Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	**802.16 BWA Air Interface Medium Access Control. Proposal for Standard**
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Re:	In response to Call for Proposals for the BWA MAC layer from Nov 22, 1999.
Abstract	A MAC which supports both synchronous and asynchronous traffic, QoS support and both FDD and TDD operational modes is presented.
Purpose	To present a proposal which will serve as a baseline of the BWA MAC layer.
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802.16 BWA Air Interface Medium Access Control Proposal

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1.1 Scope

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1.4.1. Definitions

1.4.2. Symbols & Abbreviations

ARQ	Automatic Repeat Request
ATS	Atomic Time Slot
AU	Access Unit
BER	Bit Error Rate
CCU	Connection Control Unit
CD	Committed Delay (in milliseconds).
CDR	Committed Data Rate
CDU	Connection Data Unit
CDV	Committed Delay Variation (in milliseconds)
CoS	Class of Service
CP	Contention Period
CRC	Cyclic Redundancy Check
DL	Down Link
DLC	Data Link Control
DLP	Down Link Period
EST	Elapsed Service Time
FER	Frame Error Rate
FTP	File Transfer Protocol
IE	Information Element
SC	Service Connection
SCERQ	Service Connection Establishment Request
MAC	Medium Access Control
MSDU	MAC Service Data Unit
OLRT	On Line Reservation Technique
PAT	Polling in Advance Technique
PDU	Protocol Data Unit
PHY	Physical Layer
QoS	Quality of Service
RgTS	Registration Time Slot
RRQ	Reservation Request
RSSI	Received Signal Strength Indication
RsTS	Reservation Time Slot
SF	Super Frame
SFH	Super Frame Header
SP	Scheduling Period
SU	Subscriber Unit
TTS	Time to Serve

UL	Up Link
ULP	Up Link Period
VoIP	Voice (Video) over IP
WCC	Wireless Connection Control
WMAC	Wireless Medium Access Control
WPDU	Wireless Protocol Data Unit
WPHY	Wireless Physical Layer
WTC	Wireless Traffic Convergence
WWW	World Wide Web

1.1 Reference Documents

[Ref1] P802.11D6.1. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. By The Editors of IEEE 802.11

[Ref2] Recommendation G.114. One Way Transmission Time. By ITU-T.

[Ref3] IEEE 802.16sc 99/28. Quality of Service (QoS) Classes for BWA. By Arun A. Arunachalam.

[Ref4] Gigabit Networking. By Craig Partridge.

[Ref5] Data Networks. By Dimitri Bertsekas and Robert Gallager.

[Ref6] System Requirements Assuring That Point-to-Multipoint Broadband Wireless Access Networks Are Agnostic to User and Network Protocols. By Ray W. Sanders

2 Functional Assumptions

N/A to MAC

3 Communication Protocols

N/A to MAC

4 Physical Layer

5 Media Access Control Layer

5.1 MAC Reference Model

The proposed MAC protocol is intended for ***point-to-multipoint wide-band wireless data access systems***. The protocol is suitable for both TDD and FDD. In FDD AU is assumed to be a full duplex device while SU might be either full duplex or half duplex.

The protocol includes tools that provide a possibility to support wide range of services differentiated by either content (Internet access, voice, video etc.) or requirements to data rate, delays etc.

The services provided by the MAC to the upper layers are connection oriented. Each Service Connection (SC) supports the QoS traffic contract which is negotiated upon connection establishment.

A special Signalling Connection will be allocated to each Subscriber Station upon registration. This Signalling Connection will be dedicated to service control protocols (see below).

The following figure describes the protocol model at both AU and SU.

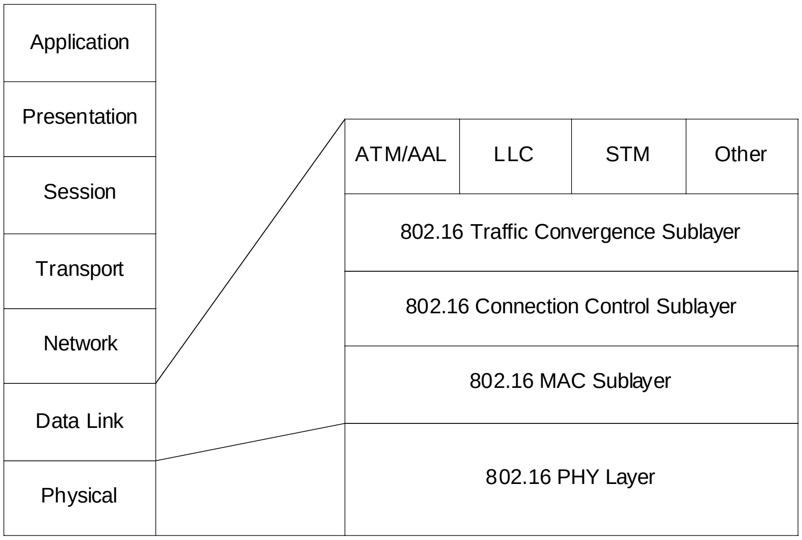

Figure 1. Protocol Layers

The following table specifies the functions of each layer.

Table 1. Protocol Layers

Sublayer	Description
Traffic Convergence	It is responsible for transforming various original traffic streams into a uniformed BWA Traffic Streams and vice versa. While different original traffic streams may be of quite different nature (E1, Ethernet, ATM, etc.), the resulting uniformed traffic streams will look alike and will be handled in similar ways. Thus the lower sublayers will be agnostic to the original traffic nature. If the original traffic is connection oriented (like ATM) then original connections will be translated into BWA Service Connections. If it is connectionless then Service Connections will be established according to the convergence rules.
Connection Control	The layer provides for control of already established Service Connections. It takes care of data integrity as well as of adaptation to environmental conditions (i.e rate, power control, time advance control, etc.).
MAC	Wireless Medium Access Layer. It is responsible for multiplexing the Service Connection Control demands into the WPDUs (see below) and SFs and vice versa.
PHY	Wireless Physical Layer.

5.2 MAC Concept

5.2.1 Relationship Between Higher Layers and MAC Protocol

The MAC distinguishes between four main Classes of Services (CoS). A greater number of CoS is **TBD**.
A peer requesting a connection with certain CoS, will offer to another peer a Traffic Contract. The parameters of the Traffic Contract depend on the CoS.

5.2.1.1 Classes of Service Definitions

5.2.1.1.1 Committed Delay Class of Service (CD CoS)

The Class of Service is dedicated to serve the isochronous data streams. The latter include PDH (E1, T1, E3, T3), SDH, Compressed or Not Compressed Voice and Video over synchronous lines. Possible applicability for ATM AAL1 CBR is left for further study.

The corresponding Traffic Contract contains the following parameters:

Table 2. CD CoS Traffic Contract Parameters

Parameter	Description
SDU Size	The size of the SDU, which enters the convergence layer. In octets.
SDU Inter-Arrival Time	The inter-arrival time between every two consecutive SDUs. In milliseconds.
Maximum Delay Allowed	The maximum access delay allowed.
SDU Tolerable Loss Rate	The loss rate lower than specified will be considered as satisfactory. The parameter is a basis for the connection acceptance decision. The parameter is given as ratio $\frac{\text{Number of Discarded SDUs}}{\text{Number of Submitted to Service SDUs}}$. In the case when (e.g. because of higher BER) the system is not able to keep the Maximum Delay commitment, the SDU Loss Rate may increase fairly for all the active Service Connections
SDU Maximum Loss Rate	If the loss rate exceeds the specified the connection should be dropped. The parameter is given as ratio $\frac{\text{Number of Discarded SDUs}}{\text{Number of Submitted to Service SDUs}}$. The Maximum Loss Rate parameter must be considerably higher than the Tolerable Loss Rate parameter.

5.2.1.1.2 Real Time Committed Rate Class of Service (RT-CR CoS)

This Class of Service is destined for variable rate services with high delay and delay variation sensitivity like ATM RT-VBR and RTP based IP applications (VoIP).
The corresponding Traffic Contract contains the following parameters:

Table 3. RT-CR CoS Traffic Contract Parameters

Parameter	Description

CommittedTime (separately for DL and UL)	The time interval during which the user can send at least **CommittedBurst** amount of data (see definition below). In general, the duration of **CommittedTime** defines the inter-burst arrival time. Incoming data triggers the **CommittedTime** interval, which is measured and applied as long as data demand exists. The parameter is specified in milliseconds. The Convergence Layer must be able to eliminate jitter of **CommittedTime** milliseconds.
CommittedBurst (separately for DL and UL)	Committed Burst Size. The amount of data (in octets) that the network commits to transfer, under normal conditions, during a time interval **CommittedTime**. Each **CommittedBurst** amount of data is either transferred during **CommittedTime** time or discarded. In the case, when (e.g. because of higher BER, oversubscription of the RT-CR CoS connections or timing constrains introduced by the Committed Delay connections) the system is not able to transfer the **CommittedBurst** amount of data during **CommittedTime** time, the degradation of service will be distributed uniformly among the active RT-CR CoS connections[1].
MinimumBurstSize (separately for DL and UL)	Minimum Burst Size (in octets). If the performance degrades to a point where the burst size delivered during **CommittedTime** interval is lower than the specified the connection should be dropped.

5.2.1.1.3 Non Real Time Committed Rate Class of Service (NRT-CR CoS)

The Class of Service is destined for variable rate services that do not have timing restrictions like ATM NRT-VBR, ATM ABR and UBR, Internet Data Services.

The corresponding Traffic Contract contains the following parameters:

Table 4. NRT-CR CoS Traffic Contract

Parameter	Description
CommittedTime (separately for DL and UL)	The time interval during which the user can send at least **CommittedBurst** committed amount of data (see definition below) and no more than **ExcessBurst** excess amount of data (see definition below). In general, the duration of **CommittedTime** defines the inter-burst arrival time. Incoming data triggers the **CommittedTime** interval, which is measured and applied as long as data demand exists. The parameter is specified in milliseconds.
CommittedBurst (separately for DL and UL)	Committed Burst Size. The amount of data (in octets) that the network commits to transfer, under normal conditions, during a time interval **CommittedTime**. In the case, when (e.g. because of higher BER, oversubscription of the NRT-CR CoS connections or timing constrains introduced by the CD CoS connections) the system is not able to transfer the **CommittedBurst** amount of data during **CommittedTime** , the degradation of service will be distributed uniformly among the active[2] NRT-CR CoS connections.

[1] I.e. those that have pending data demand.

[2] I.e. those that have pending data demand.

ExcessBurst (separately for DL and UL)	The maximum amount of data (in octets) in excess of **CommittedBurst** that the system can attempt to deliver during a time interval **CommittedTime**. This data (**ExcessBurst**) is delivered only after the committed part of the contract (**CommittedBurst**) is served and there is still enough capacity. Each **ExcessBurst** amount of data is either transferred during **CommittedTime** time or discarded.
Minimum Burst Size (separately for DL and UL)	Minimum Burst Size (in octets). If the performance degrades to a point where the burst size delivered during **CommittedTime** interval is lower than the specified the connection should be dropped.
Idle TimeOut	Time period in milliseconds. If no SDU has been submitted to service during this period on either UL or DL, the Service Connection will be suspended (but not dropped). When the service is suspended the traffic contract does not have to be honored. The connection might be resumed after an explicit request on UL or if data arrives on DL. The parameter might be set to infinity.
Service Resume Period	Time period in seconds. If the service has been suspended it will be resumed within no more than SRP (Service Resume Period) seconds since the moment of data demand arrival on either DL or UL.

5.2.1.1.4 Uncommitted CoS (UC CoS (NCR CoS)

No commitment assumed on either data rate or delays. The only parameters applicable are:

- MIR (Maximum Information Rate)
- Service Acquisition Period (Maximum time interval guaranteed between the transmission demand and actual tarnsmission start)

5.2.1.1.5 Down Link Multicast Service (DLMS)

TBD

5.2.1.2 Priorities in QoS Support

The following are the priorities of the Traffic Contracts recommended for use by scheduling algorithm:

One) (Highest) Committed Delay
Two) Real Time-Committed Rate
Three) Non-Real Time-Committed Rate
Four) Non-Committed Rate

5.2.1.3 Traffic Convergence Concept

5.2.1.3.1 Convergence of Streams into Service Connection

The original traffic streams are mapped onto Service Connection streams (see **Error! Reference source not found.**).

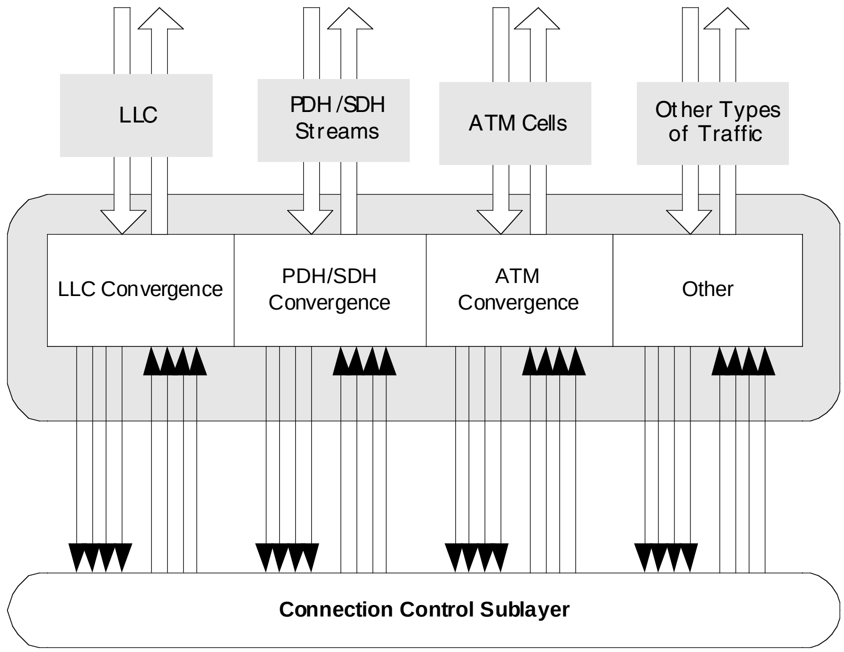

Figure 2. Convergence into Service Connections

If the original traffic is connection oriented (like ATM) then the original connections are translated into the 802.16 Service Connections.

If the traffic is connectionless then Service Connections might be established according to the convergence rules (TBD).

In general the original streams are converted into streams of MSDU (MAC Service Data Unit) per Service Connection. Each MSDU is divided into ***fragments***. Each fragment is of equal length except from the last one in the MDSU, which might be smaller). Convergence specific data is added to each MDSU descriptor. The MDSU descriptors will be transmitted to the peer convergence layer to allow correct reverse convergence.

5.2.1.3.2 LLC Traffic Convergence

For IEEE 802.x LLC traffic the MDSU descriptor contains only MDSU ID, number of fragments in the MDSU and the length of the last fragment. The MDSUs are the original LAN frames. Fragment size is not a decisive issue. The ways of mapping the LAN traffic into the Service Connections is TBD. It might be according to 802.1q VLAN ID or according to IPv6 flow labels or other methods.

5.2.1.3.3 PDH Traffic Convergence

For E1 the MDSU is the E1 multi-frame. Fragment size is not a decisive issue. Time stamp needs to be added to the MDSU descriptor (rest is TBD).

5.2.1.3.4 SDH Traffic Convergence

TBD (Probably the same as PDH)

5.2.1.3.5 ATM Traffic Convergence

Fragment size should be chosen equal to the ATM cell size. The MDSU represents the SAR-PDU of the corresponding AAL. VP/VC might be converted into Service Connections

5.2.2 Relationship Between Physical Layer and MAC Protocol

PHY Layer provides the following services to the higher layers including MAC

- RF processing
- Modulation / demodulation
- FEC encoding/decoding
- Measurements e.g. received power, quality
- Error detection
- Timing, e.g. slot & frame synchronization
- Power management (under control of higher layers)

MAC Layer provides the following control functions to PHY

- Decisions on the type of modulation and FEC encoding to use at Tx and in some cases at Rx
- RF control (e.g. Tx/Rx)
- Transfer of power control messages

5.3 Media Access Control Specification

5.3.1 Introduction

5.3.1.1 Overview

The paper presents a proposal for 802.16 BWA Medium Access Control. The proposal envisages Traffic Convergence sublayer, which takes care of converting the various transport technologies like IP, ATM, PDH, SDH, etc. into a uniformed traffic format, thus allowing the lower sublayers be agnostic to the original traffic nature. The services provided by MAC to upper layers are connection oriented, allowing Service Connection (SC) establishment and QoS per SC negotiations.

The proposed MAC allows, but not restricted to, fragmentation of MSDUs into fragments and concatenation of several MDSUs into one body. Thus the granularity of bandwidth assignment is limited by fragment size, which might be fairly small (it can be a manageable parameter or it may even be different between the Service Connections. On the other hand, MAC headers are allocated not for every fragment, but rather for group of fragments, which provides for efficient MAC overhead. Using these features the MAC scheduler can provide for dynamic, efficient and fair bandwidth sharing among the subscribers.

The proposed MAC includes mechanisms to bound delay.

The proposed MAC doesn’t relay on expensive technology and doesn’t inflict restrictive requirement to other parts of the system so it can be easily implemented using existing technologies.

The proposed MAC protocol provides for great scalabilty of bandwidth allocation per Service Connection and does not limit the number of Service Connections but rather the aggregate demand of all Service Connections.

The proposed MAC fits both TDD and FDD mode of operation, and provides for mechanisms to control and adjust the PHY parameters on both downlink and uplink.

The proposed MAC includes authentication upon registration, thus providing for security of operations. Data encryption parameters might be set upon authentication.

5.3.1.2 Definitions

AU – Access Unit. Centrally located concentrator of broadband wireless data access system. Roughly equivalent to a BS.

SU – Subscriber Unit, equivalent to CPE or SS (Subscriber Station). Connected to the terminals at user site (computers, telephones)

5.3.1.3 Future Use

The protocol may be used in the future for the systems with “Smart Antennas”.

5.3.2 Access Modes

The AU broadcasts scheduling information that defines time intervals (in FDD also frequencies) allocated for each SU for both downlink and uplink. In addition, certain time/frequency region is allocated for the random uplink accesses.

The following are the medium access modes defined by the protocol

- Downlink scheduled transmissions. This type of transmissions is applied by AU for both control and user data.
- Uplink scheduled transmissions. Used by SU for both control and user data. May include reservation requests and feedback information (acknowledgements)
- Uplink random access transmissions. Slot synchronisation is assumed between the SU and AU. Used by SUs for control data (e.g. reservation requests) and possibly for short user data messages
- Uplink random access transmissions, asynchronous. Slot synchronisation is not assumed between the SU and AU . Used by SUs for reservation requests *before* the slot synchronisation reached e.g. at the signalling connection establishment.

5.3.3 MAC Frame Format

5.3.3.1 Super-Frame and Transmission Periods

Uplink and Downlink transmissions are organised into Super Frames (SF). Each SF begins with the Super Frame Header (SFH) which describes the structure of the following SF. See the figures below for the SF structure. In TDD all the transmissions are performed at the same frequency. In FDD downlink transmissions are performed at one frequency while uplink transmissions at another one.

Contention Period (CP) is used for random medium accesses.

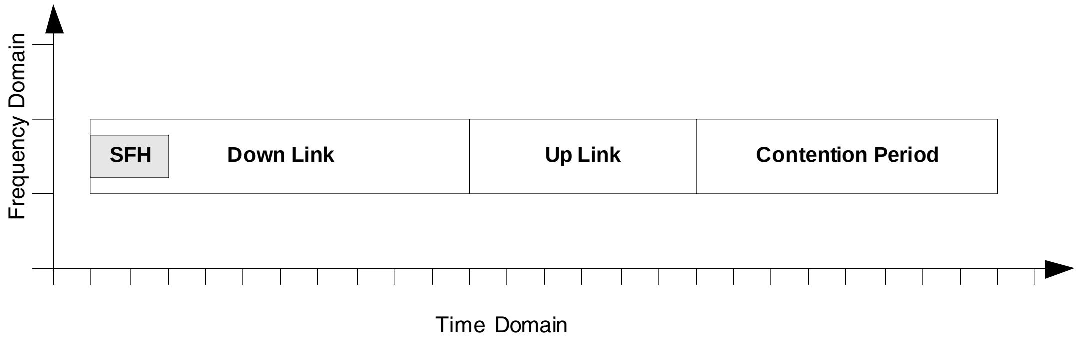

Figure 3. TDD Super-Frame Structure

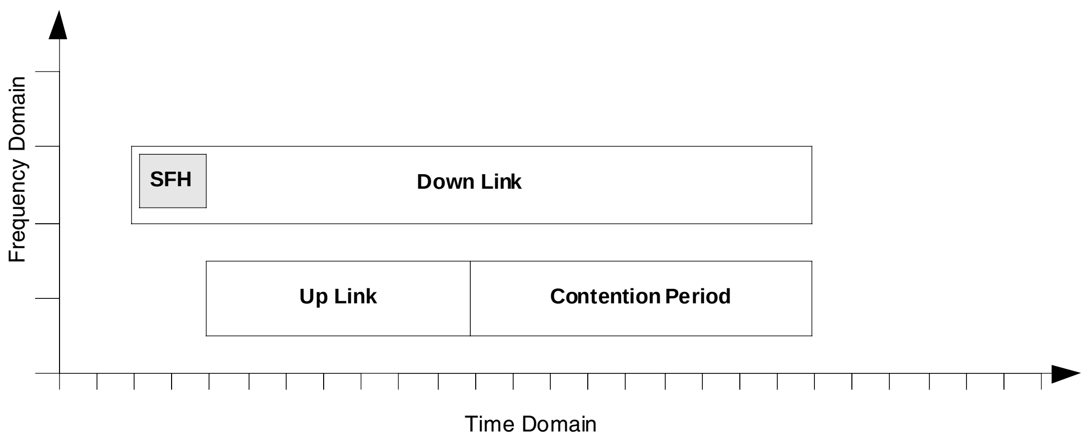

Figure 4. FDD Super-Frame Structure

The SFH describes the Super-frame layout in the terms of certain time slots (see the figure below)

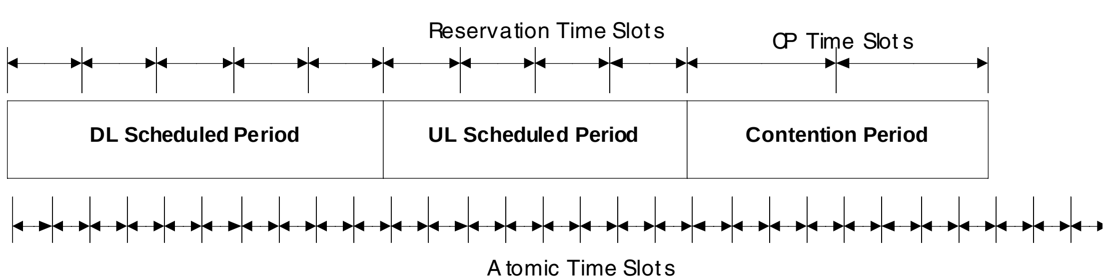

Figure 5. Time Slots

The MAC Protocol distinguishes between Atomic Time Slot (ATS), Reservation Time Slot (RsTS) and CP Time Slot.

Table 5. Time Slots

Name	Description
ATS	Atomic Time Slot. The minimum possible time quantum, which might be used for bandwidth allocation. All time periods should consist of integral number of ATS.
ReTS	Reservation Time Slot. Multiple of **ATS**. Used as a unit of time allocation for the needs of both DL and UL
CPTS	Contention Period Time Slot. Multiple of **ATS**. Used as a time unit for alignment of SU transmissions within CP

5.3.3.2 Scheduling

The protocol groups Up and Down Link fragments into MAC messages (WPDUs) and builds Super-frame as a set of WPDUs. The DL and UL transmission periods are separated either in time or in frequency. The protocol also provides Contention Period for delivery of asynchronous reservation requests and registration.

The scheduling algorithm must try to achieve maximum possible bandwidth utilisation while ensuring the quality of service requested. When working in FDD mode, there is a restriction: no SU may be scheduled to transmit and receive simultaneously.

See **Error! Reference source not found.** regarding priorities in capacity partitioning between the different types of SCs.

5.3.4 MAC Messages

In Tx, Wireless Protocol Data Units (WPDUs) are submitted from MAC to PHY for transmission over the wireless medium. In Rx, PHY supplies to MAC WPDU received from the medium.

The following picture figures the format of WPDU for all the cases: DL, UL, CP

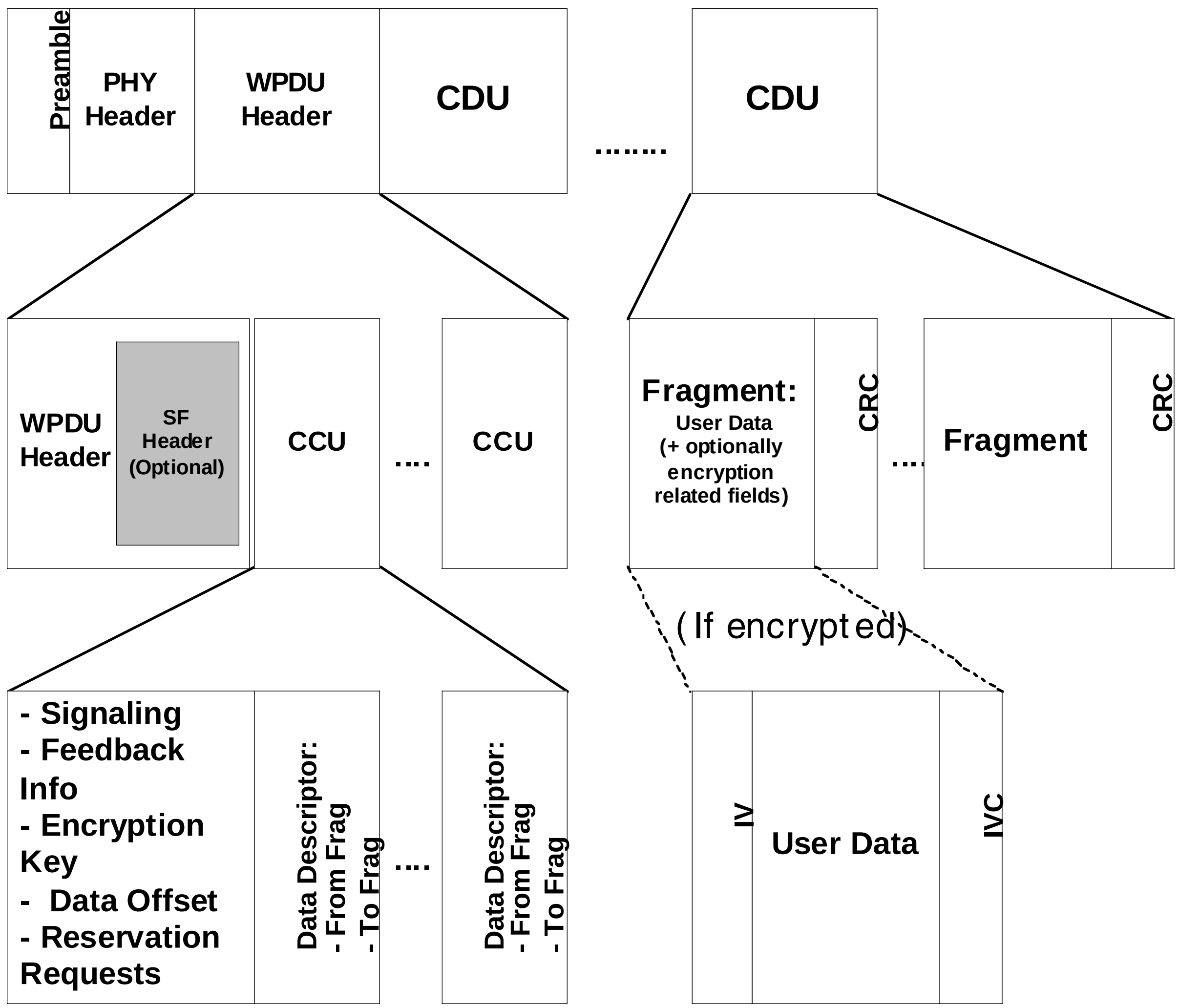

Figure 6. WPDU Format

The following table figures the WPDU components. Note that the WPDU Header may contain SF Header (for the first DL WPDU in the SF). The SF Header appears as a set of Information Elements containing the information on allocation of each WPDU (both Dl and UL) capacity to Service Connections.

Table 6. WPDU Components

Name	Meaning
Preamble	PHY Preamble for frequency/clock/frame synchronisation between Rx side and Tx side
PHY Header	Contains such parameters as modulation/coding type and possibly the length of WPDU
WPDU Header	Contains information that defines the layout of the WPDU including the offset of the first of Connection Data Units (CDUs) from the beginning of the WPDU May contain SF Header

CDU	Connection Data Unit that contains some amount of user data arranged into fragments

The following table figures the components of WPDU Header

Table 7. Components of WPDU Header

Name	Meaning
WPDU Header Info	Information on the layout of the WPDU Header and other WPDU related information
SF Header	Super-frame Header, contains information on the allocation (time slot / frequency based) and destination of each WPDU within the Super-frame. This is an optional component present only at the first DL WPDU in the Super-frame.
CCU	Describes the layout of the corresponding Connection Data Unit (CDU) within the WPDU (not for the Signaling Connection). Contains **Information Elements** carrying signaling information related to the connection, Reservation Requests, Control Protocol messages, feedback information etc.

Table 8. Components of CDU

Name	Meaning
Fragment	Fragment of MSDU. Identified by Fragment Serial Number
CRC	Redundancy Check

The Fragment data might be encrypted (working assumption is RC4 with implementation similar to 802.11 standard). Then within the Fragment a block of user data is placed together with IV (Variable part of Initialisation Vector for the encryption algorithm) and ICV (Integrity Check Value).

CCU contains the following connection related information assembled into Information Elements (IEs):

Name	Meaning
Signaling	Control messages providing transparent communication between higher layers. It might be Convergence Layer specific information e.g. Time Stamps for E1/T1 Convergence Layer
Feedback Info	Acknowledgements (with one fragment resolution)
Encryption Key	Public or private key to be used by the encryption algorithm
Data Offset from the beginning of WPDU	Offset of the connection data from the beginning of the WPDU
Reservation Requests	Reservation requests piggybacked on the uplink WPDUs
Data Descriptors	Each descriptor specifies the MDSU and the range of fragments that appear in the CDU, e.g. MDSU serial number : [From Fragment # XXX – To Fragment # YYY] : [Length of the last Fragment]

5.3.4.1 User

User data is placed in the WPDU as it described by Figure 6.

5.3.4.2 Management

The following is the list of possible Management Information Elements

- Association
- Disassociation
- Authentication
- Deauthentication
- Polling Alert
-

5.3.5 MAC Error Handling Procedures

5.3.5.1 Data Integrity Control

Data Integrity Control is a common name for re-transmission control and duplication control. The Data Integrity control ensures that the MSDUs arrive in sequence they have been sent, the duplicate MDSUs are filtered and there are no errors in MDSU content. MDSU loss is allowed as long as it doesn't violate the QoS required.

5.3.5.2 CDU Building

The data is transmitted in CDUs that are sub-elements of the Service Connection Control Information Elements. The **Error! Reference source not found.** shows an example of the CCU building.

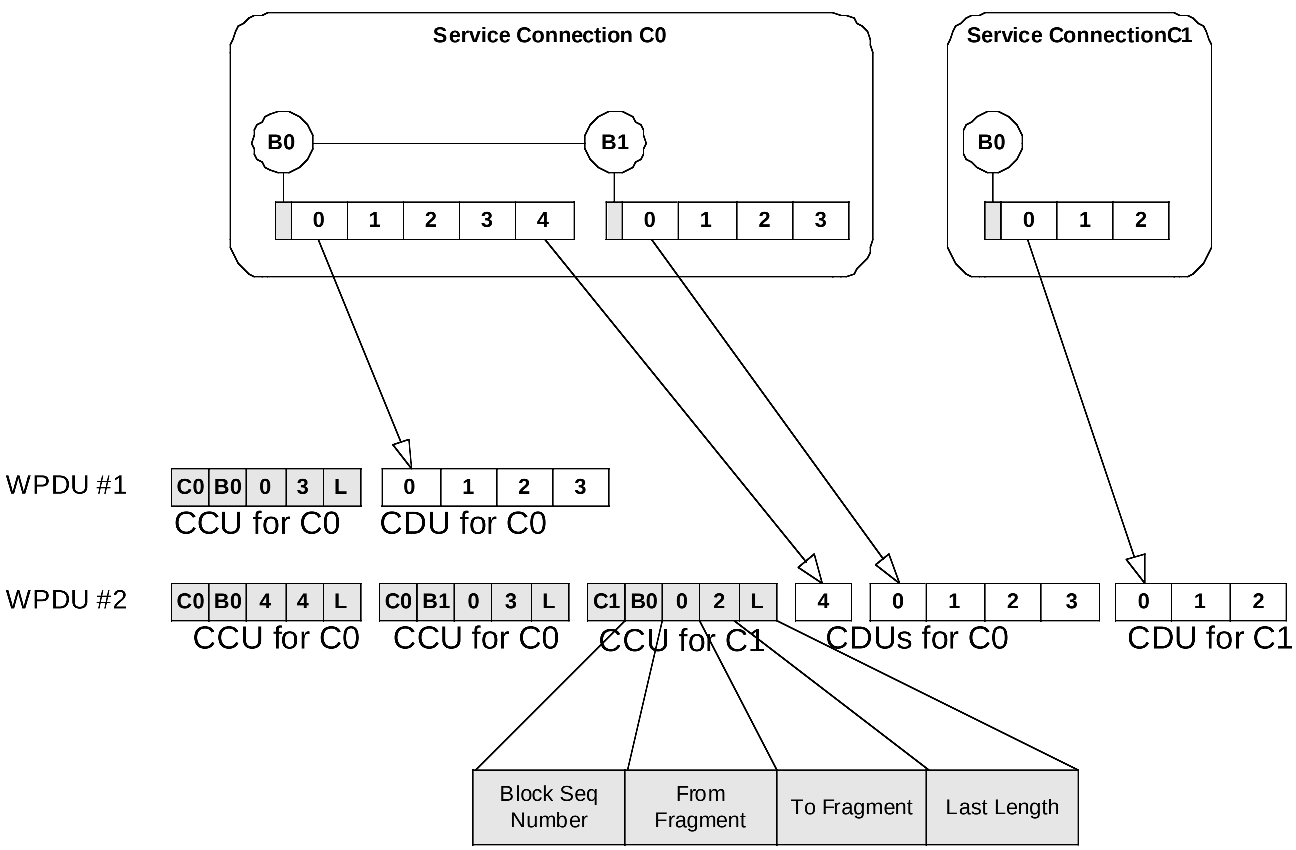

Figure 7. Example of CCU Building

Data fragments of the Service Connection C0 and Service Connection C1 are divided between 3 WPDUs. No feedback is added. Each WPDU contains 4 Data Fragments.

5.3.5.3 Feedback IE Building

The **Error! Reference source not found.** shows Tx and Rx entities located both at the same 802.16 peer. This is an example of building a single WPDU that carries a single CDU and a Feedback IE that is a part of CCU. The feedback is positive (bit P/N = ‘1’) and reports the fragments that have been received. Only the fragments that have not been acknowledged yet are sent. “MDSU SN” and “MDSU RN” are respectively the serial numbers of the last MSDU sent and the last MSDU received.

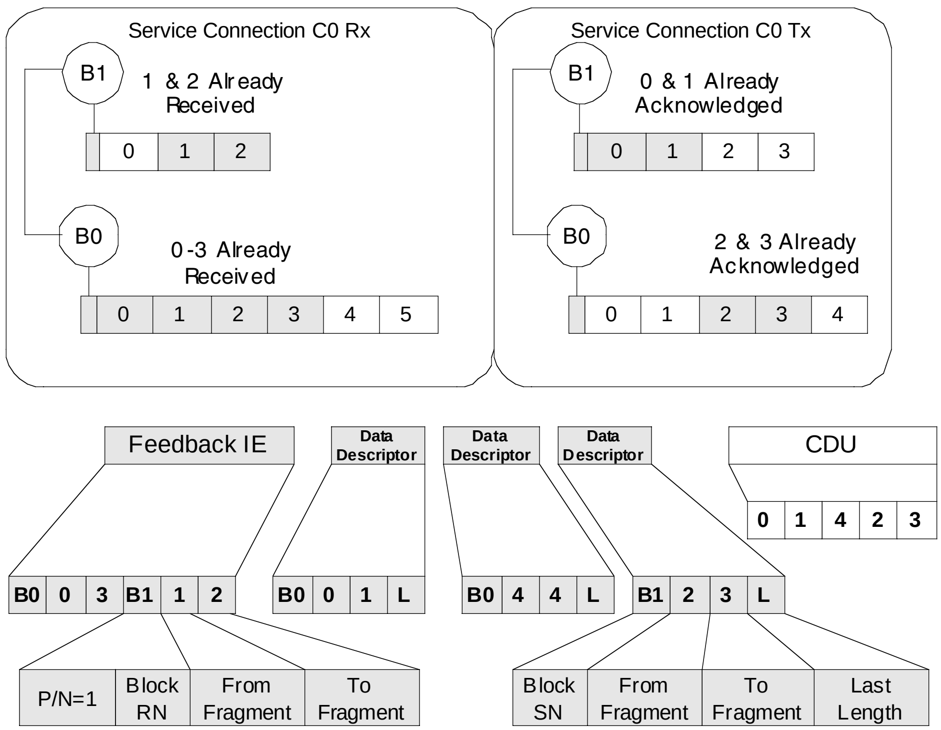

Figure 8. Example of Data Element and Positive Feedback Building

The **Error! Reference source not found.** shows the same situation but the feedback is negative (bit P/N = ‘0’) and reports the fragments that are yet to be received.

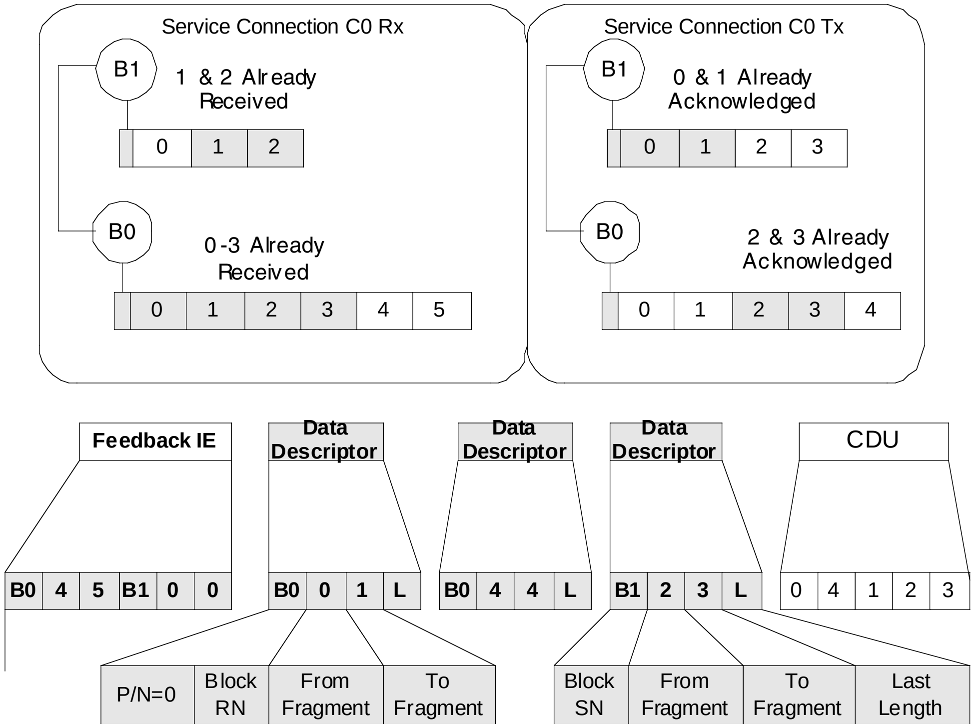

Figure 9. Example of CDU and Negative Feedback Building

5.3.5.4 Transmission, Re-Transmission and Duplication Control

The rules below should be followed.

The WPDU may consist of any number of CDUs, each of which may consist of any number of fragments. The MSDU is the unit of data delivery. In the case of Down Link transmission, the AU will allocate Up-Link time for transmitting the Acknowledge messages, either as a stand-alone or as a piggyback messages.

The MSDUs must be either delivered in whole or dropped. The receiver should preserve original MSDUs' ordering and discard the duplicated MSDUs and Fragments.

Each MSDU is assigned Time-to-Service (TTS). The MSDU might be re-transmitted as long its Elapsed Service Time (EST) doesn't exceed the TTS. The Transmitter and receiver start monitoring EST upon MDSU's entry.

The number of outstanding transmissions (i.e. without acknowledge) must be limited to the Receiver Buffer size, which defines the receiver's storage capacity for a Service Connection.

5.4 Network Entry

5.4.1 First Time Entry

5.4.1.1 Scanning and Synchronisation to Downstream

Subscriber Station will passively listen at a randomly chosen frequency to receive a Super-Frame Header. The frequency is periodically changed through all the possible channels. Once SU receives a DL WPDU with SFH, it checks whether this AU is the desired one to associate. If yes, it starts Signalling Connection establishment process.

5.4.1.2 *Obtain Upstream Parameters*

Signalling Connection establishment starts from attempts to send a frame with the corresponding request during the Contention Period. If succeeded, the AU schedules further communication with the SU. This step includes also the measurement of the distance between AU and SU and power control settings.

5.4.1.3 *Message Flows During Scanning and Upstream Parameter Acquisition*

During these steps AU and SU execute Authentication and Association Protocols that are basically the same as for 802.11 standard.

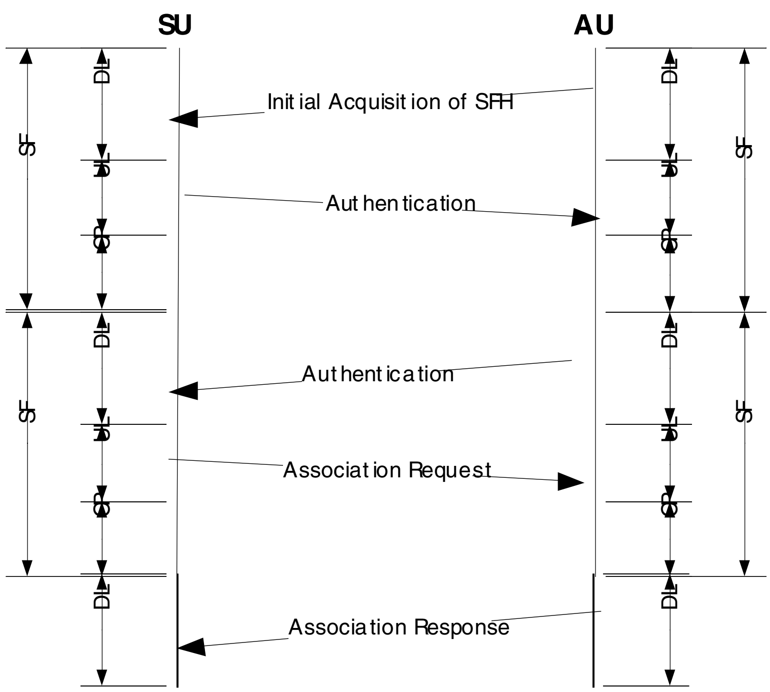

Figure 10.Authentication and Association = Establishment of Signaling Connection

5.4.1.4 *Ranging and Automatic Adjustments*

These functions are performed at the initial steps of Signaling Connection establishment.

5.4.1.5 *Initial Connection Establishment*

Finally the SU will be registered at AU. This means also that the **Signaling Connection** is established between AU and SU. For this type of connection AU uses CCU field at DL WPDUs (with empty CDU). Generally no capacity is allocated except periodic maintenance ("Still Alive") initiated by AU. At SU, for the Signaling Connection CP WPDUs are used.

5.4.2 Recurring Entry

5.4.2.1 *Scanning and Synchronization to Downstream*

If the Subscriber Station stops hearing the Super Frame Headers for a predefined duration of time it repeats the registration procedure.

5.4.2.2 Obtain Upstream Parameters

Same as for at the First Time Entry except possibly distance measurement.

5.4.2.3 Message Flows During Scanning and Upstream Parameter Acquisition

Same as for at the First Time Entry.

5.4.2.4 Ranging and Automatic Adjustments

Same as for at the First Time Entry.

5.4.2.5 Initial Connection Establishment

Same as for at the First Time Entry.

5.4.3 Reinitialization

5.4.3.1 Scanning and Synchronization to Downstream

Same as for at the First Time Entry.

5.4.3.2 Obtain Upstream Parameters

Same as for at the First Time Entry except possibly distance measurement.

5.4.3.3 Message Flows During Scanning and Upstream Parameter Acquisition

Same as for at the First Time Entry.

5.4.3.4 Ranging and Automatic Adjustments

Same as for at the First Time Entry.

5.4.3.5 Initial Connection Establishment

Same as for at the First Time Entry.

5.5 Media Access Control Protocol Operation

5.5.1 Connection Establishment

If there is a request for Service Connection establishment from the AU side, then AU starts from the Connection Establishment Request sent as an Information Element (IE) that is a part of Signaling Connection CCU. This request contains Traffic Contract information. At the same SF a time interval for the SU is reserved for expected WPDU that contains Connection Establishment Acknowledgement. The SU sends the Connection Establishment Acknowledgement and then AU allocates some link capacity to the SU according to the Traffic Contract.

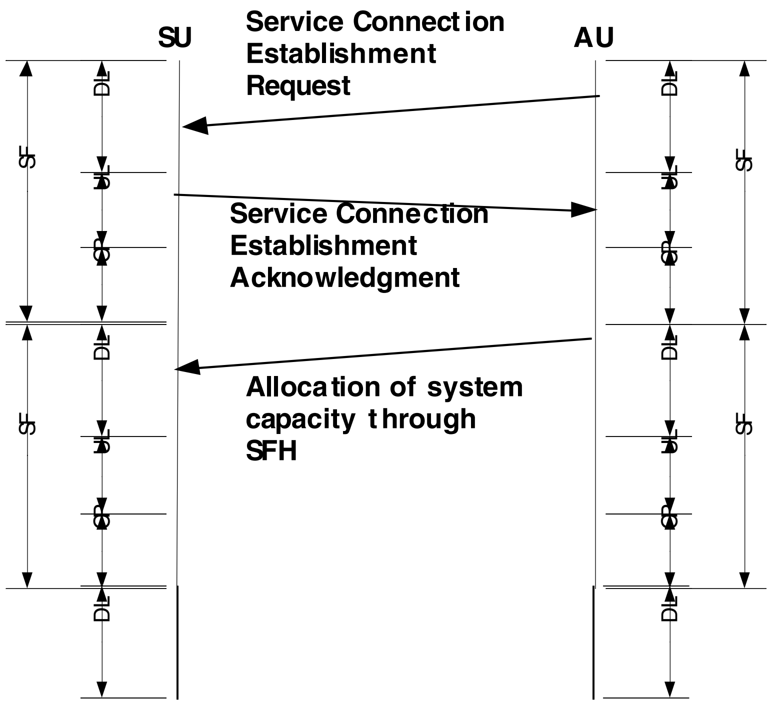

Figure 11. Service Connection Establishment Initiated by AU

If there is a request for Service Connection establishment from the SU side, then SU tries to send a Connection Establishment Request using the Signaling Connection during the Contention Period. The request contains the traffic contract information.

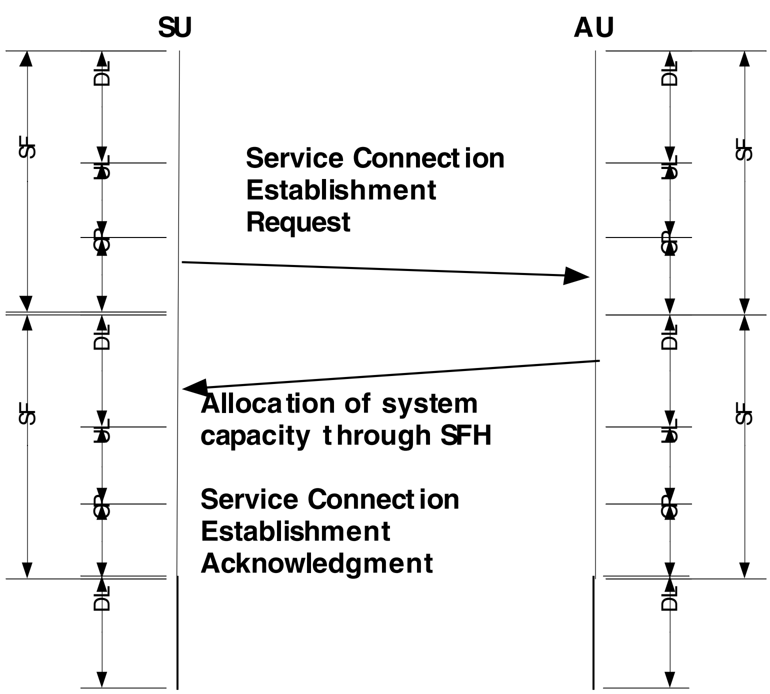

Figure 12. Service Connection Establishment Initiated by SU

5.5.1.1 Service Connection Admission

If the Subscriber Station wishes to establish a Service Connection it may send a Service Connection Establishment Request (SCERQ) to the Base Station as a separate frame during the Contention Period. The SCERQ contains the desired traffic contract. The Base Station may then accept the request or reject it. The SCERQ may be also piggybacked on the WPDU which carries data of another Service Connection.

5.5.1.2 Service Connection Admission Rules

TBD

5.5.2 Connection Release

Both AU and SU may request Service Connection release. The following pictures figure the corresponding messages exchange between the peers. These messages are sent through the Signaling Connection. In the case of release initiated by SU, the request might be may be either piggybacked on the uplink WPDU or optionally sent during CP

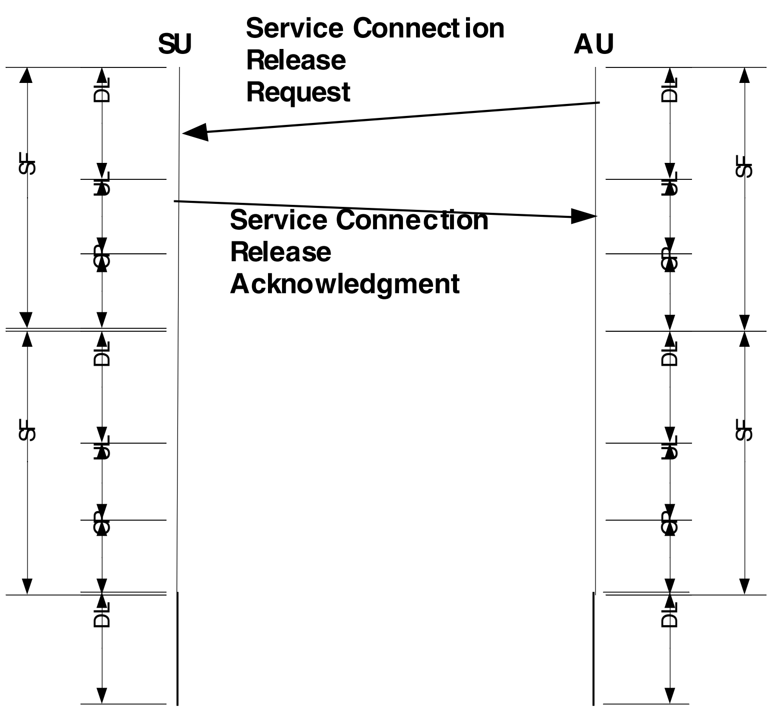

Figure 13. Service Connection Release Initiated by AU

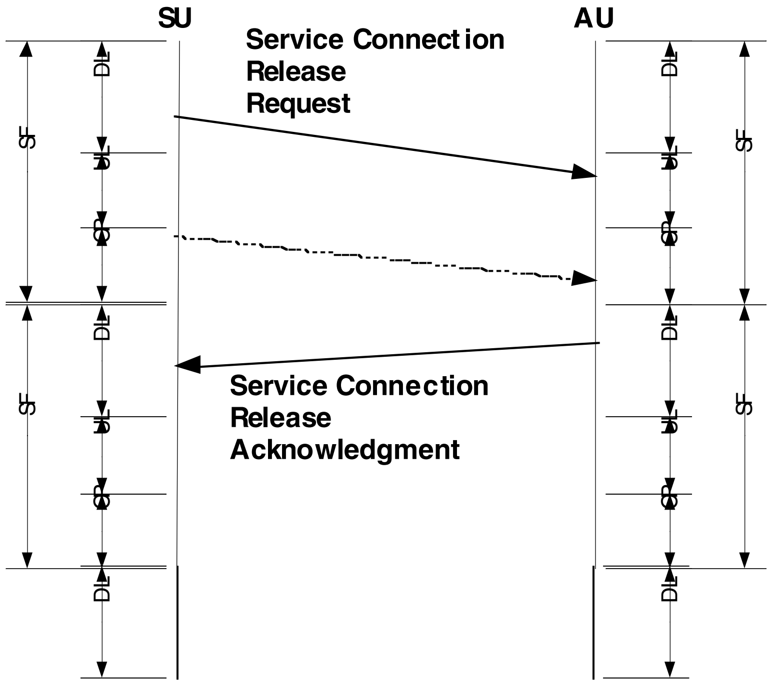

Figure 14. Service Connection Release **Initiated by S**U

5.5.3 MAC Link Management

5.5.3.1 Power and Timing Management

MAC provides the following functions to support Power and Timing management

- Power management decisions on the basis of provisioning and BER measurement
- Transfer (using Control Protocol) of the messages carrying the Power management measurements and feedbacks
- Time Stamps transfer
- Transfer (Using Control Protocol) of the messages related to the distance measurements

5.5.3.2 Bandwidth Allocation Management

The Radio channel bandwidth is allocated by the Scheduling Function located at the AU. The decisions are made on the basis of

- Traffic contracts for the active connections
- Demand for downlink transmissions coming from the upper layers at AU
- Demand for uplink transmissions coming from the associated SUs (Reservation Requests)

5.5.3.2.1 Up Link Reservation Techniques

The following paragraphs figure different techniques for delivery of the Reservation Requests (RRQs).

- **Polling in Advance Technique**

This is a case when the RR is a consequence of the Traffic Contract.

Polling is allocation of Up Link time by the AU, without an explicit reservation request from the Subscriber Station

- **On-Line Reservation Technique**

Each Up Link WPDU may contain piggybacked Reservation Requests (RRQs) for the next SF as it is shown in the **Error! Reference source not found.**.

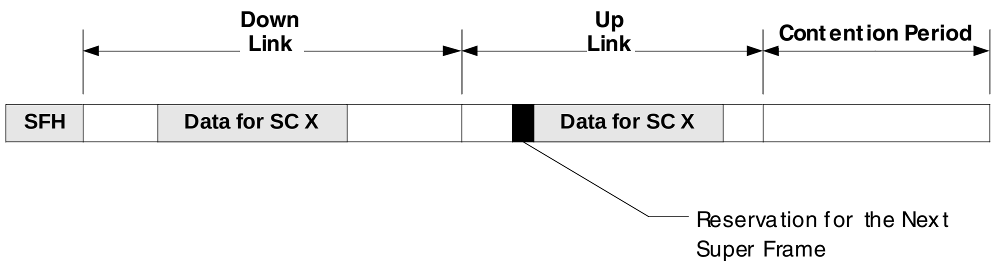

Figure 15. On-line Reservation

The AU will try to honour the reservation within the next Super-Frame. The Base Station may postpone the reservation if honouring it may affect QoS of other Service Connections.

- **Asynchronous Reservation Technique**

The Asynchronous Reservation takes place during the Reservation Period, which is a part of Contention Period (see **Error! Reference source not found.**).

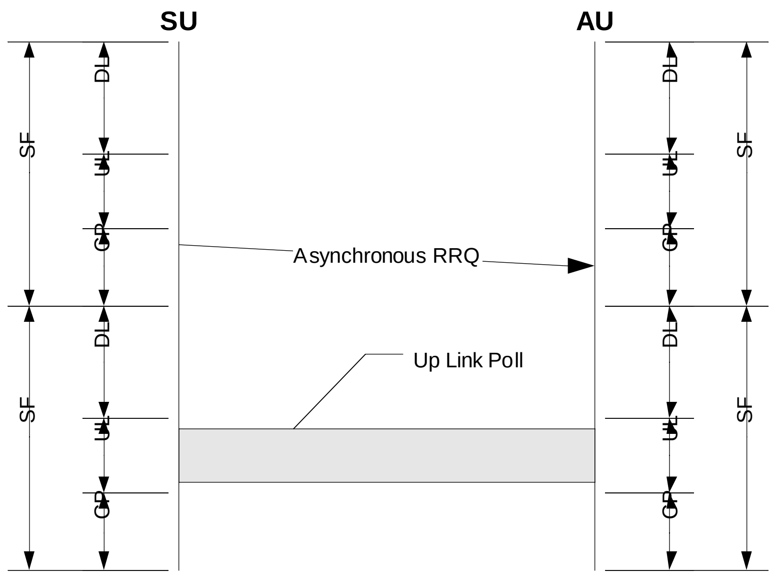

Figure 16. Asynchronous Reservation

The access method during a Reservation Period is ***p**-persistent* Slotted Aloha. The Base Station controls the persistency ***p*** of the Aloha Medium Access in each Reservation Period by distributing in the SFH the number of allocated RsTSs (***m***) and the estimated number of the subscribers to compete (***n***)

- Competition Rules

If the Reservation Period consists of m RsTSs and there are n subscribers competing for asynchronous reservation, then each Subscriber Station will chose randomly one of the reservation slots and transmit an Asynchronous RRQ with probability $p_t = \min\left(1, m/n\right)$. Thus each subscriber's probability of successful transmission appears as $P_s = \left(\frac{n-m}{n}\right)^{\frac{n-m}{m}}$ for $n > m$, and $P_s = \left(\frac{m-1}{m}\right)^{n-1}$ for $n \le m$.

Correspondingly the mean asynchronous reservation delay appears as $\overline{D_r} = \left(\frac{n}{n-m}\right)^{\frac{n-m}{m}}$ for $n > m$, and

$$\overline{D_r} = \left(\frac{m}{m-1}\right)^{n-1}$$ for $n \le m$.

For example, if there are 50 RsTSs in each Reservation Period and 100 subscribers compete for reservation, the reservation will succeed within **2** Reservation Periods. Ideally $m \cup n$, however the allocation of m depends on residual capacity. Note that if n is estimated correctly then whatever m such that $n > m > 0$ is allocated, the service acquisition delay will be predictable, and the utilisation of the Reservation Period will be ideal.

5.5.3.2.2 Scheduling Basics

The Super-frame duration is generally variable but there is a maximum allowed: **SFMaxDur** that is a protocol parameter. For certain applications the duration of the Super-frame may be chosen equal to constant e.g. 1 ms.

This paragraph contains tips for implementation of different Classes of Services (particularly, Committed Delay Service and Committed Rate Service) by means of proper scheduling.

- Scheduling Committed Delay Service Connections

Suppose we have to schedule servicing several Committed Delay connections with more or less periodic demand (packet arrival). Suppose that all the periods are multiple of **SP**. Then we may choose **SP** as a base period for scheduling so that each time interval of this length contains one or more SFs. In this case the demands arrived during some period SP are collected and scheduled to next period SP.

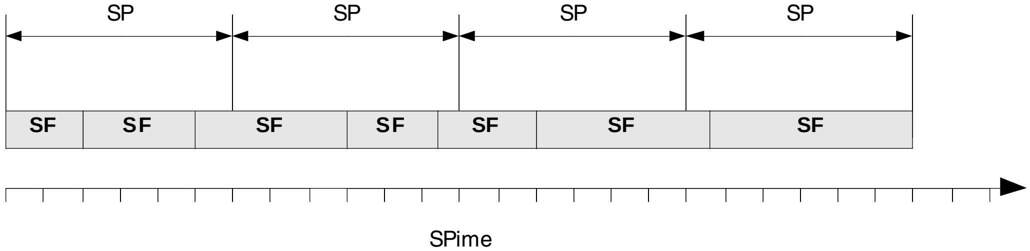

Figure 17. SPs and Super Frames

The following **Error! Reference source not found.** describes the timing of scheduling for Committed Delay Service Connection characterized by delay and delay variation (CD and CDV parameters). CD^T and CDV^T denote respectively the Committed Delay and Committed Delay Variation measured in SP units. For this kind of Service Connections a MSDU is supposed to arrive every $CD^T \pm CDV^T$ Scheduling Periods (this time period is called Possible Arrival Period). Ideally, the MSDUs arrive every CD^T exactly in the Expected Arrival SP (see).

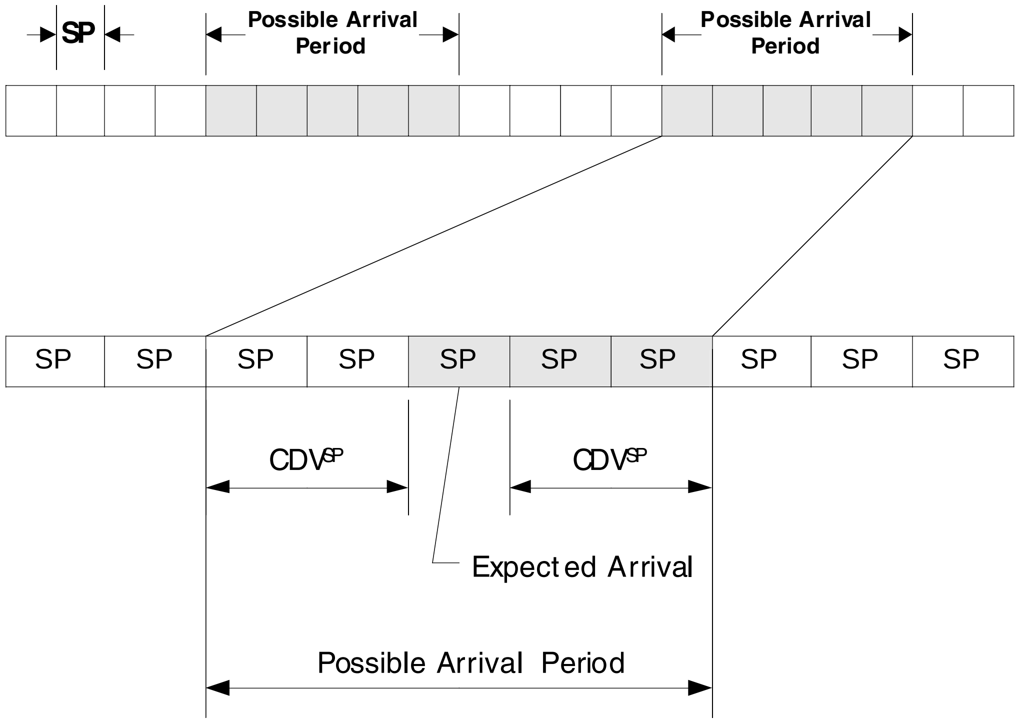

Figure 18. Arrival Expectation for CD CoS

- Scheduling Committed Rate Service Connections

The Committed Rate Service Connections will be served based on the demand and on the capacity remaining after satisfying the Committed Delay traffic requirements. In the Up Link the AU may poll the SU in advance according to the committed rate.

- Scheduling Uncommitted QoS Service Connections

The Uncommitted QoS Service Connections use Asynchronous Reservation to request service. When in service they are treated as Committed Rate Service Connections until no demand exists for a time being. Their state transitions in the Subscriber Station and in the Base Station are shown in the **Error! Reference source not found.** and **Error! Reference source not found.** respectively.

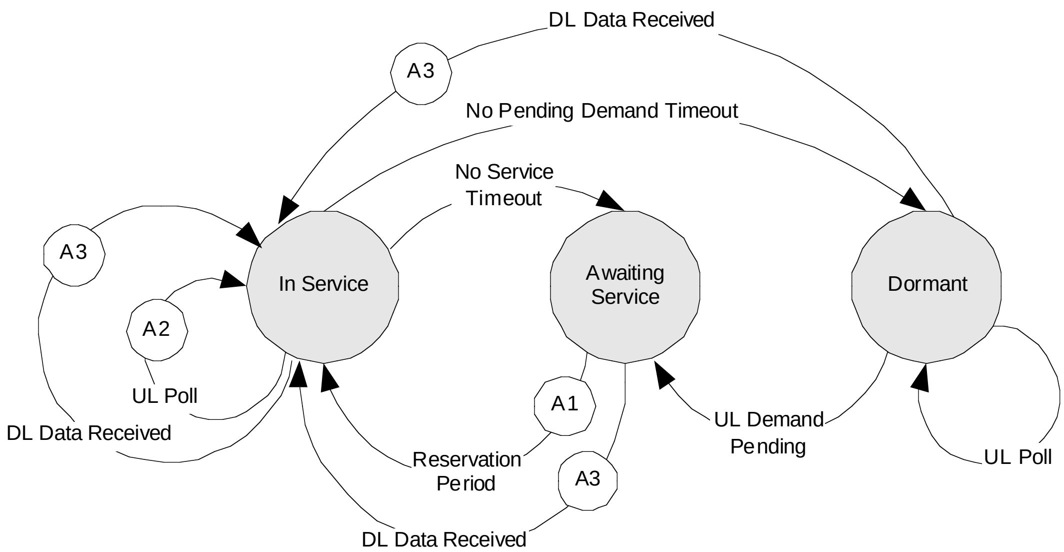

Figure 19. Uncommitted QoS Scheduling State Transitions in Subscriber Station

Table 9. Uncommitted QoS Scheduling State Transitions in Subscriber Station

Action ID	Description
A1	Send Asynchronous RRQ.
A2	Send data if any demand is pending. Use OLRT to reserve more Up Link time. Reset *No Service Timeout* timer
A3	Reset *No Service Timeout* timer

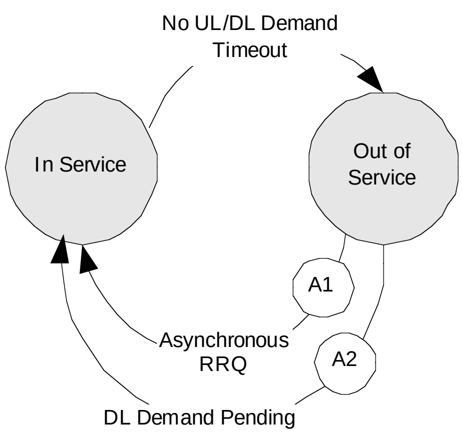

Figure 20. Uncommitted QoS Scheduling State Transitions in Base Station

Table 10. Uncommitted QoS Scheduling State Transitions in Base Station

Action ID	Description
A1	Send Asynchronous RRQ.

A2	Send data if any demand is pending. Use OLRT to reserve more Up Link time. Reset *No Service Timeout* timer
A3	Reset *No Service Timeout* timer

5.5.3.3 Channel Error Management

5.5.3.3.1 Retransmissions

The MAC protocol provides means for feedback information delivery thus allowing retransmissions to fix the channel errors.

5.5.3.3.2 Power Control

The MAC protocol uses either packet loss rate detected by the MAC or signal quality information provided by PHY level for power control. In our view, the specific algorithms are beyond the scope of MAC specifications.

5.5.3.4 Link Management Messages

TBD

Addendum A. Evaluation Table

Meets system requirements

The proposed MAC has a wide range of provisions for supporting both time-bounded, connection oriented and conectionless services. In particular, it provides an improved latency for asynchronous services by adaptively shortening the polling period, without compromising the support of delay sensitive services.

Mean access delay and variance

The MAC has the tools for prioritizing and scheduling the transmissions in order to satisfy the delay and delay variation commitments. The delay variation may be further reduced by time-stamping the MSDUs and reading those out of jitter-eliminating elastic buffers.
It is definitely possible for an operator to offer a bounded delay services.

Payload and Bandwidth Efficiency

How well does the overhead due to the proposed MAC PDU headers allow for efficient user data transfer over the 802.16 air interface? Is the proposed MAC protocol designed such that the MAC signaling is efficient in terms of not requiring excessive overhead? How well does the proposed MAC protocol provide the mechanisms for fair allocation and sharing of the bandwidth among users?

Simplicity of Implementation/low complexity

The parsing of the MAC protocol messages (WPDUs) is simple enough for either hardware or software implementation. The transmission scheduling, which is of higher complexity, is performed at the Base station, which is less sensitive to complexity and cost. The protocol described is tolerant enough to implementation efficiency (e.g. message parsing delay in the subscriber stations), so that simpler implementation will result in performance degradation rather than collapse of the system.

Scalability

The protocol parameters can be adapted to a wide range of operational bandwidths, supported data rates, physical layer characteristics.

Service Support Flexibility

1. The MAC Protocol is able to recover from events such as unexpected shutdown or loss of link
2. The MAC provides the mechanisms required for supporting the services described in 802.16s0-99/5. Those include bounded delay, flexible bandwidth allocation, etc.. The mapping of the specific services onto the MAC mechanisms will be accomplished by the appropriate Convergence Layers.

Robustness

The protocol does include retransmission mechanisms for error control. Frame numbering prevents out-of-order reassembly. The scheduling mechanisms may include provisions for prioritizing the recovery of time-bounded data.

Security

The MAC protocol can be coupled with a variety of encryption mechanisms, both for authentication and for user data transfer. This initial presentation of the protocol does not dwell on the specific methods of accomplishing this task.

Maturity

The proposed protocol is new.

Sign-on process

1. The MAC Protocol resolves initial two-way ranging during the registration procedure using frames equipped with Time Stamps.
2. The Sign-on process is completely automatic.

Convergence with existing technologies

The proposed protocol draws on some ideas familiar in the industry (DOCSIS, 802.11), however, the specific combination presented here is new.

Adequacy of Management Functions

Full range of Management Function (timing, power, frequency) will be supported based on the Signaling Connection that is “always on”Æ
Specifically, the capacity management provided by the protocol is very dynamic with very small response time for the change of the traffic demand.

Convergence with Existing Protocols

The proposed protocol draws on some ideas familiar in the industry (DOCSIS, 802.11), however, the specific combination presented here is new.

Ability to work with physical layer variations, e.g., duplexing, constellation

The proposed MAC protocol supports a wide range of variants of Physical Layer. It can operate both in TDD, FDD and FDD-half duplex modes, depending on the scheduler. The scheduling can readily incorporate the capability of the PHY to transmit at varying data rates (constellations). The protocol assumes packet transmission both in downstream and upstream, but can readily incorporate a continuous downstream in FDD mode, if desired.

Physical Channel Configurability

The MAC protocol has provisions for controlling the PHY parameters. The data rate and transmit power can be altered both in upstream and in upstream per subscriber station or even per logical connection.