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Re:	This document is presented as proposed enhancements to the current 802.16 Task Group MAC described in IEEE 802.16./D1-2000 Draft Standard. The proposed enhancements will allow the MAC described in the Draft Standard to be used in 2 to 11 GHz applications by taking advantage of existing technology. This will also be compatible with PHY proposals submitted by Yonaten Manor et al. 802.16.3c-00/37r1. This Document is in response to IEEE 802.16.3-00/25r1, CALL FOR CONTRIBUTIONS: PROPOSED MAC ENHANCEMENTS, KEY CHARACTERISTICS AND EVALUATION CRITERIA: Session #11, dated 2000-12-13. Additionally, this document was prepared using document IEEE 802.16.3p-00/56, "Using the TG1 MAC for TG3 Purposes".
Abstract	This document contains recommended MAC enhancements to the TG1 MAC that will allow it to be used for TG3 applications. It includes recommendations in the following areas: Extended Headers, Mode A piggyback request limit, MAC HCS, Added messages for support of MMDS.
Purpose	Adoption of these enhancements into the TG1 MAC document as specific enhancements for TG 3 applications will allow the TG3 standard to be developed in the shortest possible time by taking advantage of existing technology.
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Proposed Enhancements to 802.16.1 MAC for 801.16.3 Applications

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1 Scope

MMDS applications are different than LMDS. LMDS propagation is typically LOS. MMDS propagation can either be Close Line of Sight (CLOS) or Non Line of Sight (NLOS). MMDS has to counter multipath, co-channel interference, and has less bandwidth available. The system needs to operate with less C/N ratio. Adaptive modulation is optional in LMDS environment, while it is mandatory in the MMDS environment. The MAC needs to support ARQ and spatial multiplexing as well.

The proposed MAC enhancements are IP centric, designed to support all existing as well as known future IP based services. This contribution proposes meeting the MAC needs of 802.16.3 through a common MAC with 802.16.1. The common MAC contains enhancements so that it is simpler, lower cost, and more IP centric for present point-to-multipoint as well as future IP based services.

2 Introduction

High performance technology currently exists in the communications industry that would allow 802.16.3 to develop its 2 to 11GHz broadband fixed wireless access standard in a cost effective and timely manner. Adding the recommended enhancements contained in this document to the 802.16.1 MAC will allow 802.16.3 to take advantage of this technology and speed deployment of its fixed wireless access MMDS standard at the lowest possible cost.

This paper is in no way advocating the removal or changing of the current TG1 MAC document only the addition of MAC enhancements specific to the TG3 MAC.

3 Overview

This section describes highlights of the recommended MAC protocol enhancements to 802.16.1 that make it IP centric and meet the 802.16.3 FRD needs. Highlights include but are not limited to:

- A non-connection-oriented option (extended header) is added to allow direct, low-risk, proven IP MAC commonality with existing IP residential services, QoS, advanced encryption mechanisms, and allow for future expansion of common IP services.
- The Mode A piggyback request limit is increased beyond 256 bytes (which presently is much less than maximum Ethernet or IP packet (an ATM driven limitation) to eliminate unnecessary and inefficient fragmentation overhead and associated additional delay.
- The HCS is increased from 1 to 2 bytes so it is large enough for the MMDS environment.
- Provisions are added for additional messages for supporting MMDS environment (e.g. OFDM, MIMO, ARQ, and adaptive modulation. support.

4 MMDS Extensions Overview

The MMDS modifications and extensions to the DOCSIS/802.16.1 specifications provide the additional level of robustness, which is required in a typical MMDS environment. The highlights of the extensions/modifications to the DOCSIS/802.16.1 specifications are:

- Considering the large number of possible downstream schemes, automatic channel acquisition is maintained by transmitting periodically Downstream Channel Descriptor (DCD) messages over the downstream channels. These messages enable the user to acquire the information regarding all the applicable downstream channels (i.e., channels serving the user sector plus the neighboring sectors).
- UCD message has been modified to define the OFDM and MIMO parmeters
- Priorities scheme is used for an optimized selection of downstream and upstream channels, based on both system wide load balancing and per modem channel dependent performance.
- Modified allocation scheme enables a flexible allocation for OFDM and MIMO PHY, including allocation for multiple modems on the same OFDM symbol or on parallel MIMO channels, limited bandwidth allocation for improved link budget and flexible use of the MIMO bandwidth.
- Bi-directional adaptive modulation enables more efficient and flexible use of the available channels. With the limited availability of MMDS channels, it is not desired to use different channels for different PHY schemes. The use of different PHY schemes on the same channel is more efficient and the allocation between the PHY schemes is more flexible and dynamic.
- Downstream adaptive modulation is supported by multiple profiles in the DCD message and added feedback information in the RNG-RSP message that enables the implementation of smart algorithms for the downstream profile selection per modem or per CID.
- Upstream adaptive modulation is supported by definition of multiple parameters sets that enables the use of different profile based on both interval usage (as in DOCSIS and 802.16.1) and modem.
- RQ on downstream and upstream enables reliable data delivery on dynamic fading channels, typical for NLOS and CLOS. The ARQ also enables to reduce the fading margin and to use higher throughput PHY parameters (QAM level and FEC combinations). Instead of using a more robust scheme, a less robust but with higher throughput may be used with the robust scheme being used only when necessary, i.e. for retransmissions.
- The modified UCD message and the DCD message support multi-cell and multi-sector configurations.

5 MAC Management Messages

This chapter describes new messages and enhancements to the IEEE 802.16.1 messages. MAC management messages will use the extended header and the DOCSIS MAC management header. This chapter describes new messages and changes to the existing DOCSIS messages.

5.1 General Rules

5.1.1 Compatibility with future versions

The Subscriber Station (SS) and Base Station (BS) MUST ignore any additional data, if it exists, beyond the data that is expected due to the current version. This data can be used for additional parameters in future

versions. In addition, any TLV tupple with unrecognized type is ignored. The SS and BS ignore any MAC management message with an unknown version number or type.

5.1.2 TDMA/FDMA scheme

5.1.2.1 The mini-slot allocation unit

Mini-slots definition is one BI unit (thus in terms of data sub-carriers). Mini-slots are numbers subsequently within the same OFDM and the same MIMO channel. Then the numbering proceeds to other parallel MIMO channels, if used and then continues on the next OFDM channel. Numbering of mini-slots is illustrated in Table 1.

1	2	3	4	5	6	7	8		9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24		25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40		41	42	43	44	45	46	47	48
MIMO Channel 1									MIMO Channel 2							

Table 1. Numbering of mini-slots

5.1.2.2 Sub-carriers groups

Sub-carriers groups define partitions of the channel bandwidth to sub-band. The sub-carriers groups may be used in the MAP message to limit a modem to partial bandwidth or to a single MIMO channel. Partitions of different groups may be overlapped and the WMTS scheduler is responsible to not allocate overlapping groups on the same OFDM symbol. Each subcarriers group is defined by a pair of BI references, indicating the first and last BI that are included in the sub-carriers group. The BI references are the BI in sequential number, relative to the start of an OFDM symbol on the first MIMO channel, where the first mini-slot number is zero. A sub-carrier group may include mini-slots fom one or more MIMO channels.

The UDT should be able to support at least 16 different sub-carriers groups. The sub-carriers groups are defined by the WMTS in the MAC UCD message.

5.1.2.3 Transmission of a single MAC frame

The basic unit of transmission, as received from the MAC layer, is a MAC frame. A single MAC frame should be transmitted in a one or more consecutive OFDM symbols. The transmission starts on a BI boundary and continues, while using all the BIs within the allocated sub-carriers group. Both the first BI and the index to sub-carriers group are allocated by the WMTS in the MAC MAP message.

5.1.2.4 Data Section

Any PDU delivered by the CPE is packed into one or more data segments. One data segment can also include more than one MAC frame. Each data segment is one encoded FEC block with its initialization and termination. A CPE can break one MAC frame into several data segments. The fragmentation must ensure the filling with data bytes of all BI units that constitute a continuous MAC frame, excluding the last BI that covers the MAC frame. This will ensure that the HUB PHY can demodulate and decode FDMA transmission from several CPEs and at the same time the MAC can recombine MAC frames from consecutive data segments of any of the CPE transmitting at the same time.

Any CPE will be assigned by the starting BI in a any give OFDM symbol and the number of consecutive BI blocks in the data segment. The CPE will occupy the BW according to that allocation.

The MAC at the HUB will deliver the data segment allocation for all CPE occupying the OFDM symbol.

5.1.3 Changes to the generic MAC header

The Generic MAC header should be replaced by the MAC frame header of DOCSIS, including an optional extended header.

The following MAC specific header is added:

5.1.3.1 ACK Frame

The ACK Frame is the basic mechanism that a CPE or the BS uses to acknowledge successful PDU reception on ARQ enabled CID. There must be no Data or MAC PDUs following the ACK frame. The general format of the ACK MUST be as shown in the following figure and table:

TBD (Similar to DOCSIS figure 6-8)

Field	Usage	Size
FC	FC_TYPE = 11; MAC-Specific Header FC_PARM[4:0]=TBD; ACK Frame; no data PDU following EHDR_ON=0/1; 1 if extended header is included, 0 otherwise	8 bits
PDU sequential number		11 bits
CID		13 bits
EHDR		0-255 bytes
HCS		2 bytes
	Length of a REQ MAC Header	6 + extended header length

5.1.4 Extended MAC header

The extended MAC header format and types will be used as defined in DOCSIS. This scheme enables more scalability and enables future additions with backward compatibility.
The Following EH elements are added to support ARQ:

EH_TYPE	EH_LEN	EH_VALUE
9	2	ARQ Control
10	0-255	ACK

5.1.4.1 ARQ Control EH element

The ARQ Control EH element is used with any PDU for ARQ enabled CID, either on the first transmission or on a retransmission. The ARQ control EH element should not be attached to PDU on a CID where ARQ is not enabled.

Retry number	Reserved	Sequence number
(4 bits)	(1 bit)	(11 bits)

The Retry number has a value of zero for an initial transmission of a PDU. It is incremented by one for each retransmission of the same PDU (up to a terminal value of 15). The sequence number is incremented for each new PDU for the same CID. Retransmissions of a PDU will use the same sequence number as the original transmission.

5.1.4.2 ACK EH element

TBD

5.1.5 Description of MAC Management Messages

5.1.5.1 Downstream Channel Descriptor (DCD) message

This message describes the parameters of available downstream channels. A single DCD message describes a single downstream channel.
The BS generates DCD messages includes the parameters shown in Table 2. The DCD message SHALL be in the format shown in Table 3

MAC Management Message Header	As defined in DOCSIS.
Cell ID	Identifier of the Cell where this message is transmitted (1 – 255). If cell information is not being used, a single value should be indicated in all DCD messages.
Sector ID	Identifier of the geographic sector, which can use these downstream channels (1 – 255). If sector information is not used, a single value should be indicated in all DCD messages.
Configuration Change Count (8 bits)	Incremented by one (modulo the field size) by the BS, whenever any of the values of any of the downstream channels descriptors change.
Number of channels	Number of downstream channels that are available for this MAC domain. This number may include channels, which are defined in other DCD messages.

Table 2. Downstream Channel Descriptor Message Parameters

Bit	0	8	16	24	31
	Mac Management Message Header				
	Cell ID	Sector ID	Configuration Change Count	Number of channels	
	TLV-encoded information for the overall channel				
	TLV-encoded downstream profile description				
	TLV-encoded information for the subsequent downstream profile descriptors				

Table 3. Downstream Channel Descriptor message Format

All other parameters are coded as TLV tupples. The type values used are defined in table 4, for channel parameters, and table 5, for downstream profiles attributes. Channel-wide parameters MUST precede downstream profile descriptors.

Channel descriptors are compound TLV encodings that define the parameters, for each downstream channel. Within each channel descriptor is an unordered list of attributes, encoded as TLV values.

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
Downstream Channel ID	1	1	The Identifier of the downstream channel to which this message refers.
RF Frequency	2	4	RF frequency in KHz
OFDM Symbol rate	4	4	OFDM Symbol rate (Sym/sec)
Bandwidth	5	4	Bandwidth (Hz)
FFT Size	6	1	1=128 2=256 3=512 4=1024 5=2048
Other OFDM PHY parameters	TBD - TBD	TBD	TBD, based on Phy definitions
MIMO Parameters	TBD - TBD	TBD	TBD, based on definitions
Downstream Errors Threshold	8	4	Threshold of detected errors. If the number of detected errors is more than this number, a downstream channel switching MUST be initiated as defined in 6.1. The counting of errors is initialized after each measurement period as defined in the FER measurement period TLV parameter.
Priority for a new SS	9	1	Priority to be used by a new SS - Lowest number is higher priority.
Priority for changing channel	10	1	Priority to be used if the current channel has poor conditions - Lowest number is higher priority.
Cell ID	11	1	The Identifier of the Cell which transmit the described downstream channel
FER measurement period	12	1	Time period for downstream error Rate measurement (See Downstream Errors Threshold TLV parameter). Time is given in seconds, in the range of 1-255 Sec.

Downstream profile Descriptor		Variable	May appear more than once. Described below. The length is the number of bytes in the overall object, including embedded TLV items.

Table 4 –TLV Channel Parameters

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
Downstream profile ID	1	1	The Identifier of the downstream profile to which this attributes set refers.
Modulation type	2	1	1=OFDM/QPSK; 2=OFDM/QAM16; 3=OFDM/QAM64
FEC scheme	TBD	TBD	TBD, based on Phy definitions
MIMO Parameters	TBD	TBD	TBD, based on Phy definitions

Table 5 – TLV Downstream profile Attribute Parameters

The priority should be determined by the BS. The priority MAY be dynamically changed by the BS between DCD messages. Such changes MAY be used to balance the load between the channels. A different priority can be assigned for a new initializing SS or to a registered SS, which has to switch channel due to poor RF conditions. The later priority MAY depend on the current channel, in such a way that different priorities will be assigned in DCD messages that are delivered on different channels.

The method to assign the priorities to each channel is vendor dependent.

Downstream profile descriptors are compound TLV encodings that define the parameters, for each downstream profile. Within each downstream profile descriptor is an unordered list of attributes, encoded as TLV values.

5.1.4 Changes to Upstream Channel Descriptor (UCD) message

The minislot size definition is changed:

Mini-Slot Size	A mini-slot is identical to one PHY BI unit, that is a mini-slot is defined as a fixed number of data sub-carriers. In this message, the size T defines the Mini-Slot for this upstream channel. This number is the mini-slot size in terms of number of data sub-carriers. Allowable values are TBD.

The TLV parameters for the upstream channel are contained in Table 6 and added to those defined in above.

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
Sector		1	Identifier of the geographic sector, which can use these upstream channels. This parameter may appear more than once, if the same upstream channel may be used by more than one sector.
Number of channels		1	Number of upstream in the sector.

Priority for a new SS		1	Priority to be used by a new SS - Lowest number is higher priority.
Cell ID		1	Identifier of the Cell where this message is transmitted. The described upstream channel should be used on this cell.
OFDM bandwidth limit class		3	Defines a bandwidth limit constraint. These constraints may be used in the MAP message to limit a modem to partial bandwidth. First byte is the OFDM bandwidth limit class identifier (1-255). Second byte is the first mini-slot in the range. Third byte is the last mini-slot in the range. The mini-slots are indicated by their sequential number, relative to the start of an OFDM symbol, where the first mini-slot number is zero.

Table 6 – Additional TLV parameters for modified UCD message

The TLV parameters for the upstream physical-layer burst attributes are described in Table 7 and added to those defined above.

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
Upstream attributes set	129	1	Identifier of the upstream attributes set to which this burst descriptor applies. This parameter can be repeated in the same burst descriptor TLV, if the burst parameters apply to more then one set.
OFDM related parameters	TBD - TBD	TBD	TBD, based on Phy definitions
MIMO related parameters	TBD - TBD	TBD	TBD, based on Phy definitions

Table 7. TLV parameters for the upstream physical-layer burst attributes.

This added parameter would enable definition of different parameter sets, which will apply to different CPE-IDUs. This can be used to adapt the upstream physical parameters to the channel performance of each CPE-IDU.

A CPE-IDU should use the attributes, which refer to its upstream attribute set, as defined in the RNG-RSP message. If there is no set parameter for a certain IUC, this IUC has the same parameters for all the sets. Specifically the initial maintenance (IUC 3) burst attributes must not include a set of parameters, i.e. the initial maintenance attributes are the same for all the sets.

5.1.4.1 Changes to the MAP message

5.1.4.2 Upstream Bandwidth Allocation Map for OFDM PHY (MAP-OFDM)

This message replaces the DOCSIS MAP message to support OFDM PHY. This message should not be used with a single carrier PHY. This MAP-OFDM message MUST indicates version 129 and message type TBD.

For upstream channels, which use an OFDM PHY, a BS-IDU MUST generate MAP-OFDM message in the format shown in Table 8.

Bit	0	8	16	24 31
Mac Management Message Header				
Upstream Channel Group ID	UCD Count	Number of elements	Reserved	
Alloc Start Position				
Ack Position				
Ranging Backoff Start	Ranging Backoff End	Data Backoff Start	Data Backoff End	
Map Information Elements				

Table 8 – MAP-OFDM Message Description

The parameters MUST be as follows:

Upstream Channel Group ID	The identifier of the upstream channel group to which this message refers.
UCD Count	Matches the value of the Configuration Change Count of the UCD, which describes the burst parameters, which apply to this map. See Section 9.3.2.
Number of Elements	Number of information elements in the map.
Reserved	Reserved field for alignment.
Alloc Start Position	Effective start Position, time and sub-channel, (in mini-slots) for assignments within this map.
Ack Position	Latest time and sub-channel, (mini-slots) processed in upstream. This time is used by the CPE IDUs for collision detection purposes. See Section 7.4.
Ranging Backoff Start	Initial back-off window for initial ranging contention, expressed as a power of two. Values range 0-15 (the highest order bits must be unused and set to 0).
Ranging Backoff End	Final back-off window for initial ranging contention, expressed as a power of two. Values range 0-15 (the highest order bits must be unused and set to 0).
Data Backoff Start	Initial back-off window for contention data and requests, expressed as a power of two. Values range 0-15 (the highest order bits must be unused and set to 0).
Data Backoff End	Final back-off window for contention data and requests, expressed as a power of two. Values range 0-15 (the highest order bits must be unused and set to 0).
MAP Information Elements	MUST be in the format defined in Table ???. Values for IUCs are defined in Table 6-20 in DOCSIS RFIv1.1 and are described in detail in Section 7.1.2 of DOCSIS RFIv1.1. Changes to the definitions in DOCSIS are followed.

Note: That the lower (26-M) bits of the Alloc Start Position and Ack Position MUST be used as the effective MAP start and ack positions where M is given in Section 6.3.3 of DOCSIS RFIv1.1. The relationship between

the Alloc Start/Ack position counters and the timestamp counter is described in Section 7.4 of DOCSIS RFIv1.1.

Bit	0 13	14 17	18 31
	OFDM Bandwidth Limit ID	IUC=14	Offset = Initial offset for first channel
First Interval	SID	IUC	Offset
Second Interval	SID	IUC	Offset
	● ●		
Last Interval of first channel	SID	IUC	Offset
End of list for first sub-channel	SID=0	IUC=7	Offset=End of last allocation +1
	OFDM Bandwidth Limit Class ID	IUC=14	Offset = Initial offset for second channel
First Interval of second sub-channel	SID	IUC	Offset
	● ●		
Last Interval of second sub-channel	SID	IUC	Offset
End of list for second sub-channel	SID=0	IUC=7	Offset=End of last allocation +1
	● ●		
End of list for last sub-channel	SID=0	IUC=7	Offset=End of last allocation +1
	SID	IUC	Offset = Don't care
Acknowledgements and Data Grants Pending	● ●		
	SID	IUC	Offset = Don't care

Table 9 – MAP-OFDM Information Element Structure

Allocation MAP Information Elements (IE) are the same as in DOCSIS, except for the following changes:

The MAP-OFDM MAY contain allocation for number of sub-channels, which are identified by an OFDM Bandwidth Limit Class.

Additional element is added to indicate the upstream sub-channel to be used for the following allocations. There is no requirement for the allocations for all the sub-channels to start at the same mini-slot. Hence, a starting offset is added to indicate the start of first allocation of this sub-channel, relative to the Alloc start time.

IE Name	Interval Usage Code (IUC) (4 bits)	SID (14 bits)	Description
OFDM Bandwidth Limit Class	12	OFDM Bandwidth Limit Class ID	Starting Offset for this sub-channel
Ack-US	13	unicast	Starting Offset of ACK-US region

(*) These data types will be used together with long data type to support adaptive burst profile per user IUC =2 and IUC=5 will now be used only for unicast data at any length as indicated above.

OFDM Bandwidth Limit Class	OFDM Bandwidth Limit Class identifier. Refers to an OFDM Bandwidth Limit Class that is defined in the UCD message. Zero means no constraint (the entire channel bandwidth can be used). If a bandwidth limit is imposed, then only mini-slots within this limit can be used by the modem.
Ack-US	The Ack-US grant should be used by the modem for, and only for transmitting of ACK MAC menagement message. The WMTS should automatically generate such a grant, after deliver of a unicast downstream packet in ARQ mode.

The Null IE is used to terminate each one of the sub-channels. Its offset size refers to the ending offset of the previous allocation and it is not necessarily the same as the map length.

Acknowledgement and data grants pending are delivered at the end of all the sub-channels allocations. Since the map length may be different for each sub-channel, there is no meaning to this value, which is defined in DOCSIS. In these specifications, the offset for these IEs is unused and may be set by the BS IDU to any desired value.

5.1.4.1 Downstream Channel Change Request (DCC-REQ)

A Downstream Channel Change Request MAY be transmitted by a BS to cause a SS to change the downstream channel on which it is receiving. The format of a DCC-REQ message is shown in table 10.

Bit	0	8	16	24	31
	Mac Management Message Header. Type=131.				
	Downstream Channel ID				

Table 10 - Downstream Channel Change Request

Parameters MUST be as follows:

Downstream Channel ID	The identifier of the downstream channel to which the SS is to tune for downstream transmissions. This is an 8-bit field.

5.1.4.2 Downstream Channel Change Response (DCC-RSP)

A Downstream Channel Change Response MUST be transmitted by a SS in response to a received Downstream Channel Change Request message to indicate that it has received the DCC-REQ and it is tuned to the new downstream channel. It MUST also be transmitted by the SS without a preceding DCC-REQ, if the SS switches to a new downstream channel, due to poor conditions. The format of a DCC-RSP message is shown in table8.

A SS MAY ignore a DCC-REQ message while it is in the process of performing a channel change.

When a SS receives a DCC-REQ message requesting that it switches to a new downstream channel that is already used by this SS, the SS MUST respond with a DCC-RSP message on that channel, indicating that it is already using the correct channel.

Bit	0	8	16	24	31
	Mac Management Message Header. Type=132.				
	Downstream Channel ID				

Table 11- Downstream Channel Change Request

Parameters MUST be as follows:

Downstream Channel ID The identifier of the downstream channel to which the SS is tuned for downstream transmissions. This is an 8-bit field.

5.1.4.3 Downstream Channel Change Acknowledgement (DCC-ACK)

A Downstream Channel Change Acknowledgement MUST be transmitted by a BS in response to a received Downstream Channel Change Response message to indicate that it has received the DCC-RSP.

The format of a DCC-ACK message is shown in Table 9.

When a BS receives a DCC-RSP message, regarding the current downstream channel of the SS, according to the BS tables, the BS MUST respond with a UCC-ACK message on that channel indicating that it is already using the correct channel.

Bit 0 8 16 24 31

Mac Management Message Header. Type=133.	
Downstream Channel ID	

Table 9 - Downstream Channel Change Acknowledgement

Parameters MUST be as follows:

Downstream Channel ID The identifier of the downstream channel to which the SS is tuned for downstream transmissions. This is an 8-bit field.

5.1.4.4 Changes to Ranging Request (RNG-REQ)

TLV encoded information is added to the message as follows:

Bit 0 8 16 24 31

Mac Management Message Header		
SID	Downstream Channel ID	Pending Till Complete

TLV-encoded information

The following TLV parameters are defined:

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
C/N	1	1	Carrier to Noise ratio in dB.
C/N measurement time	2	2	The time period in milliseconds that has been used for the C/N measurement.
Frame errors	3	1	Number of failed MPEG frames
Frame errors measurement time	4	1	The time period in seconds that has been used for the frame errors measurement.

5.1.4.5 Changes to Ranging Response (RNG-RSP)

This message MUST be transmitted by a BS in response to received RNG-REQ or MAY be transmitted without a preceding RNG-REQ. The BS may use this message to update SS parameters based on measurement information, which has been gathered by the BS from data bursts (i.e., measurement information that is not dependent on RNG-REQ MAC messages).

This change will enable the BS to make rapid adjustment to active SSs, without generating high upstream load from RNG-REQ messages. Non-active SSs should be adjusted periodically, using RNG-REQ messages, but this can be done at lower rates.

The following TLV parameters are added to those defined in [1]:

Name	Type (1 byte)	Length (1 byte)	Value (Variable length)
Upstream attributes set	129	1	Identifier of the upstream attributes set. The CPE-IDU must use the upstream PHY parameters of this set, as defined in the UCD message.

This added parameter will enable to define different parameter sets, which will apply to different CPE-IDUs. This can be used to adapt the upstream physical parameters to the channel performance of each CPE-IDU.

6 Media Access Control Protocol Operation

6.1 Acquisition of a downstream channel

6.1.1 BS requirements

The BS MUST periodically transmit a Downstream Channel Descriptor (DCD) message. This message defines the available downstream channels. The BS MAY be configured to send a single DCD message (on each channel), which describes all the available channels. Another option is to send a separate message for each downstream channel. The second alternative enables more reliable reception, due to a shorter message length, on a poor channel. The DCD messages, for all the downstream channels that serve one downstream sector, MUST be transmitted on each of these downstream channels.

6.1.2 SS Requirements

6.1.2.1 Initial connection

A CPE MUST first try to lock on any downstream channel to get an updated DCD message. The CPE evaluates channels according to the following order:

- The last channel where the CPE has been connected in a previous session.
- The other channels which have been defined by DCD message in previous session.
- Scanning the entire available spectrum and automatically acquire the modulation and channel width.

After successful acquisition of the first downstream channel, as defined in DOCSIS, the CPE waits for a DCD message. If a non-zero sector ID is configured for the CPE, only DCD messages with this sector ID MUST be processed. If necessary, as indicated by the “Number of Channels” parameter in the DCD message, it continues to receive DCD messages until it has the parameters for all the channels

The sector of a SS MAY be configured by one of the following methods:

- Locally, using technician interface.
- Remotely, using SNMP.

If a SS is assigned manually or automatically a Sector ID of zero, it MAY use all the upstream and downstream channels, regardless of their defined sector.

If after T7 time out, which starts when the CPE is synchronized to the downstream channel, as defined in 9.2.1 of the DOCSIS specifications, the CPE has not received all the DCD messages, it tries to lock on the channels defined by the received DCD messages (with sector limitation, if defined), following the priority order. These channels MUST then be used to receive the DCD messages for the remaining channels for which a DCD message was not received.

After receiving the parameters of all the available downstream channels for its sector, a CPE will try to lock on the downstream channels, according to the assigned priorities for a new CPE. The channel to be selected is the acceptable one with highest priority. The acceptable channel with highest C/N ratio is selected from channels with the same priority. Acceptable channel is a channel where the CPE can successfully complete the registration process. The following process achieves this selection:

The CPE MAY skip channels that it has failed to lock on during the previous steps. A CPE MUST start with the highest priority channels and proceed to lower priorities, until it successfully connects to a channel (receiving SYNC messages, as defined by DOCSIS). After successfully connecting to a channel, the CPE MUST continue to check all the channels with the same priority. The channel with highest C/N ratio from these channels, with the same priority, is selected and used to continue with upstream acquisition. If upstream acquisition, using this channel fails, the next downstream channel is used.

The CPE MUST establish a channel quality table. The table MUST include the following parameters for each channel:

a. Acquisition result – Success, one failure or two failures. Should be stored for each tested channel. Other channels should be marked as unknown.

b. Carrier to Noise ratio –Should be stored for each acquired channel.

c. MPEG frames error rate - The measurement period should be as defined in the DCD FER measurement period TLV parameter. The measurement can be terminated earlier if the error rate threshold is exceeded.

d. A channel status MUST be changed to unknown after T9 interval without being tuned to that channel.

6.1.2.2 Changing of a downstream channel

If the frame error rate on the current downstream channel is not acceptable, according to the "FER Threshold" TLV parameter in the DCD message, the CPE MUST switch a downstream channel. It MUST use the information from the last successfully received DCD messages. The CPE MUST try to lock on the downstream channels, according to the assigned priorities for changing channel. Channels that have been tried in the previous T9 time period MUST be skipped. When the CPE acquires successfully the new downstream channel, it MUST transmit a DCC-RSP message and wait for a DCC-ACK message from the BS. If a DCC-ACK is not received by the CPE within T8 timeout it MUST retransmit DCC-RSP. These retransmissions MUST be repeated after each T8 timeout until a DCC-ACK is received or a T4 timeout has passed since the first DCC-RSP transmission. After T4 timeout the CPE MUST initiate an initial upstream channel acquisition with initial ranging and registration.

If the CPE cannot acquire a downstream channel after scanning all the channels (no “unknown” status channel), it MUST retry, by priority order, the previously failed channels (“One failure” status). If the CPE still cannot acquire a downstream channel, it MUST select the channel with success indicator and best MPEG frame error rate. If all the channels are marked as “Two failures”, the entire channels table MUST be initialized to “unknown” state and the CPE MUST restart initial acquisition starting from the highest priority channel, without skipping any previously tried channels.

6.2 Acquisition of an upstream channel

6.2.1 BS requirements

The BS MUST periodically transmit an Upstream Channel Descriptor (UCD) message. This message is based on the UCD message that is defined in [1], with extensions defined in Para. 5.1.2.2. The UCD message, for each upstream channel, MAY be transmitted on all or some of the downstream channels. Transmitting UCD messages on a subset of the downstream channels MAY be used to limit the upstream channel selection, based on the downstream channel selection.

6.2.2 SS Requirements

6.2.2.1 Initial connection

After acquiring a downstream channel, a CPE MUST acquire an upstream channel. The acquisition process is defined in DOCSIS, with the following changes:

- The CPE should receive UCD messages for all the available upstream channels. This can be determined by the "number of channels" parameter in the UCD message.
- The CPE MUST try the upstream channels according to the priorities for a new CPE.
- If the CPE has finished successfully ranging on an upstream channel, it MUST continue to test all the others upstream channels, if any, with the same priority. The one of these equal priority channels that requires the minimal transmitting power is selected.

The specific method of priorities allocation is depending on a specific vendor implementation. It is expected that channels that able to provide better service, based on modulation, symbol rate and current load will have higher priority. This way a SS will use the best channel it can use, choosing from channels with possibly different sectors, frequencies, and modulation scheme and symbol rate. Considering the current channels load when allocating priorities enables the BS to balance the load between the channels.

6.2.2.2 Changing of an upstream channel

Changing of an upstream channel may be desired for improvement of initial selection, load balancing, because of system and channels changes.

It is expected that the BS should initiate such changes, using the DOCSIS UCC-REQ and UCC-RSP messages. Algorithms that use these features are left for BS vendor specific implementations.

6.3 Adaptive Upstream Modulation

In the DOCSIS and 802.16.3 scheme, the burst profile parameters (including modulation scheme), are defined per each Interval Usage Code (IUC), i.e., per burst type (e.g., Initial maintenance, Data grant, Request etc.). This scheme does not allow the use of different burst profile by different CPE IDUs for the same type of burst.

The adaptive upstream modulation allows for different burst profiles to be used for supporting CPE IDUs with different channel performance, while using the same IUC. This is facilitated by adding a new Upstream Burst Attributes Set parameter.

A CPE IDU is assigned an Upstream Burst Attribute Set value using the RNG-RSP MAC management Message. It should use the parameters that are defined for this set in the UCD message. If the channel performance for a particular CPE IDU is changed, it's attribute set will be changed accordingly.

6.4 ARQ

The ARQ mode enables a reliable communication over a a channel with high bit error rate. The use of this mode is designed in such a way that the majority of transmissions that do not require retransmissions will suffer only a minimal overhead and delay, due to the ARQ mode.

The ARQ mode may imply increased latency when a retransmission is required. This implies that the ARQ mode is not suitable for use with real-time Quality Of Service classes. However, since data usually requires better bit error rates than real time services, it is reasonable to use the both modes, depending on the traffic type.

The ARQ is supported by the following MAC modifications:

- A new Interval Usage Code (IUC) is defined in the MAP message to support allocation for acknowledgements.
- A new Acknowledgement MAC header is defined to be used for acknowledgements.
- A new ACK extended header element is defined to be used for acknowledgements of multiple PDUs or to piggyback the acknowledgement with other MAC frame.
- A new ARQ extended header element is defined to deliver the information regarding PDU sequential number and retransmission number.
- A new TLV parameter has been added to the RNG-RSP message to configure the CPE-IDU to ARQ mode.

References:

[1] IEEE802.16.3-00/02r4, “Functional Requirements for the 802.16.3 Interoperability Standard”, dated 2000-09-22.

[2] R. Van Nee and R. Prasada, “OFDM for Wireless Multimedia Communications”, Artech House Publisher, year 2000.

[3] Document from IEEE 802.16.2/D1-2000

[4] 802.16.3c-00/37r1, Outline of PHY Proposal for MMDS Communications (Yonatan Manor et al)

[5] DOCSIS RFI Specification SP-RFIv1.1-I06-001215