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Re:	Invitation to join TG3/4 MAC Ad Hoc Group on ARQ, July 26, 2001.
Abstract	This document defines a MAC-level ARQ scheme for 802.16ab, along with the underlying ARQ subheaders and ARQ parameters. It also specifies the transmission and reception procedures for ARQ-enabled connections. It draws upon the ARQ material described in IEEE 802.16ab-01/01.
Purpose	For consideration by the 802.16 TG3/4 ARQ Ad Hoc Group as the draft text replacing the text on ARQ in 802.16ab-01/01, June 2001.
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ARQ For Centralized Channel Access

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Introduction

The ARQ scheme defined here shall employ selective repeat, enabling the transmitting MAC to retransmit those MAC data whose previous transmissions have failed. It organizes MAC data into fixed-size ARQ blocks, with such blocks serving as the building blocks of MAC SDUs (MSDU) or MSDU fragments. The transmitting MAC identifies ARQ blocks by including sequential block numbers in the ARQ blocks transmitted, so that the receiving MAC can determine, and acknowledge, the reception status of the ARQ blocks received or anticipated. The receiving MAC piggybacks the acknowledgment into other data going to the transmitting station, or sends the acknowledgment alone back to the transmitting station.

A separate block number is further introduced to identify ARQ blocks comprising fragments of a given MSDU. This number is local to the ARQ blocks within the MSDU, while the other number is global to the ARQ blocks across MSDUs. Fragments are constructed out of adjacent ARQ blocks, and may be of different sizes. A fragment needs to include expressly only the local number and the global number of the first ARQ block in it for an unambiguous identification of all the ARQ blocks in it. For ARQ purposes, the FC and FSN fields defined as part of a subheader on a per fragment basis in P802.16/D4 are, with a modification in their lengths and names, suitable for containing these two numbers, dispensing with the need for creating additional numbering fields within each fragment. Such ARQ numbering subfields will be introduced as part of new ARQ related subheaders below.

In addition to the definition of ARQ blocks, other ARQ related parameters are also defined for the correct operation at the transmitter and receiver when ARQ is enabled. A sliding window is needed on account of both transmit and receive buffer limits. An acknowledgment timeout is used in activating a retransmission of an unacknowledged frame. An ARQ lifetime is set to prevent the transmitter from having endless retransmissions of an ARQ block for which an acknowledgment is never to be returned by the receiver for some reasons, and thus from blocking the transmission of other buffered ARQ blocks; and to prevent the receiver from sending endless negative acknowledgments for an ARQ block that has been discarded by the transmitter, and thus from excessively delaying the delivery of received ARQ blocks to the higher layer.

The transmit and receive procedures based on the above ARQ parameters are also specified.

ARQ Types and Subheaders

The local and global numbers identifying the ARQ blocks of a fragment shall be contained in the ALN and AGN fields of the new ARQ related subheaders as defined in Tables ARQ.1 and ARQ.2. These new subheaders are coded with some of the types reserved in Tables 4 and 5 of P802.16/D4, where the FC and FSN fields are the counterparts of the ALN and AGN fields. The type is identified by the type field in the generic MAC header. MAC PDUs (MPDUs) belonging to one of these new types shall contain a CRC field.

An MPDU of type 0x0A or 0x0B shall contain one or more ARQ acknowledgment subheaders but not other subheaders nor MAC payload. All other MPDUs, which contain one or more MSDUs (or fragments thereof), shall include at most one ARQ acknowledgment subheader. This is to reduce the impact of the loss of multiple ARQ acknowledgment subheaders, since longer MPDUs are more likely to encounter transmission errors and hence to result in the loss of the ARQ acknowledgment subheaders they contain. Such a loss would result in the retransmission or drop of a large amount of traffic. An MPDU may contain different subheaders and associated payloads (if appropriate), in the combinations and orders defined in Table ARQ.1.

Table ARQ.1 - ARQ Related Type Encoding

Type	Description
0x06	ARQ packing subheaders present
0x07	Grant management subheader and ARQ packing subheaders present (uplink only)
0x08	ARQ fragmentation subheader present
0x09	Grant management subheader and ARQ fragmentation subheader present (uplink only)
0x0A	ARQ acknowledgment subheader(s) present
0x0B	Grant management subheader and ARQ acknowledgment subheader(s) present (uplink only)
0x0C	ARQ acknowledgment subheader and ARQ packing subheaders present
0x0D	Grant management subheader, ARQ acknowledgment subheader, and ARQ packing subheaders present (uplink only)
0x0E	ARQ acknowledgment subheader and ARQ fragmentation subheader present
0x0F	Grant management subheader, ARQ acknowledgment subheader, and ARQ fragmentation subheader present (uplink only)

The encoding of these ARQ related subheaders are given in Tables ARQ.2-ARQ.7.

Table ARQ.2 - ARQ Fragmentation Sub-Header Format

Syntax	Size	Notes
ARQ fragmentation sub-header () {		
FSF	1 bit	FSF: Final or Sole Fragment
ALN	3 bits	ALN: ARQ Local Number
AGN	12 bits	AGN: ARQ Global Number
}		

Table ARQ.3 - ARQ Fragmentation Sub-Header Fields

Name	Length	Description
FSF	1 bit	Final or Sole Fragment Indicates the fragmentation state of the MSDU: 1 = final or sole fragment of the MSDU 0 = neither final nor sole fragment of the MSDU
ALN	3 bits	ARQ Local Number Indicates the local number (LN) of the first ARQ block in this fragment (or MSDU if not fragmented). The LN of a given ARQ block is the number of ARQ blocks preceding that ARQ block within the MSDU containing that ARQ block.
AGN	12 bits	ARQ Global Number Indicates the global number (GN) of the first ARQ block in this fragment (or MSDU if not fragmented). The GN of a given ARQ block is the number of ARQ blocks preceding that ARQ block over the same CID, subject to the wraparound at the maximum value of the field (4095).

Figure ARQ.1 illustrates the relationships between ARQ blocks, MSDU fragments, and MSDUs. If an MSDU is smaller than an ARQ block in size, it is counted as an ARQ block and referred to as a partial ARQ block. Otherwise, it is partitioned into multiple ARQ blocks for numbering purposes, where only the final ARQ block may be a partial ARQ block (which is also counted as an ARQ block).

An MSDU, or a fragment thereof, if transmitted as an MPDU and requiring acknowledgment, shall contain an ARQ fragmentation header following the generic MAC header, with the ALN and AGN values equal to the LN and GN values of the first ARQ block of the MPDU (shown in bold print in Figure ARQ.1). Fragmentation of an MSDU, or a fragment thereof, shall occur along ARQ block boundaries. With an ARQ fragmentation header, a new fragment may be constructed from ARQ blocks of consecutive GN values belonging in the same MSDU; some of those ARQ blocks may have never been transmitted while others may have been transmitted as part of one or more previous fragments but require retransmission. During this refragmentation process the LN and GN values of a given ARQ block shall remain unchanged, while the ALN and AGN values adjust with the first ARQ block in the new fragment. The fragments may be of different sizes, but, except the very last one of the MSDU, shall have an integer number of full ARQ blocks. All other subheaders (i.e., Grant management subheader and/or ARQ acknowledgment subheader) precede the ARQ fragmentation subheader when collocated in the same MPDU.

A received fragment with the FSF bit set to 1 indicates the end of the current MSDU. Whether or not such a frame is received, the receipt of a fragment with an ALN value equal to or smaller than the ALN value contained in the last received fragment signals the arrival of a new MSDU. A received fragment with an ALN value larger than the ALN value contained in the last received fragment belongs to the same MSDU if the difference between the two ALN values is the same as the difference (modulo 4096) between the two corresponding AGN values, and to another MSDU otherwise. This rule may be used in determining the fragmentation status of received MAC frames, in cases where intervening fragments are lost. In Figure ARQ.1, the fragment with ALN=2 and AGN=6 is determined to belong in the same MSDU as the fragment with ALN=0 and AGN=4, even if the fragment with ALN=1 and AGN=5 is not received. On the other hand, the fragment with ALN=1 and AGN=9 is seen to belong in a different MSDU than the fragment with ALN=0 and AGN=7, even if the fragment with ALN=0 and AGN=8 is not received.

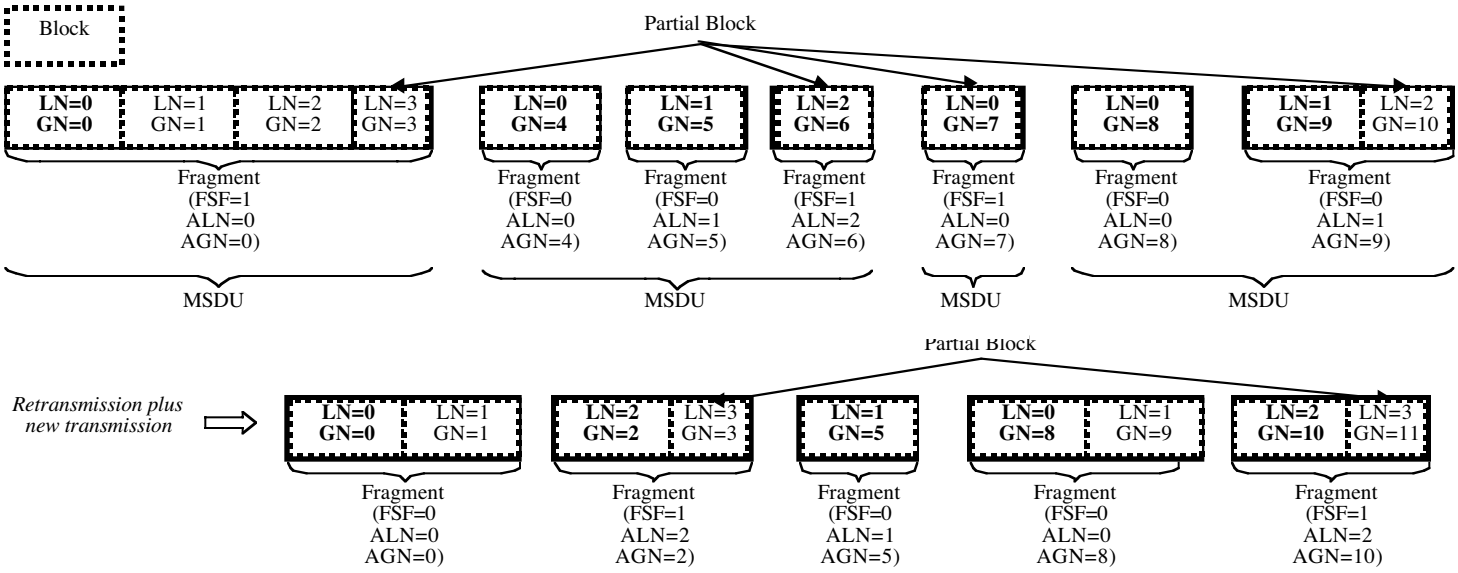

Figure ARQ.1 — Blocks, fragments, MSDUs, and ARQ fragmentation headers

If the type 0x04 Fragmentation subheader as defined in Tables 4 and 5 of P802.16/D4 were used, the loss of two consecutive fragments as illustrated below would result in the following ambiguity, thus preventing the receiver from correctly determining whether another MSDU has already started and hence from correctly assembling the received fragments or timely passing them up to the higher layer.

Fragment (FC=10 or 11) Fragment (lost) Fragment (lost) Fragment (FC=11)

The two lost fragments may have FC=11 and FC=11, in which case the current MSDU is not completed yet, or FC=01 and FC=10, in which case another MSDU has already started.

Table ARQ.4 - ARQ Packing Sub-Header Format

Syntax	Size	Notes
ARQ packing sub-header () {		
FSF	1 bit	FSF: Final or Sole Fragment
ALN	3 bits	ALN: ARQ Local Number
AGN	12 bits	AGN: ARQ Global Number
Reserved	4 bits	
PFL	12 bits	
}		

Table ARQ.5 - ARQ Packing Sub-Header Fields

Name	Length	Description
FSF	1 bit	Final or Sole Fragment Indicates the fragmentation state of the MSDU: 1 = final or sole fragment of the MSDU 0 = neither final nor sole fragment of the MSDU
ALN	3 bits	ARQ Local Number Indicates the local number (LN) of the first ARQ block in this packed fragment (or MSDU if not fragmented). The LN of a given ARQ block is the number of ARQ blocks preceding that ARQ block within the MSDU containing that ARQ block.
AGN	12 bits	ARQ Global Number Indicates the global number (GN) of the first ARQ block in this packed fragment (or MSDU if not fragmented). The GN of a given ARQ block is the number of ARQ blocks preceding that ARQ block over the same CID, subject to the wraparound at the maximum value of the field (4095).
PFL	12 bits	Packed Fragment Length Indicates the length, in bytes, of the packed MSDU or MSDU fragment, including the four-byte packing subheader.

ARQ packing subheaders further expand the framing functionality of ARQ fragmentation subheaders to allow for the transmission as a single MPDU of ARQ blocks that are not of consecutive GN values or not part of the same MSDU, but are associated with the same CID. Frames constructed using ARQ fragmentation subheaders only as shown at the bottom of Figure ARQ.1 may be reorganized with the use of ARQ packing subheaders as shown in Figure ARQ.2, where a double dashed line denotes presence of an ARQ packing subheader. All other subheaders (i.e., Grant management subheader and/or ARQ acknowledgment subheader) precede the first ARQ packing subheader when collocated in the same MPDU.

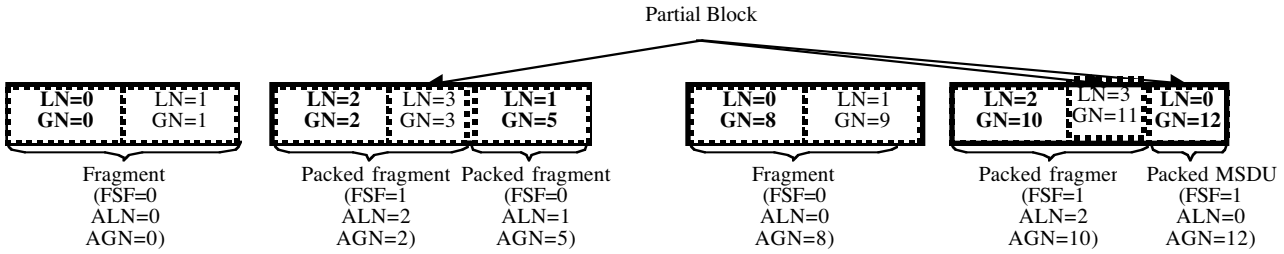

Figure ARQ.2 — MPDUs with ARQ packing headers

Table ARQ.6 - ARQ Acknowledgment Sub-Header Format

Syntax	Size	Notes
ARQ acknowledgment sub-header () {		
CID	16 bits	CID: Connection ID
SHL	4 bits	SHL: Subheader Length
GN	12 bits	GN: Global Number
if (SHL > 2) {		
for (*i* = 3; *i* < SHL; *i*++) {		
AG	1 bit	AG: Another GN
if (AG == 1) {		
GN	12 bits	
BM	3 bits	BM: Bit Map
}		
Else {		
BM	15 bits	
}		
}		
}		
}		

Table ARQ.7 — ARQ Acknowledgment Sub-Header Fields

Name	Length	Description
CID	16 bits	Indicates the CID for which the ARQ acknowledgment is generated.
SHL	4 bits	Indicates the length, in units of 16 bytes, of this sub-header, with a minimum value of 2.
GN	12 bits	Indicates the GN of a received ARQ block.
AG	1 bit	Indicates if the remaining 15 bits of this two-byte subfield specifies another GN plus a 3-bit bit map or contains a 15-bit bit map based on the preceding GN.
BM	3 or 15 bits	Indicates the bit map of the reception status of the ARQ blocks sequentially following the ARQ block identified by the preceding GN or BM , with a 0 value for an unsuccessful reception and a 1 value for a successful reception of the corresponding ARQ block.

All GNs indicated in a given ARQ acknowledgment subheader, either explicitly by the GN fields or implicitly by the BM fields, shall refer to the ARQ blocks sent over the same CID as also indicated in that subheader. Different ARQ acknowledgment subheaders may contain different CIDs, even when they are allowed to appear in the same MPDU.

Figure ARQ.3 show two example ARQ acknowledgment subheaders. The first subheader furnishes a positive acknowledgment to an ARQ block identified by the sole GN field therein. The second subheader provides 1) a positive acknowledgment to an ARQ block identified by the first GN field, and a positive or negative acknowledgment to the following 15 ARQ blocks of consecutive GN values via the first BM field; 2) a positive acknowledgment to an ARQ block identified by the second GN field, and a positive or negative acknowledgment to the following three ARQ blocks of consecutive GN values via the second BM field; 3) a positive acknowledgment to an ARQ block identified by the third GN field, and a positive or negative acknowledgment to the following 18 ARQ blocks of consecutive GN values via the third and fourth BM fields; 4) a positive acknowledgment to an ARQ block identified by the fourth GN field, and a positive or negative acknowledgment to the following three ARQ blocks of consecutive GN values via the fifth BM field.

CID (16 bits)	
SDL = 2 (4 bits)	GN (12 bits)

CID (bits)		
SDL = 7 (4 bits)	GN (12 bits)	
AG = 0	BM (15 bits)	
AG = 1	GN (12 bits)	BM (3 bits)
AG = 1	GN (12 bits)	BM (3 bits)
AG = 0	BM (15 bits)	
AG = 1	GN (12 bits)	BM (3 bits)

Figure ARQ.3 — Example ARQ acknowledgment subheaders

ARQ Parameters

The ARQ parameters are ARQ_Blocksize, ARQ_Window, ARQ_Timeout, and ARQ_Lifetime. These parameters assume on some default values, but may be redefined on a per CID basis at the time the connection identified by that CID is created or changed.

ARQ_Blocksize specifies the size of an ARQ block. It shall not be smaller than the quotient, rounded up to the next higher integer if not an integer, of the maximum MSDU size in bytes divided by eight. An MSDU, or its final ARQ block, may be smaller than ARQ_Blocksize, but is counted as an ARQ block for numbering purposes.

ARQ_Window specifies the maximum number of ARQ blocks a transmitter may transmit over the CID to which this parameter applies, counting consecutively from the ARQ block of the smallest GN value not yet positively acknowledged and circularly around 4095. It shall not be smaller than one nor larger than 4096. For instance, for an ARQ_Window of 5 ARQ blocks, if ARQ block 4094 (i.e., GN=4094) is the ARQ block for which a positive acknowledgment has not yet been received, but all the ARQ blocks of smaller GN values have been acknowledged positively, then only ARQ blocks 4095, 0, 1, and 2 may be transmitted prior to the reception of a positive acknowledgment for ARQ block 4094, even after the later four ARQ blocks have been transmitted and positively acknowledged, unless ARQ block 4094 has reached its ARQ lifetime as defined below.

ARQ_Timeout specifies the minimum time interval a transmitter shall wait before retransmitting an unacknowledged ARQ block since the last transmission of that ARQ. For instance, for an ARQ_Timeout of 10 ms, a retransmission of an ARQ block for which no acknowledgment has been received shall not take place within 10 ms of the previous transmission of that ARQ block.

ARQ_Lifetime specifies the maximum time interval beyond which a transmitter shall discard an ARQ block not yet positively acknowledged, measuring from the first transmission of that ARQ block. It is also used as the maximum time interval a receiver shall wait for other missing ARQ blocks before passing up a received ARQ block to the higher layer since the reception of that block. The value of ARQ_Lifetime shall not be smaller than the value of ARQ_Timeout. For instance, for an ARQ_Lifetime of 20 ms, an ARQ block shall be discarded if no positive acknowledgment has been received within 20 ms of its first transmission; an ARQ block shall be passed up to the higher layer within 20 ms of its reception, even if some ARQ blocks of smaller GN values have not been received. With this parameter, a transmitter avoids an endless retransmission of an ARQ block for which the receiver is not to return an acknowledgment for some reasons, so that the transmitter can proceed to transmit other buffered ARQ blocks; the receiver also avoids sending endless negative acknowledgments for an ARQ block which the transmitter has already discarded due to some other timeout mechanisms, and thus avoids excessively delaying the delivery of received ARQ blocks to the higher layer.

ARQ Procedures

1. Transmitter

A station may transmit ARQ blocks whose GN values fall within the sliding windows pertaining to the corresponding CIDs over which the ARQ blocks are to be sent. The sliding window for a given CID spans consecutive GN values starting at GN1 and ending at GN2, where GN1 is the smallest GN value (circular around 4095) of the ARQ blocks sent over that CID but not yet positively acknowledged, and GN2 = GN1 + ARQ_Window – 1, with the ARQ_Window relating to that CID. Whenever the ARQ block corresponding to the starting value of the sliding window is acknowledged positively, the sliding window is advanced (in a circular fashion around 4095) such that its starting value equals the next higher GN value, within the current sliding window, of ARQ blocks not yet positively acknowledged. An ARQ block is acknowledged positively when the transmitting station receives a positive acknowledgment for that ARQ block. An ARQ block is not acknowledged so long as the transmitting station has not received an acknowledgment for it, which may or may not have been sent by the receiving station. However, for the purpose of advancing the sliding window, an ARQ block is considered to have been acknowledged positively when it reaches its ARQ lifetime, i.e., when a time interval of ARQ_Lifetime defined for the connection of that ARQ block has elapsed sine the first transmission of that ARQ block, even if the transmitter has not received a positive acknowledgment for it.

A station may retransmit an ARQ block after receiving a negative acknowledgment for that ARQ block, or after waiting for ARQ_Timeout defined for the connection of that ARQ block since the last transmission of that ARQ block if no acknowledgment is received yet for that ARQ block. A station may retransmit an ARQ block, even prior to receipt of an acknowledgment for the ARQ block, if the station is not being allowed to transmit new ARQ blocks due to the ARQ_Window constraints.

A station shall discard an ARQ block not yet positively acknowledged no later than the ARQ block reaches its ARQ lifetime. A station shall ignore any positive or negative acknowledgment for an ARQ block that has been discarded.

2. Receiver

A station shall pass up a received MSDU for a given connection to the higher layer after all the same-connection ARQ blocks of GN values smaller than or equal to (circular around 4095) the largest GN value of the ARQ blocks comprising that MSDU have been received, but no later than ARQ_Lifetime from the reception of the earliest arrived ARQ block of that MSDU, even if some of the same-connection ARQ blocks whose GN values are smaller than the largest GN value implied in that MSDU have not been received. A station shall discard received ARQ blocks of GN values smaller than the GN value of the last ARQ block passed up for the same CID to the higher layer.

A station shall not acknowledge, positively or negatively, ARQ blocks with GN values at least ARQ_Window smaller than (circular around 4095) the largest GN value of the ARQ blocks received. Such not-to-acknowledge ARQ blocks are considered to have been received for the purpose of passing up ARQ blocks of higher GN values.

A station shall include only such ARQ acknowledgment subheaders in an MPDU that the CIDs contained in those subheaders refer to connections opposite to the connection identified by the CID contained in the generic MAC header of that MPDU. Subject to this constraint, a station shall include no more than one ARQ acknowledgment subheader in an MPDU containing one or more MSDU fragments. A station may include multiple ARQ acknowledgment subheaders with identical or different CIDs in a single MPDU not containing any MSDU or MSDU fragment. A station should attempt to transmit pending ARQ acknowledgment subheaders prior to, or in concurrence with, the MAC payload transmission.