Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Data Integrity in 802.16.4 MAC**
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Re:	This document contains change request needed to include full data integrity functionality into the 802.16 baseline MAC. It is submitted in response to IEEE 802.16.4-00/01 **Call for Contributions for Modifications of 802.16 MAC and 802.11a - HIPERLAN/2 PHY for the WirelessHUMAN Standard** "
Abstract	The following issues considered: – Fragmentation /Reassembling – ARQ – Concatenation
Purpose	To figure data integrity functionality to be added to the 802.16 baseline MAC to serve needs of TG4 MAC
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Data Integrity in 802.16.4 MAC

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[2] IEEE 802.16.1-00/01r4, September 2000. Air Interface for Fixed Broadband Wireless Access Systems
[3] IEEE 802.16.3-00/02r4. Functional Requirements for the 802.16.3 Interoperability Standard
[4] IEEE 802.16.1mc-00/19 Specifying an ARQ mechanism for 802.16.1 MAC layer. By Yigal Leiba
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Glossary

ARQ	Automatic Repeat Request
CS PDU	Convergence Sublayer PDU
DL	Downlink
FC	Frame Control (field in MAC header [2])
FSN	Fragment Sequence Number
MPDU	MAC PDU
MSDU	MAC Service Data Unit , i.e. CS PDU
MSN	MAC PDU Serial Number
PDU	Protocol Data Unit
QoS	Quality of Service
UL	Uplink

Foreword

Subject of this Document

This document contains topics proposed to be included into the 802.16 MAC to reflect the Data Integrity functions of the 802.16 compliant systems.

All the topics except the Foreword are suggested for insertion into [2] under the heading **6.2.6. Data Integrity** , so that Scope and Modes of Data Integrity Support becomes 6.2.6.1 etc. The authors comments that should be eliminated by the editor are marked by <<< >>>.

Motivation

802.16.4 (WirelessHUMAN) applications will operate in unlicensed frequency bands thus suffering from the interference caused by non-802.16.4 compliant devices and possibly 802.16.4 compliant devices that belong to another wireless operators. So there is always a potential for transmission loss. It is common practice for such applications to fix the problem using MAC level tools for the data integrity support. This issue naturally includes several sub-issues: Fragmentation /Reassembling, ARQ and Concatenation functions.

This proposal is equivalent to the one submitted to 802.16.3 MAC Group thus allowing to join efforts in integration of this important function into the 802.16 MAC.

ARQ

The need for ARQ mechanism in 802.16 MAC has been pointed by several authors ([1], [3] —[5]). The proposal [4] specifies details of ARQ mechanism but does not concern fragmentation. Proposal [5] is very detailed but lacks several important features: selective retransmissions (that are obligatory in wireless environment), the details of discard of higher layer PDUs, the support of 802.16.1 fragmentation (see MAC headers structures in [2]). In addition, ARQ implementation proposed by [5] requires changes in request/grant mechanism and serious changes in the format of MAC headers.

This proposal, following some ideas presented in [1]-[5], adds new ideas to go along with the following requirements:

1. ARQ should be implemented at MAC layer
2. Full scale ARQ, both DL and UL should be employed
3. The ARQ process context should be limited to a connection context
4. There should be a possibility to enable/disable ARQ function for each connection separately
5. The tools used by the ARQ mechanism (like change in frame formats) have to add zero or negligible overhead to the connections with ARQ disabled
6. Selective retransmissions should be employed
7. Possibility for piggybacking the ACK Information on the data transmissions should be employed
8. Discard algorithm should operate at the level of CL PDUs
9. Algorithm should provide group ACKs

In addition to these requirements to ARQ algorithm, there are some requirements coming from the minimizing the time of the standard development:

1. The ARQ mechanism should be implementable with no or minor changes in the message formats defined in [2] to avoid massive changes in that document
2. The ARQ mechanism should be simple enough to provide simple procedure of the consistency verification

Concatenation

Concatenation is described according to [5] with minor changes.

Integration into the Baseline

This is how this proposal is assumed to be integrated into the [2] baseline.
The additions to the frame formats should enter into the normative part of the standard while the algorithms should be placed in the informative part.

Some TBD changes may be needed in the following functions:

- Reservation/Grant Functionality
- QoS Support

This proposal does not require changes in the MAC message format as it described in [2]. But such changes may be recommended to improve MAC extendibility and provide better MAC characteristics. They will be addressed in the separated submission.

1. Scope and Modes of the Data Integrity Support

The following functions are assumed to be a part of the Data Integrity functionality.

- Fragmentation / Assembling
- Concatenation
- Integrity check
- ARQ (Retransmissions)

The context of the Data Integrity function is a single connection. In particular, all the types of serial numbers and fragmentation control fields are handled per connection.

The following options of Data Integrity modes SHOULD be supported. It means that any specific connection may be configured to conform one of the following combinations

Options	Fragmentation / Reassembly	Concatenation	Integrity check	ARQ
1	X			
2	X	X		
3	X		X	
4	X	X	X	
5	X	X	X	X

2. Identification of MSDUs

MAC assigns to each MSDU received from the Convergence Layer a serial number (MPDU Serial Number = MSN) in the interval from 0 to 2^{12}-1. It is an assumption (not specified in the standard) that the transmitter somehow cares on the non-ambiguity of the serial numbers, for example, by limiting the number of outstanding transmissions.

Once assigned to the MSDU, serial number never changes.

The serial number should be indicated within the same MAC message as the MSDU fragment to support reassembling of the MSDU at the receiver side and optionally the retransmission of lost fragments.

3. Fragmentation / Assembling Functions

3.1. Fragmentation

This is similar to the fragmentation defined in [2]

The MSDU might be fragmented by the transmitter for the following reasons

- Lack of the frame time when allocating the air time to the given MSDU
- High BER that requires employing integrity check for smaller data blocks

A MSDU might be transformed to a single MAC payload (MPDU) thus staying non-fragmented.

Once applied, the fragmentation of the given MSDU never changed except the cases explicitly specified in the standard. The standard does not preclude from interleaving of the operation of fragmentation and sending the fragments (of the same MSDU). The number of fragments SHOULD not be more than 16.

When created, the MAC payload (MPDU) should be assigned by

- Fragment Serial Number (FSN) with possible value 0 to 15
- Fragment Control code (FC) with the following meaning:
  - 00 = non-fragmented MPDU
  - 01 = last fragment
  - 10 = first fragment
  - 11 = continuing (middle) fragment

The FSN is assigned to the fragment at the moment of the fragment creation. The possible FSN values are 0 to 15. The FSN is always transmitted within the same MAC message as the fragment data.

3.2. Reassembling

At the receiving side the fragments are assembled back into the MSDU, according to MSN, FSN, FC values.

4. Concatenation Function

Several small MSDUs addressed to the same CID may be concatenated to form a single MPDU with the purpose to decrease the MAC overhead. Only the MSDUs with the consequent MSN numbers are allowed.

The following picture figures the structure of the payload of such an MPDU that we shall call an *aggregate*. The MPDU has to have the Base MPDU Serial Number = BMSN encoded the same way as for the regular MPDU <<<depends>>>

MSDU Delimiter #1	MSDU #1	MSDU Delimiter #2	..	MSDU Delimiter #N	MSDU #N
2 bytes	Variable	2 bytes		2 bytes	Variable

The following is the structure of the MSDU Delimiter:

MSN Offset	MSDU Size
4 msb	12

where MSN offset is used to figure the MSN for the given MSDU: MSN = BMSN + MSN Offset. The MSDU Size is figured in bytes.

At the receiving side, the MPDU of the above structure should be decomposed into separated MSDUs.

In the case when ARQ is enabled for the given connection, MSDUs ones transmitted within an aggregate, might be retransmitted in a separated MPDU or even fragmented and retransmitted as a set of MAC payloads.

5. ARQ

5.1. Units to be Controlled / Retransmitted

These units are the *Fragments* (of MSDUs), as a particular case, these may be complete MSDUs. Such a unit is identified by the pair **{MSDU Number, FSN}**. For a non-fragmented MSDU always FSN = 0. Each unit when transmitted should be protected by CRC field. In the case of concatenated MSDUs one CRC field protects several MSDUs.

5.2. Integrity Check

The Integrity Check is performed at the level of MAC payload by using CRC-32 according to [2]. For the connections with ARQ enabled all the MAC message have to have CRC enabled.

5.3. ARQ Feedback Format

The ARQ feedback fields (AFB) are used for encoding the results of integrity check performed on the MPDUs. MAC payloads. These fields are to be inserted into the MAC messages transferred in the direction opposite to the direction of the connection. Exact location of these fields in the MAC message is described in 6.2.1 <<< references to the D1-2000 document >>>. The ARQ feedback is transferred using one or several AFB fields of the following possible formats:

Table 1. AFB Short Format

Subfield	Last	Mode
Size, bits	1 msb	3

Table 2. AFB Long Format

Subfield	Last	Mode	SerNo	Mask
Size, bits	1 msb	3	12	16 (absent if N/A)

Last = 1 marks the last AFB in the MAC Message
Mode defines the meaning of another subfields:

Mode value	Meaning	SerNo	Mask
000	Appears in AFB Short format only. Being used by the SS, this AFB	N/A	N/A

	means that this SS has successfully received all the DL MAC headers within the latest frame and all the MAC messages addressed to the given connection were received successfully Being used by the BS, this AFB means that the BS has successfully received all the UL MAC headers from the given SS within the latest frame and all the MAC messages addressed to the given connection were received successfully		
001	The value M means that all the MSDUs with all the serial numbers < M were successfully received		N/A
010	The value M means the interval M M+15 of the serial numbers (MSN) of the consecutive MSDUs. The acknowledgements for these MSDUs are provided by the correspondent **Mask** bits		1 in the Mask means a positive acknowledgement for the corresponding MSDU
011	The value M means the MSN of the fragmented MSDU so that the acknowledgements for the fragments are provided by the correspondent **Mask** bits		1 in the Mask means a positive acknowledgement for the correspondent MSDU fragment
100	Same as above plus indication that all the serial numbers < M were successfully received.		1 in the Mask means a positive acknowledgement for the correspondent MSDU fragment
101-111	Reserved		N/A

Thus the feedback field may contain 4, 16 or 32 bits.

5.4. Discard Related Signaling

Discard decision is to be done by the transmitter according to the QoS requested for the given Service Flow (SF) associated with the given connection and the ARQ status of the connection. Such a decision concerns a single MSDU or a group of MSDUs. The exact algorithm of the decision is out of scope of the standard.

The transmitter MAY inform the receiver on the discard decision by sending the discard acknowledgment (DAF = discard acknowledgement field). Such an acknowledgment should be sent as a part of MAC message through the same connection as the data itself. DAF has the following format:

Table 3. DAB Format

Subfield	Reserved	SerNo
Size, bits	4	12

This field means that all the MSDUs with the serial numbers < Ser.No. were discarded by the transmitter. The opposite side MAY answer to this information by sending the Short AFB with the same Serial Number value.

5.5. Acknowledge and Discard Operations at Transmitter and Receiver

The algorithm figured in this paragraph should be considered as an informative part of the standard.

5.5.1. Regular Operations

5.5.1.1. Receiver

A MPDU has been received from the PHY Convergence Layer. We will denote the MSDU sequence number MSN and the fragment sequence number FSN. In the process described below we assume that there is only one MSDU per MPDU and the discard process is explicit, that is, it requires discard messages.

- Is the MPDU CRC OK?
  No —send general NACK to inform sender of receiver error even if the CID of the received MPDU is not known.
  Yes — continue.
- Is the MSN valid for reception (see *Identification of MSDUs* and *Identification of the ARQ Units* for details)?
  No — Discard MPDU. If there is no ACK awaiting transmission for this CID, create an ACK of the type 0 (see 5.3) for this CID indicating the next MSN valid for reception.
  Yes — continue.
- Is the MPDU a fragment of a MSDU?
  No — continue.
  Yes — reassemble the fragment to the MSDU (see *Fragmentation / Assembling Functions* for details). If the MSDU is not yet complete, prepare an ACK of type 2. If the MSDU is complete, continue.
- Prepare an ACK of type 0 or 1: If there are gaps of missing of incomplete MSDU s, prepare an ACK of type 1. Otherwise prepare an ACK of type 0 (note that an ACK of type 1 may include an ACK of type 0).
- Update the first MSN valid for reception and dispatch MSDUs to the Convergence Sublayer if necessary.
- Transmit all prepared ACK s in the next transmit opportunity assigned for ACKs for this CID.

5.5.1.2. Transmitter

When an AFB is received. It will be handled according to its type. If the MSN indicated in the SerNo field of the AFB is not outstanding, then the receiver and transmitter may have lost synchronization and the connection may require resetting.

We will denote the MSN indicated in the SerNo field of the AFB *M*.

AFB type 0:

M is the the MSN of the next expected MSDU and cumulatively acknowledges all MSDUs preceding it.

- All outstanding MSDUs with MSN < *M* shall be marked as transmitted successfully and removed from the transmission queue.
- All outstanding MSDUs with MSN ‡ *M* shall be considered rejected and should be retransmitted.

AFB type 1:

MSDUs *M* through *M+15* are represented by the 16 bits in the mask.

- All the set bits in the mask represent acknowledged MSDUs. These MSDUs shall be marked as transmitted successfully, if they are outstanding. If the first MSDU in the transmission queue is marked as transmitted successfully it should be removed from the transmission queue.
- All the bits in the mask which are not set represent rejected MSDUs. These MSDUs shall be considered rejected and should be retransmitted, if they are outstanding.
- If the AFB is also cumulative, it should now be processed as an AFB of type 0.

AFB type 2:

The fragments of MSDU *M* are represented by the 16 bits in the mask.

- All the bits set in the mask represent acknowledged fragments of *M*. These fragments shall be considered transmitted successfully.
- All the bits in the mask which are not set represent rejected fragments of *M*. These fragments should be retransmitted, if they are outstanding.

Note that a fragmented MSDU may be acknowledged by and AFB type 0 or 1 if all fragments are received before any of the fragments are acknowledged.

5.5.2. Discard Operation

See *Discard Related Signaling* for additional details.

5.5.2.1. Transmitter

We will denote the MSN of the last (or only) MSDU discarded *M*.

- Transmit a discard message with the SerNo field set to *M-1*.
- If an AFB with a MSN smaller than *M* is received after the discard message has been transmitted, the transmitter and receiver may have lost synch and the discard message should be retransmitted.

A discard message may be retransmitted if it is not acknowledged.

5.5.2.2. Receiver

We will denote the MSN in the SerNo field of the discard message *M*.

- All MSDUs with MSN < *M* shall be considered discarded. If any have already been received they may be dispatched to the CL.
- Prepare an AFB of type 0 with the SerNo field set to *M* and transmit it at the next transmit opportunity assigned for ACKs for this CID.
- The next MSN expected shall be *M*.

5.6. ARQ Support by Reservation / Grant Process

5.6.1. Downlink Data Transmission

The (data) fragments are transmitted as payloads of MAC messages, marked by the MSDU Ser. No. (MSN) and Fragment Serial Number (FSN).

No reservation request needed from the SS for transfer of the correspondent AFBs. The BS provides all the UL allocations needed to transfer the AFBs assuming them to be included into the UL MAC messages, particularly, into BW Request Messages (Headers).

The allocation decision is to be done according to the DL Service Flow QoS Parameters for the given connection (e.g. transfer delay restrictions) and uplink service in effect.

5.6.2. Uplink Data Transmission

The BS allocates the time needed for the transmission of the correspondent AFBs. The AFBs are included into the DL MAC messages. The allocation decision is to be done according to the UL Service Flow QoS Parameters for the given connection e.g. delay restrictions.