above γ_{th}, but channel quality below Q_{th} are designated as the critical RSs by the decision logic. The algorithm set forth can be executed at a central node (e.g., BS-A in Figure 2) and communicated to the other relays or it can be executed in a distributed fashion at each RS.

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IV. Advantage

- Provides an increased reliability against the critical transmission failures for multicast/broadcast applications over multicast/broadcast channels in multi-hop networks while maintaining the spectral efficiency.
- Under the conditions where there are only a few critical intermediate wireless relays at each hop, the procedure allows an intelligent mechanism to send back feedback from the receiving nodes.
- Since the method provides a reliable link layer in critical directions of multicast information dissemination, it presents better QoS for a larger set of end users.

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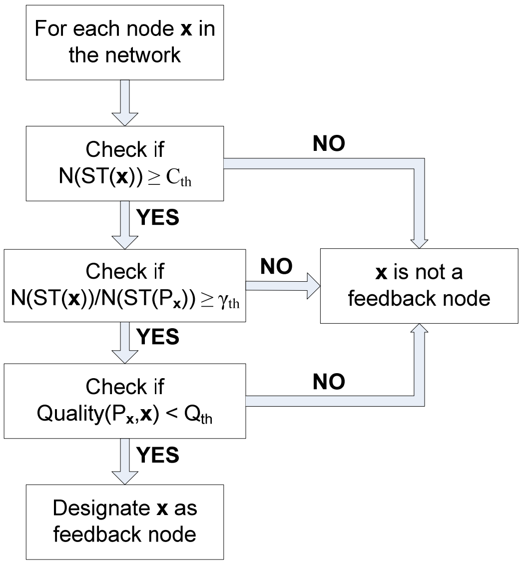

N(ST(**x**)): number of client nodes under the sub-tree with root node **x**
ST(**x**): sub-tree defined by the root node **x**
P_x: parent node of node **x**
Quality(y,x): channel quality from node y to node **x**
C_{th}: service capacity (i.e., number of clients that are served) threshold
Q_{th}: channel quality threshold

Figure 3: An example of decision logic algorithm for the selection of critical RSs

V. Related ToC

6.3.4 ARQ Mechanism
- 6.3.4.1 ARQ Block usage
- 6.3.4.2 ARQ Feedback IE format
- 6.3.4.3 ARQ parameters
- 6.3.4.4 ARQ procedures
- 6.3.4.5 ARQ-enabled connection setup and negotiation
- 6.3.4.6 ARQ operation

6.3.12 Assigning SSs to multicast groups
6.3.13 Establishment of multicast and broadcast transport connections
6.3.23 Multicast and broadcast services (MBS)
- 6.3.23.1 Single-BS access
- 6.3.23.2 Multi-BS access

11.7 REG-REQ/RSP management message encodings
- 11.7.1 ARQ Parameters
- 11.7.8.1 ARQ Support

11.13.18 ARQ TLVs for ARQ-enabled connections
- 11.13.18.1 ARQ Enable

VI. Text Proposal

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Include the following paragraph at the end of subsection 6.3.4

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6.3.4 ARQ Mechanism

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ARQ may be applicable to multicast connections for critical RSs as will be specified in Section 6.3.13.

Change subsection 6.3.13 as indicated

6.3.13 Establishment of multicast and broadcast transport connections

6.3.13.1 Default Multicast Mode

The BS may establish a downlink multicast or broadcast service by creating a connection with each SS/RS to be associated with the service. Any available traffic CID value may be used for the service (i.e., there are no dedicated CIDs for multicast transport connections). To ensure proper multicast operation, the CID used for the service is the same for all SSs/RSs on the same channel that participate in the connection. The SSs need not be aware that the connection is a multicast or broadcast transport connection. The data transmitted on the connection with the given CID shall be received and processed by the MAC of each involved SS. Thus, each multicast SDU is transmitted only once per BS channel. Since a multicast or broadcast transport connection is associated with a service flow, it is associated with the QoS and traffic parameters for that service flow. This mode of multicast transmission will be referred to as the "D*efault Multicast Mode*" (DMM).

ARQ is not applicable to ~~multicast~~ DMM connections.

If a downlink multicast connection is to be encrypted, each SS/RS participating in the connection shall have an additional security association (SA), allowing that connection to be encrypted using keys that are independent of those used for other encrypted transmissions between the SSs/RSs and the BS.

Include a new subsection 6.3.13.2 as indicated.

6.3.13.2 Reliable Multicast Mode

The relay-based network topology has some unique aspects in which, enabling a limited ARQ targeting a critical subset of RSs can improve the reliability of multicast transmissions for a large number of SSs. Such a mode of operation is referred as *"Reliable Multicast Mode"* (RMM). In DMM, multicast/broadcast packets are not acknowledged hence they are not retransmitted by the sender. In RMM, a subset of receivers is selected, the members of which are to provide feedback about whether the packet has been successfully recovered at those locations. Implementation of RMM-ARQ is optional.

In general, there may exist simultaneous connections operating in DMM and RMM modes. A multicast connection can be either a DMM connection or an RMM connection. The RSs with no support of RMM may only join a DMM connection, while the RSs that support RMM may join both DMM and RMM connections.

The first step in establishing an RMM connection is for the relays to declare their ARQ capabilities. They can have (1) no support for ARQ, (2) support for ARQ but no support for RMM ARQ, or (3) support for both ARQ and RMM ARQ. If no ARQ capability is negotiated between any RS and BS, the default assumption is (1) among these options. The declaration of the RMM-ARQ support can be made by using REG-REQ/REG-RSP type of messages.

If an RS supports and enables RMM, it can either be an RMM critical RS (RMM-CRS) or an RMM non-critical RS (RMM-NCRS). RMM-CRSs are responsible for sending positive or negative acknowledgement messages to the BS. RMM-NCRS do not send back any acknowledgement message; however, they are still capable of detecting duplicate packets and they continue updating their ARQ_RX_WINDOW_START variables for a smoother switching to the RMM-CRS mode when needed. Enabling and disabling of the RMM-ARQ can be done using REG-REQ/REG-RSP and DSA-REQ/DSA-RSP type of messages.

The critical RS(s) may be determined by the serving MMR-BS and how they are selected is implementation dependent. Some of the factors for deciding if a RS is critical or not may include the channel qualities and serving capacities of the RSs, and the overall network topology.

Note that the network is dynamic in general. The service capacity as well as the channel qualities of RSs are time-varying as SSs and obstacles move around (in some cases relays can be moving too). Moreover, new nodes can join to the multicast session or the existing ones might leave. Therefore, the set of critical RSs might be dynamically changing and such decisions should be communicated to the RSs. Any decision leading to a change in the set of critical RSs requires an update on the RMM connections, which can be communicated through DSA-REQ/DSA-RSP type of messages.

One scenario where RMM can be quite useful happens in the context of MBS specified in Section 6.3.23. In MBS, relays and BS must synchronize their transmissions to the SSs and a packet must be pre-transmitted from BS to the RSs for such a synchronization. RMM then becomes an ideal transmission mode for pre-transmission since it is more reliable than the default multicasting and more bandwidth efficient than the unicasting.

MMR-BS can use HARQ for transmissions for delay sensitive service flows. In this case, MMR-BS transmits the next HARQ subpacket if there is at least one CRS from which an ACK is not received. If there is more than one CRS, a fast feedback channel must be provided to each CRS.

The RMM-ARQ uses the ARQ mechanisms including ARQ feedback IE and ARQ parameters introduced in Section 6.3.4 except for the ones redefined or exluded in subsections 6.3.13.2.1 and 6.3.13.2.2.

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Include a new subsection 6.3.13.2.1 as indicated.

6.3.13.2.1 Transmitter state machine for RMM-ARQ

The RMM-ARQ transmitter state diagram in Figure XXX is very similar to the ARQ transmitter state diagram in Figure 33, with the difference that a packet must receive ACK from all critical RSs before transitioning to "Done" state. As long as there is/are ACK message(s) pending from at least one of the RSs, the block stays in the "Outstanding" state.

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There is no transmitter-initiated reset mechanism (i.e., as in Figure 34) for RMM-ARQ for the synchronization of transmitter and receiver windows. If the ARQ_TX_WINDOW_START is not updated for a certain period of time and the timer exceeds ARQ_SYNC_LOSS_TIMEOUT, the BS removes the lagging RS(s) from RMM-CRS mode and places them into RMM-NCRS mode. When no RS is in RMM-NCRS state, the transmitter state machine reduces to the one used in the DMM connections.

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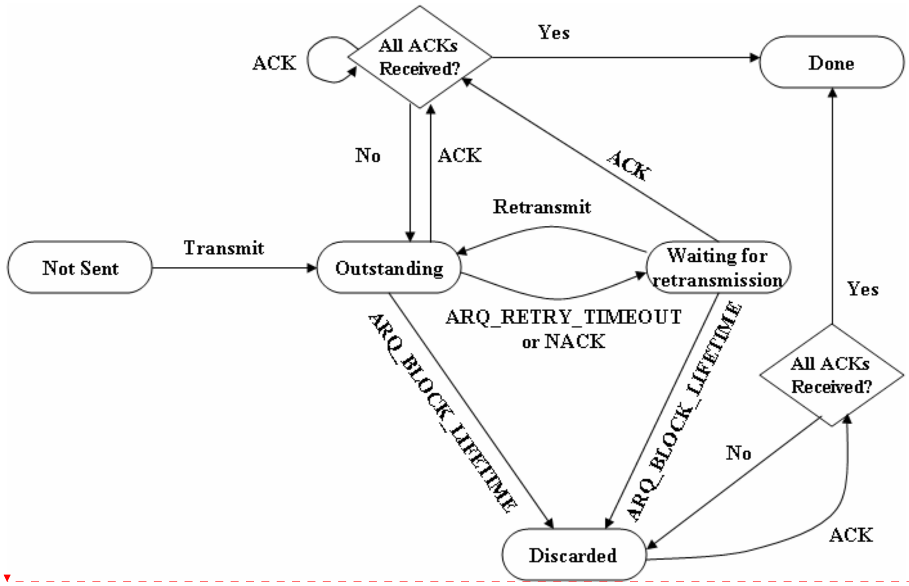

Figure XXX RMM-ARQ transmit block states

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Include a new subsection 6.3.13.2.2 as indicated.

6.3.13.2.2 Receiver state machine for RMM-ARQ

For RMM-CRSs, the RMM-ARQ receiver state diagram in Figure YYY is the same as the ARQ receiver state diagram in Figure 36. On the other hand, if a RS is RMM-NCRS, it is still required to keep track of the ARQ_RX_WINDOW_START so that it may easily switch to RMM-CRS mode if needed. Moreover, duplicate packets are detected and discarded.

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There is no receiver-initiated reset mechanism (i.e., as in Figure 35) for RMM-ARQ for the synchronization of transmitter and receiver windows. If the ARQ_RX_WINDOW_START is not updated for a certain period of time and the timer exceeds ARQ_SYNC_LOSS_TIMEOUT, the RS decides to switch from RMM-CRS mode to RMM-NCRS mode. RS should inform MMR-BS and receive confirmation from MMR-BS before completing the switching to RMM-NCRS mode.

Change the table in Section 11.7.8.1 as indicated.

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11.7.8.1 ARQ Support

Type	Length	Value	Scope
10	1	0: No ARQ of any kind is supported ~~support capability~~ 1: ARQ supported ~~2-255: *Reserved*~~ 2: RMM-ARQ supported 3-255: *Reserved*	REG-REQ REG-RSP

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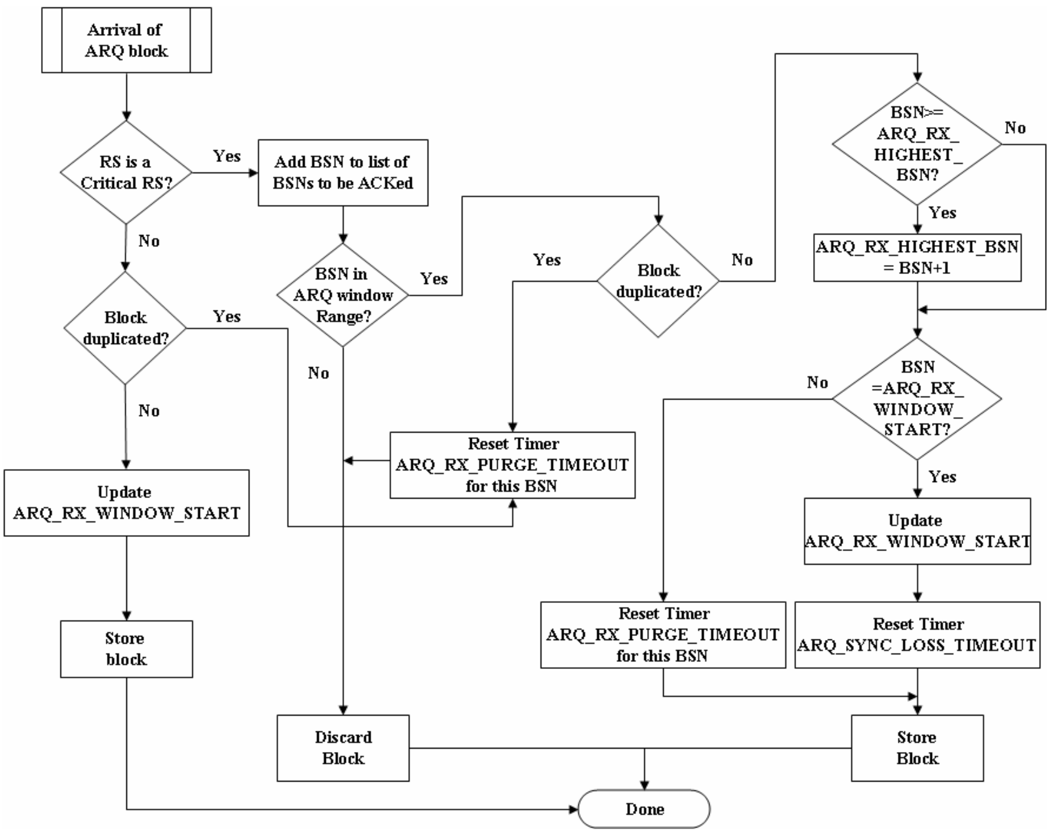

Figure YYY RMM-ARQ block reception

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Change first paragraph and the table in Section 11.13.18.1 as indicated.

11.13.18.1 ARQ Enable

This TLV indicates whether or not ARQ use is requested for the connection that is being setup. A value of 0 indicates that ARQ is not requested and a value of 1 indicates that ARQ is requested. A value of 2 indicates that the RMM-CRS mode is requested and a value of 3 indicates that RMM-NCRS mode is requested. The DSA-REQ shall contain the request to use ARQ or not as well as to use RMM-ARQ or not. The DSA-RSP message shall contain the acceptance or rejection of the request. ~~ARQ shall be enabled for this connection only if both sides report this TLV to be non-zero.~~ The SS/RS shall either reject the connection or accept the connection with ARQ or with RMM-ARQ.

Type	Length	Value	Scope
[145/146].18 1.18	1	0: ARQ Not Requested/Accepted 1: ARQ Requested/Accepted 2: RMM Critical RS Requested/Accepted 3: RMM Non-Critical RS Requested/Accepted 4-255: *Reserved*	DSA-REQ, DSA-RSP REG-REQ, REG-RSP

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