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Title	**Specifying an ARQ mechanism for 802.16.1 MAC layer**
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Re:	
Abstract	This documents provides further details on the MAC layer ARQ mechanism present in Document IEEE 802.16.1mc-00/15
Purpose	Provide details on the ARQ mechanism in Document IEEE 802.16.1mc-00/15
Notice	
Release	
Patent Policy and Procedures	

Specifying an ARQ mechanism for 802.16.1 MAC layer

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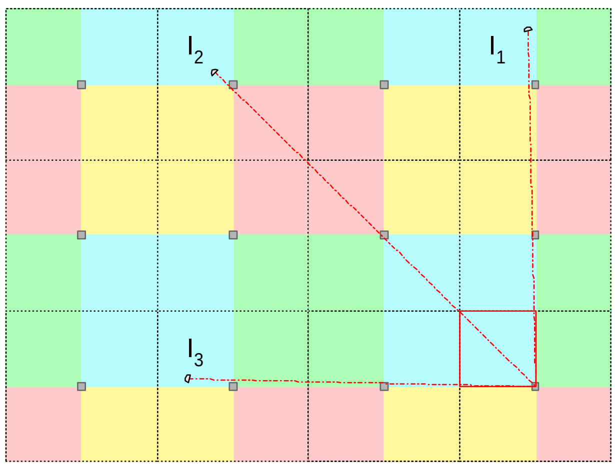
General

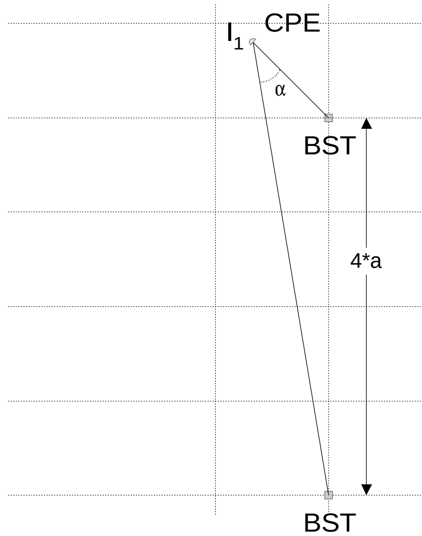
The ARQ mechanism is part of the low-level MAC. The ARQ is optional, and is only used for services and installations that may benefit from its use. Specifically, ARQ as an error correction method is especially effective in burst noise environments typical of the up-link direction in a cellular distribution networks.

Why is ARQ needed at all

To see why ARQ might be required at all, let us look at a popular frequency reuse scheme for LMDS deployment. Each color in the drawing below corresponds to a different frequency or polarization. Also drawn are possible interference sources to the up-link receiver from neighboring cells. Next, we will try to quantify the amount of interference.



We will use a geometric analysis to try to determine what is the percentage of CPE units that might cause interference to a neighboring cell. The drawing below shows what are the geometric relations a CPE unit in cell I_1 is required to fulfill in order to be considered a source of interference.



The triangle created by the interfering CPE, its BST, and the interfered BST a known angle. The angle α represents half the beam width of the CPE antenna. Known is also the distance between the BST units, that is four times the cell width, a. Using some geometric identities we can express the x-y coordinates of the interference boundary curve in parametric form (h is the parameter),

$$x = -4 \cdot a \cdot h \cdot \left(\sin\alpha \cdot \sqrt{1 - h^2 \cdot \sin^2\alpha} + h \cdot \sin\alpha \cdot \sqrt{1 - \sin^2\alpha} \right)$$

$$y = 4 \cdot a \cdot h \cdot \left(1 + h \cdot \left(\sqrt{1 - \sin^2\alpha} \cdot \sqrt{1 - h^2 \cdot \sin^2\alpha} - h \cdot \sin^2\alpha \right) \right)$$

Using these equations and setting $\alpha = 1^{O}$, gives an interference boundary curve that shows that about one percent of the CPE units in the cell might cause interference to an adjacent cell. The distance between the interfering CPE units and the BST, is equivalent to a C/I ratio of about 14dB. Taking into account the inaccuracies of power control loops, and the relatively weak error correction scheme used for the up-link, it appears that the interference limits the up-link modulation to QPSK. However, the fact is that interference only exists for a small percentage of the time. In such a scenario, usage of ARQ might increase the up-link throughput by allowing use of higher modulations, and correcting errors caused by interference.

Specifying usage of ARQ

Upon connection establishment, it is determined whether ARQ will be used, and the associated ARQ parameters are set. For those connections that use ARQ, ARQ is defined as part of the LL-MAA layer services.

ARQ operation – sender

The ARQ mechanism works by adding a sequence number to each packet, and placing it in a retransmission queue. Packets are then selected from the queue and sent over the air. Each packet should be acknowledged by the receiver as soon as it is received. Packets that were not acknowledged within a predefined time are assumed lost and are resent. The number of times a specific packet may be resent is one of the ARQ parameters, and can be limited in order to guarantee a maximum transmission delay. Packets to transmit are selected from the retransmission queue based on a window algorithm.

The ARQ service in the sending party performs the following list of functions

Identify packets belonging to ARQ-enabled connections.

Add to each ARQ-enabled packet an ARQ header containing a x-bit sequence number.

Place the packet in the retransmission queue of its connection.
Select packet(s) from the retransmission queue for transmission.
Maintain the retransmission queue by eliminating packets that were acknowledged, or passed their maximum allowed retransmissions limit

ARQ operation – receiver

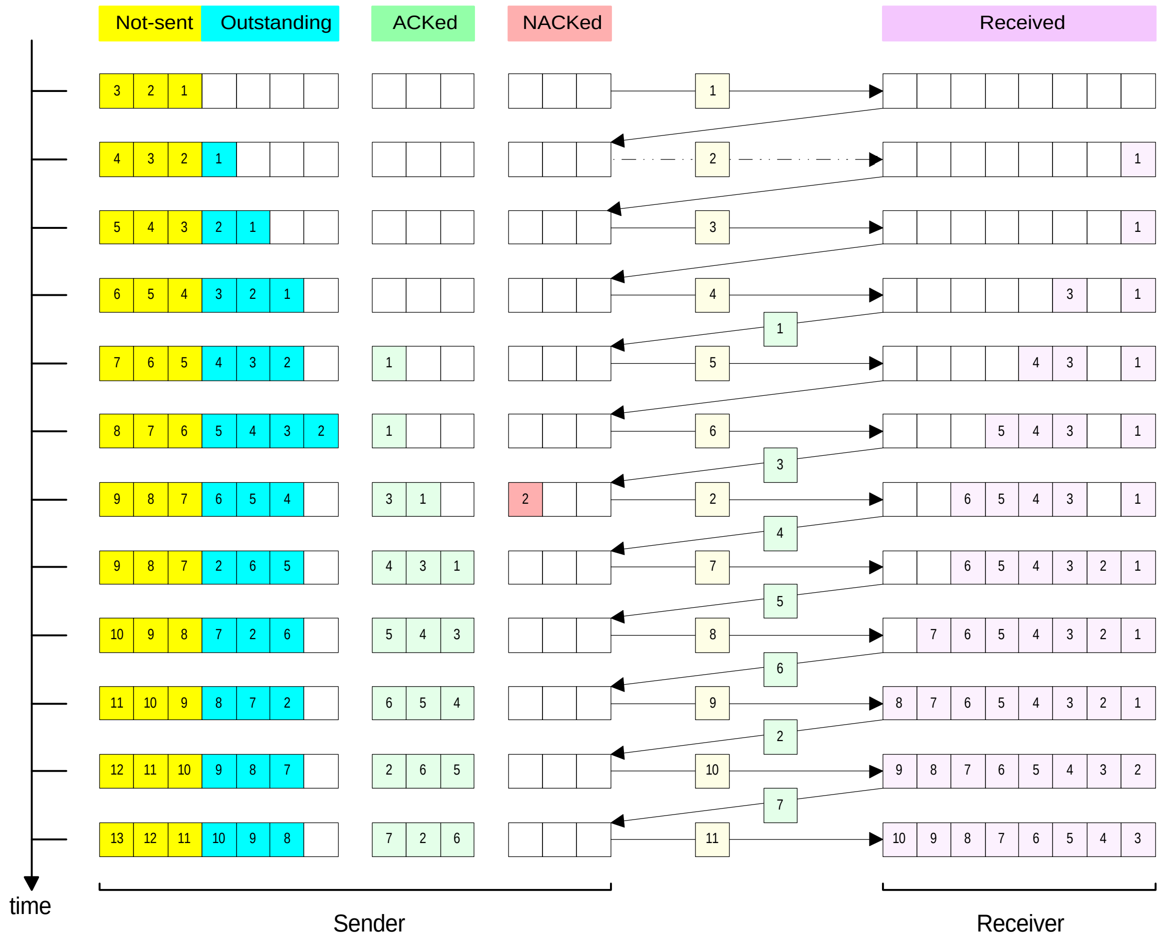
The ARQ mechanism in the receiver examines each incoming packet belonging to ARQ-enabled connections. The packet integrity is determined from the integrity of the TC data units from which it is extracted. The integrity of each TC data unit is verified by comparing its CRC16 field to its actual CRC. An acknowledgment message is sent to the sender for packets received correctly. The acknowledgment message may group together more than one packet, and carries the sequence number(s) for packets that have been correctly received. The receiver should expect duplicate packets to arrive (due to loss of an ACK message for instance), and discard these duplicates.
The ARQ service in the receiving party performs the following list of functions:
Identify packets belonging to ARQ-enabled connections.
Check packet integrity based on CRC value.
Place packet received correctly and in sequence, in the receive queue.
Send acknowledgement messages for correctly received packets.
Maintain the receive queue by handing to the upper layers packets that where either correctly received, or timed out.

ARQ operation – window algorithm

The window algorithm enables the sending party at each transmission opportunity, to determine whether it should attempt to send a new packet or re-send an already sent one. The basic parameter of this algorithm is the window width, which measures the amount of time since a certain packet is sent until is acknowledged by the receiving party. This time includes all processing delays of both PHY and MAC at both the transmitter and the receiver. The window algorithm divides the packets at the sender to four types, not-sent, outstanding, acknowledged and not-acknowledged. Any packet begins as not-sent. When it is sent it becomes outstanding for a window duration, after which it either is acknowledged, or becomes not-acknowledged. The window algorithm defines the following policy that if any not-acknowledged packets exist, they should be transmitted at the next transmission opportunity, otherwise a not-sent packet should be sent. Note that the window duration is a system parameter set by the existing processing delays, and not a parameter set per ARQ-enabled connection.

ARQ operation – dynamic behavior example

The drawing below shows the start of a transaction of several packets for an ARQ-enabled connection. For simplicity, the packets are shown as they appear to the LL-MAA layer. The transmission convergence and the PHY layers beneath it are not shown.

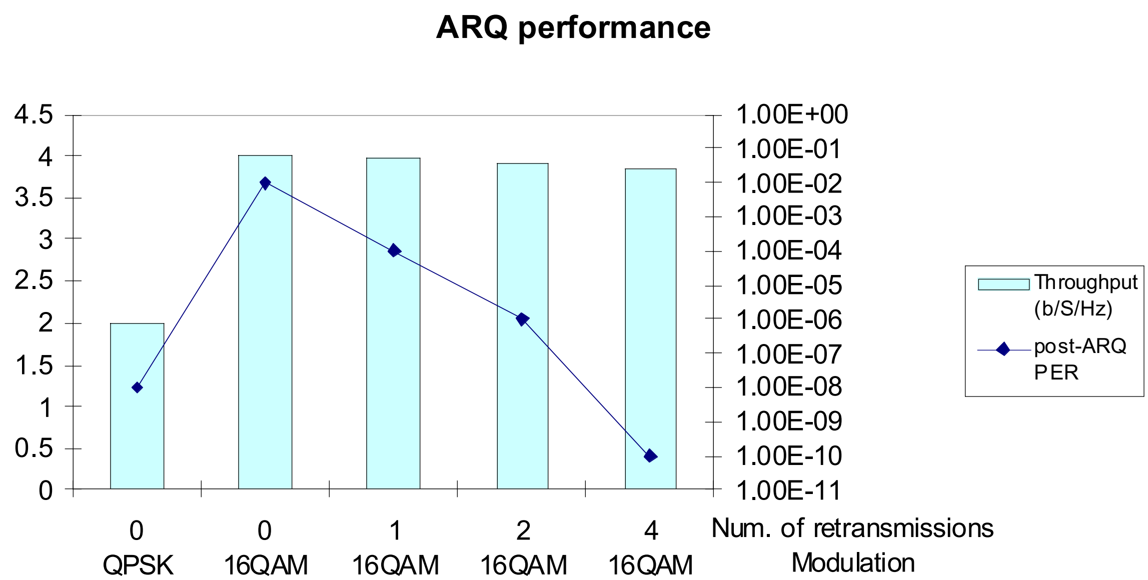


ARQ in a point-to-multipoint system

The ARQ algorithm presented so far has assumed a point-to-point connection between the sender and the receiver. In reality, we are dealing with a point-to-multipoint system, and therefore the upstream direction and downstream directions behave differently. In the upstream direction, ARQ is easier to implement, as the feedback path (that is the return channel carrying ACK messages) is fully controlled by the receiver (the base station in this case). In the downstream direction, implementing ARQ requires allocation of time slots for the feedback path, which is not controlled by the receiver (the CPE in this case). Given this fact, and the expectation that the noise and interference in the downstream direction will be less bursty, ARQ is proposed only for the upstream direction.

Expected ARQ performance

To give an idea about the throughput impact of ARQ, the graph below shows the throughput vs. packet error rate (PER). The graph is based on an initial PER of 0.01 (roughly the percent of interfering CPE units from all interfering cells). The graph and compares different limits on the number of times a packet retransmitted. 16QAM modulation is assumed for the cases where ARQ is used.


ARQ performance
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
0 QPSK
0 16QAM
1 16QAM
2 16QAM
4 16QAM
Num. of retransmissions
Modulation
Throughput (b/S/Hz)
post-ARQ PER