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Source	Brian Petry (editor) 3Com 12230 World Trade Dr. San Diego, CA 92128	Voice: Fax: E-mail:	858-674-8533 858-674-8733 brian_petry@3com.com
Re:	This functional requirements document is output from the 802.16.1 System Requirements Task Group. Please be sure you are reading the most recent published version of this document (802.16s-xx/y where xx/y is the version number) which can be found at: http://grouper.ieee.org/groups/802/16/sysreq		
Abstract	This document provides functional requirements that are guidelines for developing an interoperable 802.16.1 air interface. The 802.16.1 committee desired to reach an understanding and consensus for the functional requirements of 802.16.1 protocols before proceeding with developing the standard and thus formed a System Requirements Task Group to produce this document.		
Purpose	At 802.16 session #4, the 802.16 working group accepted this version as a binding document for development of the 802.16.1 air interface standard (please refer to session #4 minutes).		
Notice	This document has been prepared to assist the IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.		
Release	The contributor acknowledges and accepts that this contribution may be made publicly available by 802.16.		

Revision History

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Arun Arunachalam

Robert Duhamel

George Fishel

Imed Frigui

Marianna Goldhammer

Hossein Izadpanah

David Jarrett

Leland Langston

John Liebetreu

Willie Lu

Scott Marin

James Mollenauer

William Myers

Asif Rahman

Margarete Ralston

Gene Robinson

Michael Stewart

Jung Yee

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1 Introduction

This document provides functional requirements that are guidelines for developing an interoperable 802.16.1 air interface. The 802.16.1 committee desired to reach an understanding and consensus for functional requirements before proceeding with developing standards for 802.16.1 MAC and PHY protocols and thus formed a System Requirements Task Group to produce this document.

Please note that this document provides guidelines for the 802.16 working group. Its purpose is to formulate and facilitate consensus on some general issues prior to plunging into MAC and PHY details. As such, the functional requirements are subject to change as the 802.16 working group debates the issues, makes revisions, and approves this document as a basis for starting the “Interoperability Standard” [20].

The Functional Requirements will not be published or sold by the IEEE. The requirements, with possible future amendments, are binding to the future development of 802.16.1 air interface protocols. This means that the forthcoming air interface standard MUST comply with the functional requirements.

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST" or “SHALL” These words or the adjective "REQUIRED" means that the item is an absolute requirement..

"MUST NOT" This phrase means that the item is an absolute prohibition.

"SHOULD" This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.

"SHOULD NOT" This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

"MAY" This word or the adjective "OPTIONAL" means that this item is truly optional. One implementation may include the item because the target marketplace requires it or because it enhances the product, for example; another implementation may omit the same item.

1.1 Scope

For the purposes of this document, a “system” constitutes: an 802.16.1 MAC and PHY implementation, in which at least one subscriber station communicates with a base station via a point-to-multipoint (P-MP) radio air interface, the interfaces to external networks, and services transported by the MAC and PHY protocol layers. So, “functional requirements” describes the properties of typical systems in terms of how they affect requirements of interoperable 802.16.1 MAC and PHY protocols. The functional requirements describe 802.16.1 systems and

requirements in broad terms: *what* they are, but not *how* they work. The *how* part is left to the forthcoming 802.16.1 interoperability standard [20], which will describe in detail the interfaces and procedures of the MAC and PHY protocols.

Since many BWA *systems* are conceivable, with many possible interconnections, inter-working functions [17] and parameters, this document does not specify them all, but focuses on the bearer services that an 802.16.1 system is required to transport. These *bearer services* have a direct impact on the requirements of the 802.16.1 MAC and PHY protocols. When the 802.16 working group produces an interoperable air interface standard that meets these functional requirements, resulting 802.16.1 systems provide the services required to neatly interface into many conceivable BWA systems. See section 1.2.

Other goals of this document are to formulate reference models and terminology for both network topology and protocol stacks that help the 802.16 working group to discuss and develop the MAC and PHY protocols.

The 802.16.1 air interface interoperability standard SHALL be part of a family of standards for local and metropolitan area networks. The 802.16.1 protocols relate to other 802 standards and to the OSI model as shown in Figure 1.

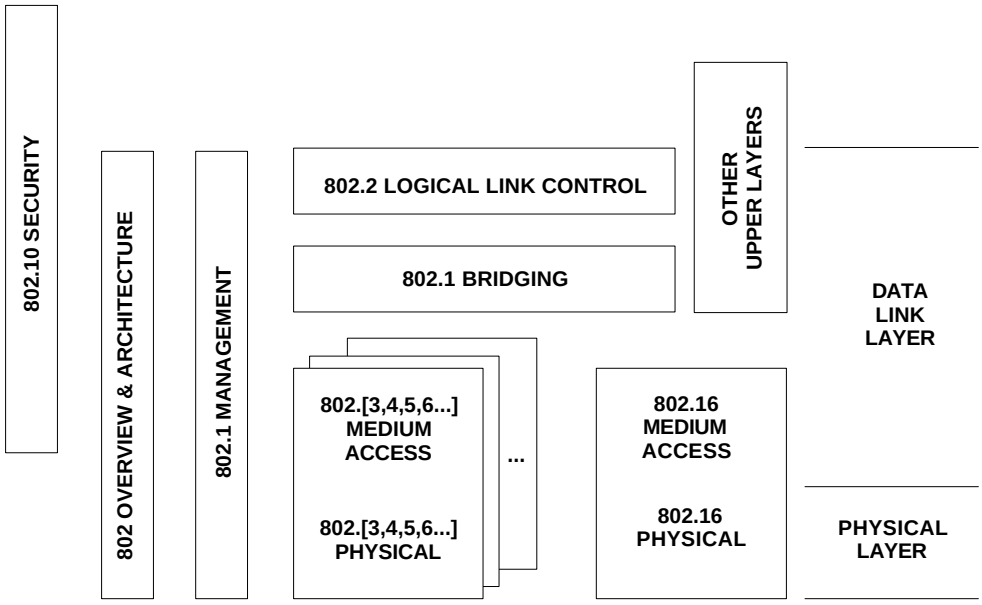

Figure 1: Relationship between 802.16.1 and other Protocol Standards (the numbers in the figure refer to IEEE standard numbers)

This family of standards deals with the Physical and Data Link layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO 7498: 1984). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards that define the technologies noted in the above diagram are as follows:

IEEE Std 802: Overview and Architecture. This standard provides an overview to the family of IEEE 802 Standards. This document forms part of the 802.1 scope of work.

ANSI/IEEE Std 802.1B [ISO/IEC 15802-2]: LAN/MAN Management. Defines an Open Systems Interconnection (OSI) management-compatible architecture, environment for performing remote management.

ANSI/IEEE Std 802.1D [ISO/IEC 10038]: MAC Bridging. Specifies an architecture and protocol for the interconnection of IEEE 802 LANs below the MAC service boundary.

ANSI/IEEE Std 802.1E [ISO/IEC 15802-4]: System Load Protocol. Specifies a set of services and protocols for those aspects of management concerned with the loading of systems on IEEE 802 LANs.

ANSI/IEEE Std 802.2 [ISO/IEC 8802-2]: Logical Link Control

ANSI/IEEE Std 802.3 [ISO/IEC 8802-3]: CSMA/CD Access Method and Physical Layer Specifications

ANSI/IEEE Std 802.4 [ISO/IEC 8802-4]: Token Bus Access Method and Physical Layer Specifications

IEEE Std 802.10: Interoperable LAN/MAN Security, Secure Data Exchange (SDE)

1.2 Target Markets

The target markets described in this section are not an exhaustive set, but serve as guidelines and examples that suffice for meeting the broad applicability goals set forth by the air interface “Five Criteria” [20a].

A broadband wireless access (BWA) system based on 802.16.1 protocols is expected to address markets similar to wired broadband access technologies such as:

- Copper digital subscriber line (DSL) technologies
- Digital cable TV hybrid fiber/coax (HFC) networks
- Integrated Services Digital Network (ISDN)
- Legacy TDM digital transmission systems (e.g., Full and Fractional T1, E1, ISDN-PRI etc.)
- The services that such legacy systems carry: data, voice and audio/video [8].

The initial target markets to be addressed by the 802.16.1 protocols in BWA networks are small to large businesses, and multi-tenant dwellings such as high rise buildings. 802.16.1 protocols in BWA networks may address the target market for single-family residences.

A key word in BWA is “access:” *access* to some other network such as the Internet, a private network, a telephony network, etc. An 802.16.1 access system generally provides access to an external network, and by itself is not intended to form an end-to-end communication system. 802.16.1 systems are fixed.

Sometimes, the word *subscriber* is associated with a single customer that is billed for a service. But it is important to note that a BWA system SHOULD support more than one paying customer at a single access point to a subscriber BWA radio. In other words, the subscriber access point is for "wholesale" connection of multiple "retail" subscribers [14]. For instance, an office building may be well served by a single BWA radio, but house many tenants who are billed separately. This requirement may for instance affect multiplexing in the MAC layer, security (see section 8), and accounting (see section 7.3).

The target markets can be further described by Figure 1-2 and Figure 1-3.

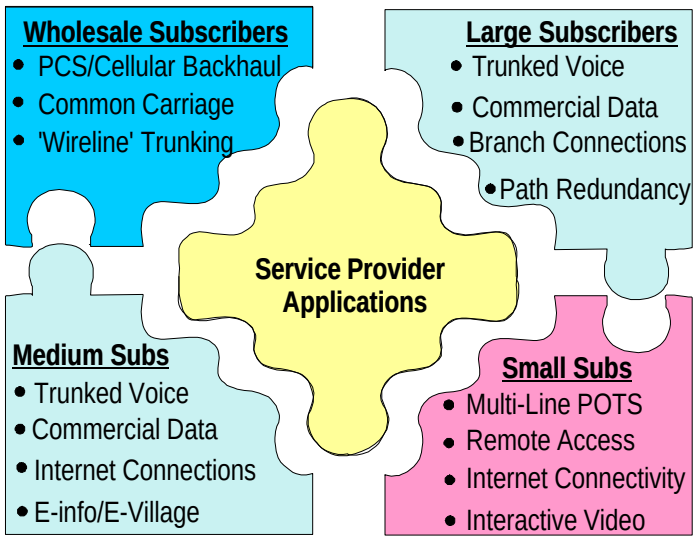

Figure 1-2: Summary of 802.16.1 Example Applications and Services

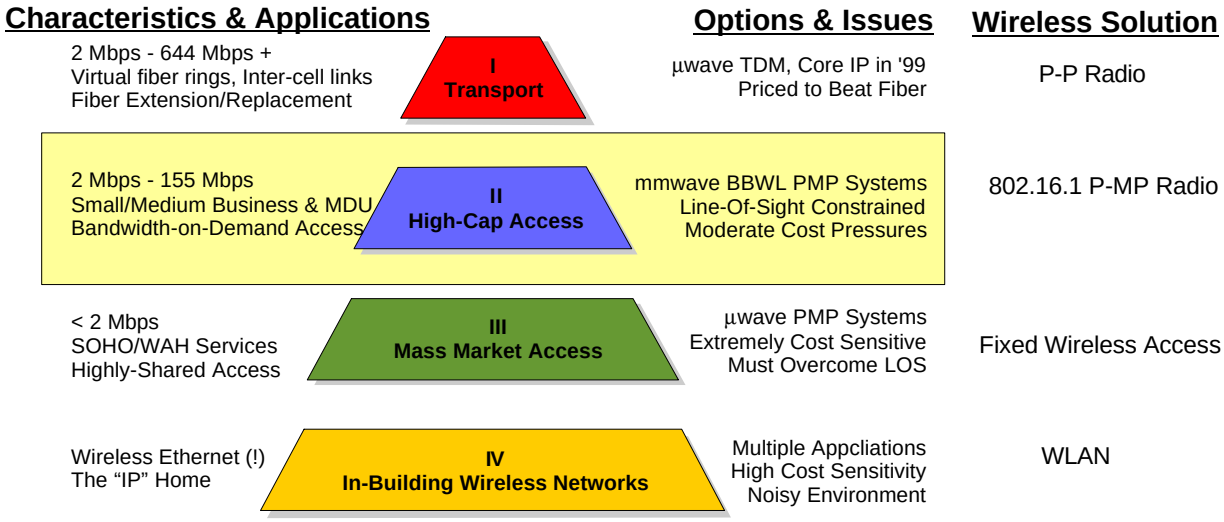

Figure 1-3: A Multi-Tier Perspective of Wireless Transmission and Distribution Systems

2 802.16.1 System Model

This section presents a high level description of a system model to be used as a framework for developing 802.16.1 protocol standards. The model describes some of the main features of an 802.16.1 system, and the terminology to be used by the 802.16 working group in the creation of the standards.

As mentioned in section 1.1, an 802.16.1 “system” constitutes: an 802.16.1 MAC and PHY implementation, in which at least one subscriber station communicates with a base station via a radio air interface (an 802.16.1 system), and services transported by the MAC and PHY protocols. An 802.16.1 system employs point-to-multipoint (P-MP) radios operating in the vicinity of 30 GHz, but generally in the range from 10 GHz to 66 GHz, to connect a base station to one or more subscriber stations [4][9]. Radio communications in the above range require line-of-sight (LOS) between a base station and subscriber station. LOS blocked by foliage also contributes heavily to signal attenuation. Figure 2-1 and Figure 2-2 [13] depict some typical 802.16.1 systems. 802.16.1 systems SHALL be multiple-cell frequency reuse systems. The range of 802.16.1 radios varies with transmit power, LOS blockage, availability requirement, and atmospheric conditions.

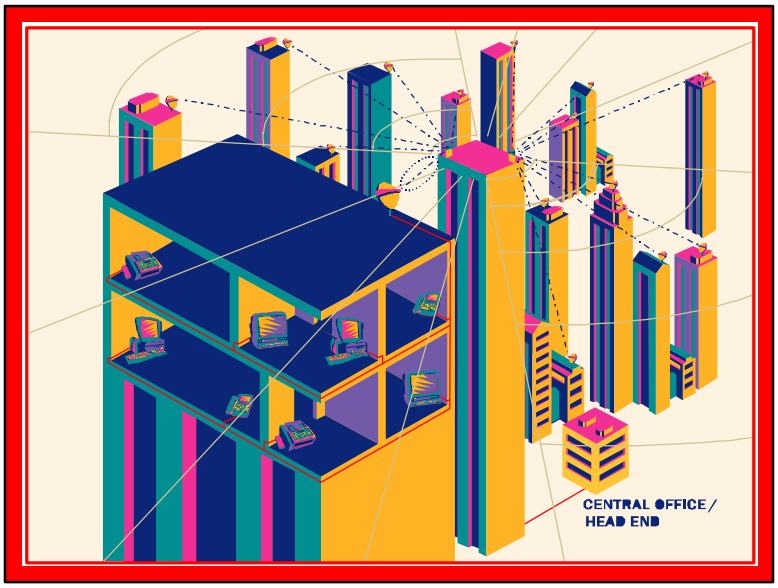

Figure 2-1: System Showing a Base Station Mounted on a Tall Bulding

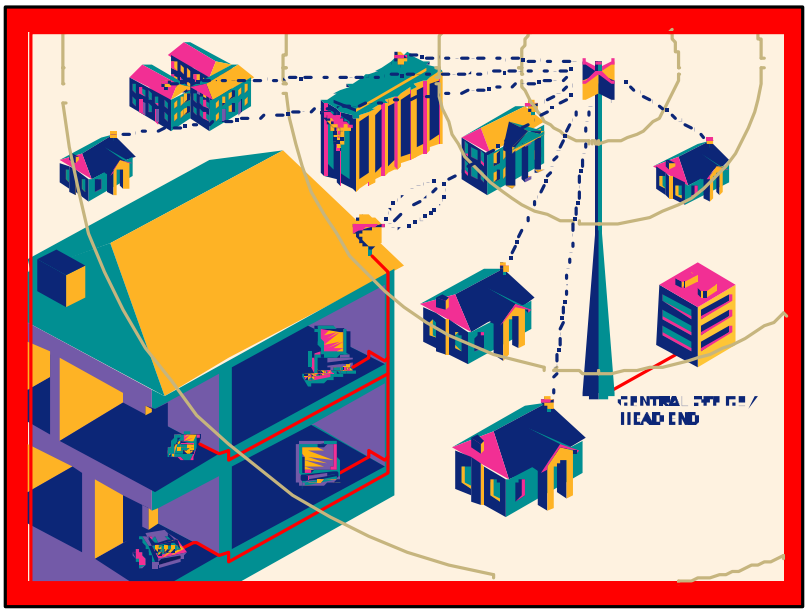

Figure 2-2: System Showing a Base Station Mounted on a Tower

Note that, in concern for simple terminology, an 802.16.1 *system* consists of one base station radio and one or more subscribers. Thus an 802.16.1 system also defines 802.16.1 base station and subscriber station radios that communicate using the 802.16.1 MAC and PHY protocols. The base station radio SHOULD be P-MP, radiating its *downstream* signal with a shaped sector antenna achieving broad azimuthal beam width to "cover" a prospective number of subscribers. Each subscriber station employs a highly directional radio pointed at the base station. Note that with this arrangement, direct radio communications between subscriber stations is not possible. Furthermore, the 802.16.1 system does not define radio communications between base stations. Since the base station radios are "sector oriented," multiple base station radios will likely, in practice, be co-located (subject to frequency re-use requirements), and even share physical hardware.

The frequency bands used by 802.16.1 systems vary among governed geographies [19].

2.1 System Reference Model

Figure 2-3 shows the 802.16.1 system reference points, depicting the relevant elements between a subscriber network and the "core" network (the network to which 802.16.1 is providing *access*). The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage. A greater system encompassing user terminals, base station interconnection networks, network management facilities, etc. [1] may be envisaged, but the 802.16.1 protocols focus on the simplified model shown in the figure. Also not shown are the internal physical characteristics of the base station and subscriber station: the concepts of "indoor" and "outdoor" units. The description of possible separation of base station and subscriber station into indoor and outdoor units is beyond the scope of this document. One addition to this model to be considered are security systems (see section 8). Two key interfaces "to the outside world" are shown in the figure: the Base Station Network Interface (BNI) and the Subscriber Station Network Interface (SNI). A single SNI may support multiple subscriber networks: LANs, Voice PBXs, etc. And recall from section 1.2 that the SNI may support multiple paying subscribers, such as within a

multi-tenant office building or dwelling. A base station interfaces to one or more core networks through one or more BNIs. For the purposes of 802.16.1, the SNI and BNI are abstract concepts. The details of these interfaces, which are sometimes called inter-working functions (IWFs), are beyond the scope of this document and are not specified by the forthcoming interoperability standard [20] [17]. Since many subscriber and core network technologies are possible, many different IWFs are conceivable. The simplified reference model, serves to discuss the impact of core network technologies and bearer services (see section 3.1) on the requirements of 802.16.1 protocols by drawing focus to the air interface and the immediate requirements imposed by the surrounding networks. The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and common modulation technique(s).

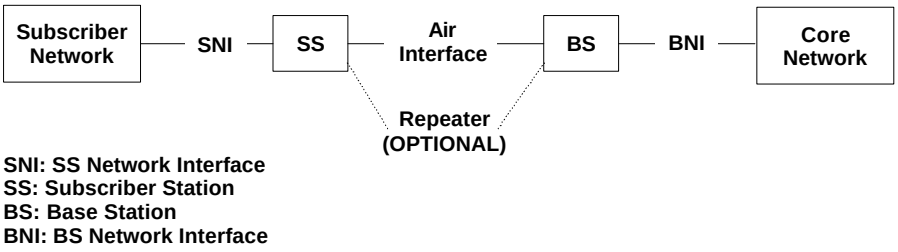

Figure 2-3: System Reference Points

2.2 Topology

Since all data traffic in a single cell of an 802.16.1 network MUST go through the base station, that station SHALL serve as a radio resource supervisor [10]. The subscriber stations may request bandwidth to achieve QoS objectives (see section 6), but it may be convenient for the base station to implement the “smarts” of bandwidth allocation.

In the downstream direction, within a channel, the network topology is similar to a contention-less broadcast bus, since all transmissions are transmitted by the base station, and more than one subscriber station could share a downstream channel. In the upstream direction, if subscriber stations share a channel, the topology is similar to a contention-oriented bus, 802.16.1 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.

3 Supported Services

This section describes the bearer services that an 802.16.1 system at least SHOULD support (some services MUST be supported). First, typical target markets are described, then the particular bearer services which an 802.16.1 system is expected to transport.

It may be difficult to comprehend services the system supports without first understanding the system model. Please refer to section 2 if necessary.

3.1 Bearer Services

This section describes typical services, transported by an 802.16.1 system. In this document, *bearer services* refer to the services provided by the protocols that can appear in the layer sitting directly over the MAC layer. The meaning of bearer services in this document also includes the types of networks that are able to interface with 802.16.1-based BWA networks. [12] [54].

The MAC and PHY protocols may not have explicit support for each and every bearer service, since they SHOULD be handled as data streams in a generic fashion. But it is important to consider all the bearer services for any particular requirements they may have and extract the "common denominators" that result as generic parameters of MAC and PHY protocols.

3.1.1 Digital Audio/Video Multicast

802.16.1 protocols SHOULD efficiently transport digital audio/video streams to subscribers. This form of digital transport MAY bypass the MAC protocol layer. The streams flow in the direction of the infrastructure network to subscriber(s) only, and do not originate from subscribers. Digital Audio/Video Multicast service is thus similar to digital video capabilities of digital broadcast cable TV, and digital satellite television service.

3.1.2 Digital Telephony

802.16.1 systems SHOULD support supplying telephony "pipes" to subscribers in a way that eases the migration of legacy telephony equipment and public switched telephone network (PSTN) access technologies to 802.16.1 systems. 802.16.1 protocols MAY transport any layer in the nationally- and internationally-defined digital telephony service hierarchies: Synchronous Digital Hierarchy (SDH) or Plesiochronous Digital Hierarchy (PDH) (please see the glossary entries in appendix B).

Note that many forms of digital telephony are possible:

- Narrow band/Voice Frequency Telephony - POTS (supporting FAX services), Centrex, ISDN BRI
- NxDSO Trunking - Fractional DS1/E1 to PBXs and/or data equipment, ISDN PRI
- Full DS1/E1 - transparent mapping including all framing information
- Voice Over IP, Voice Over Frame Relay, Voice and Telephony over ATM (VTOA), and similar services

802.16.1 systems and protocols MUST support the QoS requirements of these services, as defined in Section 6.

3.1.2.1 Telephony Service Properties

The relevant properties of telephony services are [12] [54]:

- Bandwidth – in general, the codings used in these services require bandwidths in the range of 64 Kbps or less per call (one exception is ISDN BRI service with both B channels and the D channel active, which uses 144 Kbps). There are also some subjective quality metrics for the clarity of the encoded speech signals, that can vary based on the quality of the services sold to the end user (e.g., residential vs. business).

- Low delay – as apparent to the end users, the amount of delay between a user speaking and another user hearing the speech MUST be kept below a certain level to support two-way conversation. Again, the specific amount of delay can vary based on the quality of the service sold to the end user.

- Timing - (Fractional) DS1/E1 services require timing to be delivered from the network to the end user's equipment, whether the timing is synchronous with the network (i.e., based on the serving network's clock) or asynchronous with the network (based on a clock other than the serving network's clock).

BWA protocols MUST support efficient transport of encoded voice data in terms of bandwidth, reliability and delay. Other properties are managed by digital signaling protocols (see section 3.1.2.2).

3.1.2.2 Signaling Systems and Protocols

Telephony and video conferencing signaling protocols may place specific requirements on 802.16.1 protocols. Some relevant telephony signaling protocols are: Bellcore TR-008, V5.X, Q.931, Q.2931, H.225, H.245, H.323, MGCP, Bellcore GR-303, , MFC R2, E&M, Q.sig, IETF SIP, etc. [12] [17] [61] [editor's note: protocol references not cited].

In digital telephony hierarchies, periodic bits in the time-division-multiplexed data stream, sometimes "robbed" from encoded voice streams, are used to transport signaling and troubleshooting information [12]. Other signaling protocols (such as those used in ISDN and B-ISDN/ATM) are message-oriented and do not utilize periodic bits in a TDM data stream. The 802.16.1 protocols MUST meet the transport requirements of such telephony signaling, whether TDM- or message-oriented.

3.1.3 ATM Cell Relay Service

ATM standards define a rich set of quality of service (QoS) guarantees for various service categories [8].

802.16.1 protocols SHOULD be defined such that an 802.16.1 system can efficiently transport ATM cell relay service and preserve its QoS features (see section 6).

Also note that, since ATM cell relay service is circuit-based, it employs message-based signaling protocols (Q.2931) to establish, maintain and tear down switched virtual circuits as well as signal QoS-based services and perform network management. 802.16.1 protocols may need to be cognizant of such ATM signaling to enable an 802.16.1 system to preserve QoS (see also section 3.1.2.2).

802.16.1 SHOULD provide a means to utilize ATM addresses such as ITU-T E.164 [74]. For instance, 802.16.1 MAY provide a direct ATM addressing mode for 802.16.1 nodes, or MAY provide a means to translate ATM addresses to 802 addresses [10].

3.1.4 Internet Protocol Service

The 802.16.1 system MUST directly transport variable length IP datagrams efficiently. Both IP version 4 and 6 MUST be supported. For efficient transport of IPv6, TCP/IP header compression over the air interface SHOULD be supported.

The 802.16.1 IP service MUST provide support for real-time and non-real-time services. It SHOULD be possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated Services [43, 44] and Integrated Services [42].

3.1.5 Bridged LAN Service

The 802.16.1 protocols MAY support bridged LAN services, whether directly or indirectly.

3.1.6 Other Services

Other services that for instance require QoS-based delivery of the MAC services similar to channelized SDH/PDH telephony, cell relay service, IP service or bridging service (see above sections), are envisaged. These services do not place any special requirements on 802.16.1 systems (MAC and PHY protocols) not already covered in the above sections. Some services are:

- **Back-haul service** for cellular or digital wireless telephone networks. An 802.16.1 system may be a convenient means to provide wireless trunks for wireless telephony base stations. The channelized SDH/PDH services or ATM cell relay service may be appropriate.

- **Virtual point-to-point connections** for subscriber access to core network services [9]. In the example system described in [9], the Internet-oriented point-to-point protocol (PPP) is employed to make virtual connections between subscribers and service providers and PPP is encapsulated directly in the 802.16.1 MAC protocol. PPP has some benefits such as simple authentication, privacy/encryption, data compression, and layer 3 network parameter assignment. PPP-over-802.16.1 is not expected to place any additional requirements on 802.16.1 protocols, and is expected to be similar to IP or bridged LAN service.

- **Frame Relay Service** Frame Relay is a packet/frame-based protocol, circuit-based data service that uses a simple variable-length frame format. Some basic QoS guarantees are defined for frame relay, but not as rich as ATM. Frame relay networks typically use provisioned permanent virtual circuits (PVCs), although a signaling protocol for switched virtual circuits (SVCs) is defined (Q.933) and in use. Frame Relay also defines a management protocol. [3] [12].

The 802.16.1 protocols SHOULD not preclude the transport of the above mentioned services.

4 Protocols

Protocols are the heart of the 802.16.1 standard that, when described well, result in interoperability of multiple vendors' equipment. Protocol interoperability occurs at each level in the protocol "stack" [16]. IEEE 802 protocols reside at layer 1 and 2 and consist primarily of Logical Link Control (802.2) [67] and the various MAC and PHY layers for each LAN or MAN standard. The IEEE Std 802-1990 *Overview and Architecture* [21] describes these layers as follows (excerpt from 802-1990) :

"The LLC Sublayer (sublayer of layer 2) describes three types of operation for data communication between service access points: unacknowledged connectionless (type 1), connection-oriented (type 2), and acknowledged connectionless (type 3).
With type 1 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. These LLC frames are not acknowledged, nor are there any flow control or error recovery procedures.
With type 2 operation, a logical link is established between pairs of LLC entities prior to any exchange of information frames. In the data transfer phase of operation, information frames are transmitted and delivered in sequence. Error recovery and flow control are provided.
With type 3 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. However, the frames are acknowledged to allow error recovery and proper ordering. Further, type 3 operation allows one station to poll another for data."

"The MAC Sublayer performs access control functions for the shared medium in support of the LLC Sublayer. For different applications, different MAC options may be required. The MAC Sublayer performs the addressing and recognition of frames in support of LLC. MAC also performs other functions, such as frame check sequence generation and checking, and LLC protocol data unit (PDU) delimiting."

"The Physical Layer provides the capability of transmitting and receiving bits between Physical Layer Entities. A pair of Physical Layer Entities identifies the peer-to-peer unit exchange of bits between to MAC users. The Physical Layer provides the capability of transmitting and receiving modulated signals assigned to specific frequency channels, in the case of broadband, or to a single-channel band, in the case of baseband."

The 802.16.1 protocol stack reference diagram is shown in Figure 4-1. In addition to the LLC, MAC and PHY layers suggested by the generic 802 architectures [21] [22] [23], 802.16.1 protocols transport other categories of "upper protocols" that correspond to the requirements of the bearer services described in section 3.1.

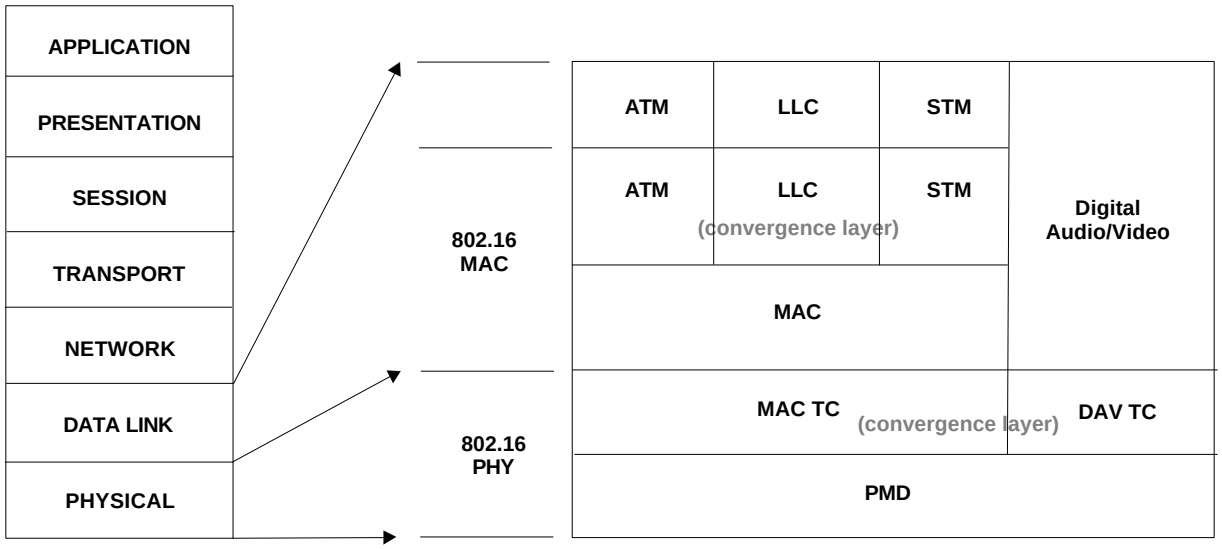

Figure 4-1: Protocol Stack Reference Model

This protocol stack reference model is intended to help develop terminology, and possibly protocol architecture. Each of the "special" protocols above the MAC and PHY are given "convergence sub-layers.". The convergence sub-layers [2] [17] may be necessary to:

- Encapsulate PDU framing of upper layers into the native 802.16.1 MAC/PHY PDUs. [17]
- Map an upper layer's addresses into 802.16.1 addresses
- Translate upper layer CoS/QoS parameters into native 802.16.1 MAC constructs
- Adapt the asynchronous, synchronous or isochronous data pattern of the upper layer into the equivalent MAC service
- Reduce the need for complex inter-working functions (IWFs) [17]

For instance, in the ATM world a Transmission Convergence (TC) layer is defined for each link type that carries ATM cells. The purpose of this layer is to delimit cells using the particular link technology, and to signal idle time, or insert idle ATM cells on the link. 802.16.1 borrows this terminology to accommodate "special" requirements of the multiple upper layer protocols.

Another assumption made in the diagram is that digital audio/video (DAV) service bypasses the MAC protocol layer and accesses the PHY layer directly. This assumption is made because the DAV multicast bearer service (see section 3.1.1) is transmitted in the downstream direction only, and does not require the main service of the MAC: channel contention (access control).

The central purpose of the MAC protocol layer in 802.16.1 is sharing of radio channel resources. The MAC protocol defines how and when a base station or subscriber station may initiate transmission on the channel. Since key layers above the MAC, such as ATM and STM, require service guarantees, the MAC protocol MUST define interfaces and procedures to provide guaranteed service to the upper layers. In the downstream direction, since only one base station is present, and controls its own transmission, the MAC protocol is simple. But in the upstream direction, if one radio channel is allocated to more than one subscriber station, the MAC protocol MUST efficiently resolve contention and bandwidth allocation. Note that the function of the MAC layer is not to provide error correction by retransmission, or automatic repeat request (ARQ). In the 802 model, those functions if necessary, are provided by the LLC layer

The PHY layer is similarly subdivided between a convergence layer and a physical medium-dependent (PMD) layer. The PMD is the "main" part of the PHY. Like the MAC convergence layers, the PHY convergence layers adapt/map the "special" needs of the MAC and DAV services to generic PMD services. For instance, to best support DAV services, the PHY MAY provide TDM-based encapsulation of DAV streams in TDM MPEG-II frames [14].

Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16.1 MAC and PHY task groups while developing the air interface interoperability standard.

5 Performance and Capacity

This section addresses some issues regarding 802.16.1 system performance and capacity. Specifying protocols such that an 802.16.1 system can maintain a specified/mandated performance level in the face of rapidly changing channel characteristics (e.g., due to rain) will be a difficult problem for the 802.16.1 working group. This section specifies the target performance levels. Given the target performance levels, planning and provisioning an 802.16.1 system instance is also a difficult problem. The 802.16.1 system capacity at the target performance levels for all

subscribers, given geographically local LOS obstruction and atmospheric conditions will also be difficult. This section also outlines some of the issues for 802.16.1 capacity planning.

Note that ITU-R (WP 9A) has presented several questions regarding the need for performance objectives for fixed wireless access radio systems. [16]

5.1 Scalability

The 802.16.1 protocols SHOULD allow for different "scales" of capacity and performance for 802.16.1 system instances.

5.2 Delivered Bandwidth

802.16.1 protocols SHALL be optimized to provide the peak capacity from 2 to 155 Mbps to a subscriber station sufficiently close to the base station. The 802.16.1 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond 155 Mbps. However, 802.16.1 protocols SHALL not preclude the ability of an 802.16.1 system to deliver less than 2 Mbps peak per-user capacity.

5.3 Flexible Asymmetry

802.16.1 protocols SHOULD allow for flexibility between delivered upstream and downstream bandwidth and CoS/QoS. Some target markets utilize naturally asymmetrical bandwidth, such as for generic Internet access where most of the bandwidth is consumed in the downstream direction. Some markets utilize asymmetrical bandwidth, using more in the upstream direction, such as a video multicast from a corporate or distance-learning source. Other markets and applications require symmetrical bandwidth, such as telephony and video conferencing [17].

A high degree of flexibility may be achieved by utilizing the MAC protocol to arbitrate channel bandwidth in either direction, upstream or downstream.

5.4 Radio Link Availability

An 802.16.1 system SHOULD be available to transport all services at better than their required maximum error rates (see section 5.5) from about 99.9 to 99.999% of the time [2, 11] , assuming that the system and radios receive adequate power 100% of the time and not counting equipment availability. Note that 99.999% availability amounts to approximately 5 minutes of outage a year. The 802.16.1 specifications SHALL NOT preclude the ability of the radio link to be engineered for different link availabilities, based on the preference of the system operator.

A period of unavailable time begins at the onset of ten consecutive SES events based on the following definitions (cite G.826).

- Severely Errored Second (SES) is defined as a one-second period which contains 30% errored blocks.

- Errored Block (EB): A block is defined as a set of consecutive bits associated with the path. Consecutive bits may not be contiguous in time. A block is typified as data block containing an error detection code for service performance monitoring. An errored block is a block in which one or more bits are in error.

It is expected that the highest contributor to 802.16.1 system outage will be excessive attenuation due to atmospheric conditions (e.g., rain rate, droplet size and other factors) [50] [51] [52] [53] [72]. 802.16.1 MAC and PHY protocols MUST accommodate atmospheric conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements. Since statistical atmospheric conditions vary widely in geography, the 802.16.1 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance that varies with geography [11]. Bandwidth and cell radius are critical components of system/cell capacity planning (also see section 5.7).

802.16.1 MAC and PHY protocols SHOULD specify functions and procedures to adjust power, modulation, or other parameters to accommodate rapid changes in channel characteristics due to atmospheric conditions.

5.5 Error Performance

The error rate, after application of the appropriate error correction mechanism (e.g., FEC), delivered by the PHY layer to the MAC layer SHALL meet IEEE 802 functional requirements: The bit error ratio (BER) is 10E-9. Note that this BER applies to a BWA system which is only one component of a network's end-to-end BER. Additionally, each block of data delivered by the PHY to the MAC MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3 errored bits (a Hamming Distance of 4) [7]. Note that the size of the data block is TBD.

5.6 Delay

Variation of delay, or jitter, is important to consider. For example, a high variation of delay can severely impact telephony services. But generic Internet access can tolerate a high degree of delay variation.

The end-to-end delay is a subjective metric and depends on an entire application-specific network encompassing all 7 layers of the OSI model. In a telephony network, for example, the maximum acceptable end-to-end delay for the longest path is RECOMMENDED to be less than 300ms [15] [17] [75].

The budget for 802.16.1 system transit delay and access delay MUST be derived. [15] [17]. The MAC layer may have different requirements for each direction, upstream and downstream. In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes. The budget for 802.16.1 transit delay is suggested to be less than 19.5 ms [15] for "stringent QoS" services.

ITU I.356 [73] recommends end-to-end variation (jitter) for "stringent QoS class" to be less than 3 ms. Multimedia videoconferencing requires delay variation to be less than 200 ms end-to-end to allow for reasonable synchronization of audio and video streams [17]. It is suggested that the budget for 802.16.1 systems be 1.5ms [15] for "stringent QoS" services.

Please refer to section 6.2, descriptions of QoS parameters.

5.7 Capacity Issues

802.16.1 system capacity requirement is defined as the product of the number of subscribers, their peak bandwidth requirements and load factor based on quality of service guarantees. The delivered capacity can vary depending on attenuation due to atmospheric conditions, LOS blockage, transmit power, etc. In a given 802.16.1 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and minimum error rates are met. Given the atmospheric conditions statistics in a geographic area, and the development of a channel link budget [11], the following parameters of an 802.16.1 system SHOULD be addressed by the MAC and PHY protocols [11]:

- Radio range (shaped sector radius)
- Width of the sector
- Upstream/downstream channels' data rates
- Allocation of prospective subscriber data rate to channels. Note: the MAC and PHY standards MAY allow subscribers to hop between channels
- Types of modulation

The MAC and PHY protocols MUST accommodate channel capacity issues and changes in channel capacity to meet contracted service levels with customers. For example, flexible modulation types, power level adjustment, and bandwidth reservation schemes MAY be employed. Also, as subscribers are added to 802.16.1 systems, the protocols MUST accommodate them in an automated fashion.

The time-variant impairments, rain fade and multi-path interference, are expected to be the most significant contributors to channel impairments and complexity in cell capacity planning [7] [37] [38] [39] [40] [11] [50] [51] [52] [53]. Common metrics, such as dispersive fade margin (DFM) [7] for frequency-selective fading environments, may be employed to compare the performance of 802.16.1 equipment (e.g., radios and modems).

6 Class of Service and Quality of Service

This section describes the classes of service and quality of service for 802.16.1 systems. Terminology is borrowed from the ATM Forum and Internet Engineering Task Force (IETF) worlds.

802.16.1 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the bearer services (see section 8) that an 802.16.1 system MUST transport. Each bearer service defines guarantees that they "expect" to be preserved by an 802.16.1 system. Thus, 802.16.1 protocol standards MUST define interfaces and procedures that accommodate the needs of the bearer services with respect to allocation of prioritization of bandwidth. Additionally, 802.16.1 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements [2] (see section 7.1). **Error! Reference source not found.** Table 1 provides a summary of the QoS requirements that the PHY and MAC SHALL provide. Note that delay in the table refers to the transmission delay from the MAC input from the upper layer at the transmit station to the MAC output to the upper layer the receiving station for information transmission. It does not include setup time, link acquisition, etc.

The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH. For instance, the MAC layer MAY employ TDM allocation of bandwidth within a channel for these services. TDM bandwidth allocation may be performed dynamically to allow for both 1) turning up fixed-bandwidth Permanent Virtual Circuits (PVCs) and 2) for dynamically changing bandwidth of a virtual circuit once it has been established.

For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols MUST support bandwidth negotiation "on-demand" [9]. For instance, the MAC protocol MAY allocate bursts of time slots to bearer services that require changes in bandwidth allocation. Such allocation is thus performed in a semi-stateless manner. A connection-oriented bearer service may require "state" information to be maintained for the life of a connection. But the 802.16.1 MAC layer interface MAY provide a connection-less service interface that requires a higher-layer "adaptation" to maintain the "state" of a connection and periodically allocate bandwidth. For instance, the MAC may need to maintain "state" information about a QoS data flow only for the duration of an allocation.

Table 1: Services and QoS Requirements

Bearer Service	**MAC Payload Rate**	**Maximum Ratio**	**Maximum Delay (One way)**
Circuit-Based			
High Quality Narrowband/Voice Frequency Telephony (Vocoder MOS ≥ 4.0)	32 kbps – 64 kbps	10^{-6} BER	5 msec
Lower Quality Narrowband/Voice Frequency Telephony (Vocoder MOS < 4.0)	6 kbps – 16 kbps	10^{-4} BER	10 ms
Trunking	<=155 Mbps	10^{-6} BER	5 msec
Variable Packet [71]			
Time Critical Packet Services	4-13 kbps (voice) and 32-1.5 Mbps (video)	BER 10^{-6}	10ms
Non- Time Critical Services: IP, IPX, FR… Audio/video streaming, Bulk data transfer etc..	<= 155 Mbps	BER 10^{-8}	N/A
MPEG video	<=8 Mbps	BER 10^{-11}	TBD
Fixed-length Cell/Packet [73]			
ATM Cell Relay - CBR	16 kbps – 155 Mbps	CLR $3*10^{-7}$ CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}	10 ms
ATM Cell Relay - rt-VBR	Same as CBR above	CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}	10 ms

ATM Cell Relay – other	<= 155 Mbps	CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}	N.A.

6.1 Types and Classes of Service

Traffic for all services is roughly categorized as follows [2] [8] [4] (using ATM terminology):

- Constant Bit Rate (CBR). The bearer service requires a constant, periodic access to bandwidth. SDH/PDH falls into this category.
- Variable Bit Rate: Real-Time (VBR-rt). The bandwidth requirements vary over time, within a specified range, but delay and delay variance limits are specified. Examples that fall into this category are voice-over-IP (VoIP), videoconferencing, video on demand (VoD), and other "multimedia" applications.
- Variable Bit Rate: Non-Real-Time (VBR-nrt). The bandwidth varies, within a specified range, but has loose delay and delay variance requirements. Applications which are limited in their bandwidth usage may fall into this category. In one example, corporate database transactions could be relegated to this category.
- Available Bit Rate (ABR). The bandwidth varies within a wide range, and is allowed to burst up to the maximum link bandwidth when CBR and VBR traffic are not using bandwidth. Higher variations of delay may be tolerable since applications that fall into this category allow for priority traffic to preempt their bandwidth consumption.
- Unspecified Bit Rate (UBR). The bandwidth and delay requirements are not specified. Bandwidth is delivered on a "best effort" basis.

6.2 Parameters

ATM standards describe service categories (see section 6.1) in terms of traffic descriptors [9] [12] [54]:

- Peak Cell Rate (PCR). The maximum rate at which cells will be transmitted.
- Sustainable Cell Rate (SCR). The cell rate which could be sustained for a certain length of time.
- Maximum Burst Size (MBS). The maximum number of cells that could be transmitted "back-to-back."
- Minimum Cell Rate (MCR). The minimum cell rate supported by a connection (applies to ABR service only).

Other ATM QoS parameters are:

- Cell Loss Ratio (CLR)
- Maximum Cell Transfer Delay (MCTD)
- Cell Delay Variation Tolerance (CDVT)

802.16.1 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for both ATM- and IP-based services.

6.3 Bearer Service QoS Mappings

The classes of service and QoS parameters of bearer services SHALL be translated into a common set of parameters defined by 802.16.1. A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16.1 system MUST participate in signaling protocols to set up QoS parameters for connection-oriented services.

For example, if an ATM network is to be transported over an 802.16.1 system, ATM switched virtual circuits negotiate QoS parameters for the circuit. The IWF MUST participate in the ATM signaling protocol that sets up the circuit. It also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.

Similarly, a QoS-based IP network may employ the Resource Reservation Protocol (RSVP) [70] to "signal" the allocation of resources along a routed IP path. If 802.16.1 is to be a "link" in the IP network, an IWF MUST interface with 802.16.1 to negotiate resource allocation.

The specification of how IWFs operate is outside the scope of this document and the forthcoming 802.16.1 interoperable air interface standard [20] [20a]. However, the QoS parameters for 802.16.1 MUST be chosen and interface primitives defined that allow for bearer services' IWFs to negotiate QoS "through" an 802.16.1 system.

The basic mechanism available within 802.16.1 systems for supporting QoS requirements is to allocate bandwidth to various services. 802.16.1 protocols SHOULD include a mechanism that can support dynamically-variable-bandwidth channels and paths (such as those defined for ATM and IP environments).

7 Management

As outlined in IEEE Std 802-1990 [21], The LLC Sublayer, MAC Sublayer and Physical Layer standards also include a management component that specifies managed objects and aspects of the protocol machine that provide the management view of managed resources. The aspect of management considered are (FCAPS):

- Fault management
- Configuration management
- Accounting management
- Performance management (see also 5)
- Security (see also section 8)

The 802 standards define a framework for LAN/MAN management in ISO/IEC 15802-2: 1995(E) [24]. The framework contains guidelines for managed objects, management protocol, and the relationship to ITU management protocols (CMIP/CMIS).

7.1 Service Level Agreements

The 802.16.1 protocols MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means [3]. The 802.16.1 protocols MUST also permit

subscribers to monitor performance service levels of the 802.16.1 services being provided at the delivery point.

7.2 Malfunctioning Subscriber Station or Base Station

The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction. The operator also MUST have the means to shut down a base station remotely. The 802.16.1 protocols SHOULD support a function that automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power limits exceeded).

7.3 Accounting and Auditing

The 802.16.1 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing. An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber. Also recall from Section 1.2 that a single subscriber station can interface to multiple subscribers that an operator could bill separately.

8 Security

The 802.16.1 system SHALL enforce security procedures described in this section.

The security system chosen by 802.16.1 SHALL be added to the protocol stack (Figure 4-1) and reference points (Figure 2-3) to include security protocols, and "database" servers for authentication, authorization, key management, etc. [29] [30]

8.1 Authentication

There are two levels of authentication for an 802.16.1 system. The first level of authentication is when the subscriber station authenticates itself with the base station at the subscriber station's network entry. This initial authentication MUST be very strong in order to prevent "enemy" subscriber station from entering the network or an "enemy" base station from emulating a real base station. Once the initial authentication at this level is complete, future authentication at this level can be a little more relaxed. This level of authentication MUST be supported by the 802.16.1 MAC layer.

The second level of authentication is between the subscriber and the BWA system. This may or may not be the responsibility of the 802.16.1 protocols. It MAY be handled by higher layer protocols.

An additional level of authentication may exist between the other two. This additional layer is the authentication of the subscriber with the subscriber station. This is beyond the scope of the 802.16.1 protocols.

The authentication mechanisms MUST be secure so that an "enemy" subscriber station is not able to gain access to an 802.16.1 system, or to the core network beyond. Passwords and secrets MUST NOT be passed "in the clear" through the air interface.

8.2 Authorization

Authorization is a security process that determines what services an authenticated subscriber is permitted to invoke. Each subscriber has a set of credentials that describe what the subscriber is "allowed" to do. The 802.16.1 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials. Some possible credentials are:

- Permission to access the 802.16.1 system
- Permission to request up to a defined QoS profile (bandwidth, delay, etc.)
- Permission to operate certain bearer services (ATM, IP, Remote Bridging, Digital Audio/Video, etc.)

Subscriber authorization requests and responses MUST be transacted securely.

8.3 Privacy

Privacy is a security concept that protects transmitted data from being intercepted and understood by third parties (e.g., an "enemy" subscriber station, base station or passively "listening" radio). Wire-equivalent privacy (WEP) [10] and shared private key [10] privacy have been suggested as minimum required privacy levels for 802.16.1 systems.

802.16.1 standards SHOULD allow a strong cryptographic algorithm to be employed that is internationally applicable. Facilities SHOULD also be defined in the protocol for the use of alternate cryptographic algorithms that can be used in certain localities and that can replace algorithms as they are obsoleted or "legalized" for international use.

9 802 Conformance

As mentioned in some earlier sections of this document, 802.16.1 SHOULD strive to fit into the 802 system model. Some particulars with the 802 model (see *IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture* (IEEE Std 802-1990) [21]) are:

- The 802.16.1 MAC supports 802 “universal” 48 bit addresses.

- An 802.16.1 system supports MAC multicast. Note that 802.16.1 protocols support multicast in the downstream direction only, not upstream.

- The 802.16.1 protocols support 802.1 bridging services and protocols, including support of the 802.1q virtual LAN tag and 802.1D priority ID [25] [26] [28].

- The 802.16.1 protocols support encapsulation of 802.2 (LLC) [67] by the MAC protocol .

- Conform to the 802 conventions and structures for “interface primitives:” logical structures that are passed between protocol layers to invoke processes and transact data.

- Address the 802 system management guidelines (see section 7) [27].

- Provide a MAC service interface that complies to 802 conventions [22].

Appendix

A Requirements Summary

This section contains tabular summaries or requirements found in the text of this document. Requirements are separated into three categories: required, recommended and optional.

Each requirement is numbered for easy reference. Future revisions of this document will keep the requirement reference numbers intact such that the number for a requirement will not change from revision to revision.

To better discern the meaning and intent of a requirement, please refer to the text.

Editor's note: As additional information for 802.16 task groups, the areas of the standard which a requirement is most likely to affect are also given: MAC, PHY, Management (MGMT), and Security (SEC). This additional information, selected by the editor, is meant as a guideline only: task groups should examine the impact of *all* requirements.

A.1 Mandatory

It is mandatory that the 802.16.1 standard support or specify the items in Table 2.

Table 2: Mandatory Requirements

#	Section	Requirement	Affects Mostly
M1	1	The forthcoming air interface standard MUST comply with the system requirements.	All
M2	1.1	The 802.16.1 air interface interoperability standard SHALL be part of a family of standards for local and metropolitan area networks.	All
M3	2	802.16.1 systems SHALL be multiple-cell frequency reuse systems.	MAC PHY
M4	2.1	The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage.	PHY
M5	2.1	The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and common modulation technique(s).	MAC PHY
M6	2.2	All data traffic in a single cell of an 802.16.1 network MUST go through the base station.	MAC
M7	2.2	The base station SHALL serve as a radio resource supervisor.	MAC
M8	2.2	802.16.1 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.	MAC
M9	3.1.2	802.16.1 systems and protocols MUST support the QoS requirements of the services:	MAC

		• Narrowband/Voice Frequency Telephony - POTS (supporting FAX services), Centrex, ISDN BRI 35 • NxDSO Trunking - Fractional DS1/E1 to PBXs and/or data equipment, ISDN PRI 36 • Full DS1/E1 - transparent mapping including all framing information • Voice Over IP, Voice Over Frame Relay, Voice and Telephony over ATM (VToA), and similar services	
M10	3.1.2.1	The amount of delay between a user speaking and another user hearing the speech MUST be kept below a certain level to support two-way conversation.	MAC PHY
M11	3.1.2.1	BWA protocols MUST support efficient transport of encoded voice data in terms of bandwidth, reliability and delay.	MAC PHY
M12	3.1.2.2	MUST meet the transport requirements of telephony signaling, whether TDM- or message-oriented.	MAC
M13	3.1.4	802.16 MUST directly transport variable length IP datagrams efficiently.	MAC
M14	3.1.4	Both IP version 4 and 6 MUST be supported.	MAC
M15	3.1.4	The 802.16.1 IP service MUST provide support for real-time and non-real-time services.	MAC
M16	4	The MAC protocol MUST define interfaces and procedures to provide guaranteed service to the upper layers.	MAC
M17	4	The MAC protocol MUST efficiently resolve contention and bandwidth allocation.	MAC
M18	4	Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16.1 MAC and PHY task groups while developing the air interface interoperability standard.	All
M19	5.2	802.16.1 protocols SHALL be optimized to provide the peak capacity from 2 to 155 Mbps to a subscriber station sufficiently close to the base station.	MAC PHY
M20	5.2	802.16.1 protocols SHALL NOT preclude the ability of an 802.16.1 system to deliver less than 2 Mbps peak per-user capacity.	MAC PHY
M21	5.4	The 802.16.1 specifications SHALL NOT preclude the ability of the radio link to be engineered for different link availabilities, based on the preference of the system operator.	PHY
M22	5.4	802.16.1 MAC and PHY protocols MUST accommodate atmospheric conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements.	MAC PHY MGMT

M23	5.4	Since statistical atmospheric conditions vary widely in geography, the 802.16.1 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance that varies with geography.	MAC PHY MGMT
M24	5.5	The error rate, after application of the appropriate error correction mechanism (e.g., FEC), delivered by the PHY layer to the MAC layer SHALL meet IEEE 802 functional requirements: The bit error rate (BER) is 10E-9.	MAC PHY
M25	5.5	Each block of data delivered by the PHY to the MAC layer MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3 errored bits (a Hamming Distance of 4).	PHY
M26	5.6	The budget for the 802.16.1 system transit delay and access delay MUST be derived. The MAC layer may have different requirements for each direction, upstream and downstream.	MAC PHY
M27	5.6	In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes.	MAC
M28	5.7	In a given 802.16.1 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and maximum error rates are met.	MGMT
M29	5.7	The MAC and PHY protocols MUST accommodate channel capacity issues and changes in channel capacity to meet contracted service levels with customers.	MAC PHY MGMT
M30	5.7	As subscribers are added to 802.16.1 systems, the protocols MUST accommodate them in an automated fashion.	MAC MGMT
M31	6	802.16.1 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the bearer services that an 802.16.1 system MUST transport.	MAC
M32	6	802.16.1 protocol standards MUST define interfaces and procedures that accommodate the needs of the bearer services with respect to allocation of prioritization of bandwidth.	MAC
M33	6	802.16.1 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements.	MAC MGMT
M34	6	The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH.	MAC
M35	6	For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols MUST support bandwidth negotiation "on-demand."	MAC
M36	6	Table 1 provides a summary of the QoS requirements that the PHY and MAC SHALL provide.	MAC PHY
M37	6.2	802.16.1 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for both ATM- and IP-based services.	MAC

M38	6.3	The classes of service and QoS parameters of bearer services SHALL be translated into a common set of parameters defined by 802.16.1.	MAC
M39	6.3	A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16.1 system MUST participate in signaling protocols to set up QoS parameters for connection-oriented services.	MAC
M40	6.3	The IWF MUST participate in the ATM signaling protocol that sets up the circuit.	MAC
M41	6.3	The IWF also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.	MAC
M42	6.3	If 802.16.1 is to be a “link” in the IP network, an IWF MUST interface with 802.16.1 to negotiate resource allocation.	MAC
M43	6.3	The QoS parameters for 802.16.1 MUST be chosen and interface primitives defined that allow for bearer services’ IWFs to negotiate QoS “through” an 802.16.1 system.	MAC
M44	7.1	The 802.16.1 protocol MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means.	MAC MGMT
M45	7.1	The 802.16.1 protocols MUST permit subscribers to monitor performance service levels of the 802.16.1 services being provided at the delivery point.	MAC PHY MGMT
M46	7.2	The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction.	MAC PHY MGMT
M47	7.2	The operator MUST have the means to shut down a BTS remotely.	MAC PHY MGMT
M48	7.3	The 802.16.1 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing.	MAC MGMT
M49	7.3	An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber.	MAC
M50	8	The 802.16.1 system SHALL enforce security procedures described in section 8.	MAC SEC
M51	8	The security system chosen by 802.16.1 SHALL be added to the protocol stack (Figure 4-1) and reference points (Figure 2-3) to include security protocols, and “database” servers for authentication, authorization, key management, etc.	SEC
M52	8.1	This initial authentication MUST be very strong in order to prevent	MAC

		an “enemy” subscriber station from entering the network or an “enemy” base station from emulating a real base station.	SEC
M53	8.1	Initial authentication MUST be supported by the 802.16.1 MAC layer.	MAC SEC
M54	8.1	The authentication mechanisms MUST be secure so that an “enemy” subscriber station is not able to gain access to an 802.16.1 system, or to the core network beyond.	MAC SEC
M55	8.1	Passwords and secrets MUST NOT be passed “in the clear” through the air interface.	MAC SEC
M56	8.2	The 802.16.1 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials.	MAC SEC MGMT
M57	8.2	Subscriber authorization requests and responses MUST be transacted securely.	MAC SEC

A.2 Recommended (R)

It is recommended that the 802.16.1 standard support or specify the items in Table 3. “Recommended” means that there may exist valid reasons in particular circumstances to ignore an item, but the full implications should be understood and the case carefully weighed before choosing a different course.

Table 3: Recommended Requirements

#	Section	Requirement	Affects Mostly
R1	1.2	802.16.1 SHOULD support more than one paying customer at a single access point to a subscriber BWA radio.	MAC MGMT SEC
R2	2	The base station radio SHOULD be P-MP.	MAC PHY
R3	3	An 802.16.1 system SHOULD support the services described in section 3	MAC PHY MGMT
R4	3.1	The MAC and PHY protocols may not have explicit support for each and every bearer service, since they SHOULD be handled as data streams in a generic fashion.	MAC PHY
R5	3.1.1	802.16.1 SHOULD efficiently transport digital audio/video streams to subscribers.	MAC PHY
R6	3.1.2	802.16.1 systems SHOULD support supplying telephony “pipes” to subscribers in a way that eases the migration of legacy telephony equipment and public switched telephone network (PSTN) access	MAC PHY MGMT

		technologies to 802.16.1 systems.	
R7	3.1.3	802.16.1 protocols SHOULD be defined such that an 802.16.1 system can efficiently transport ATM cell relay service and preserve its QoS features.	MAC
R8	3.1.3	Provide a means to utilize ATM addresses such as ITU-T E.164.	MAC
R9	3.1.4	For efficient transport of IPv6, TCP/IP header compression over the air interface SHOULD be supported.	MAC
R10	3.1.4	It SHOULD be possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated Services and Integrated Services.	MAC
R11	3.1.6	The 802.16.1 protocols SHOULD NOT preclude the transport of the following services: • Back-haul service • Virtual point-to-point connections • Frame Relay Service	MAC
R12	5.1	The 802.16.1 protocols SHOULD allow for different “scales” of capacity and performance for 802.16.1 system instances.	MAC PHY
R13	5.2	802.16.1 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond 155 Mbps.	MAC PHY
R14	5.3	802.16.1 protocols SHOULD allow for flexibility between delivered upstream and downstream bandwidth and CoS/QoS.	MAC PHY
R15	5.4	An 802.16.1 system SHOULD be available to transport all services at better than their required maximum error rates from about 99.9 to 99.999% of the time, assuming that the system and radios receive adequate power 100% of the time and not counting equipment availability.	PHY
R16	5.4	802.16.1 MAC and PHY protocols SHOULD specify functions and procedures to adjust power, modulation, or other parameters to accommodate rapid changes in channel characteristics due to atmospheric conditions.	MAC PHY MGMT
R17	5.6	In a telephony network, for example, the maximum acceptable end-to-end delay for the longest path is RECOMMENDED to be less than 300ms.	MAC PHY
R18	5.7	The following parameters of an 802.16.1 system SHOULD be addressed by the MAC and PHY protocols: • Radio range (shaped sector radius) • Width of the sector • Upstream/downstream channels’ data rates	MAC PHY MGMT

		• Allocation of prospective subscriber data rate to channels. Note: the MAC and PHY standards may allow subscribers to hop between channels • Types of modulation	
R19	6.3	802.16.1 protocols SHOULD include a mechanism that can support dynamically-variable-bandwidth channels and paths (such as those defined for ATM and IP environments).	MAC
R20	7.2	The 802.16.1 protocols SHOULD support a function that automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power limits exceeded).	MAC PHY MGMT
R21	8.3	Allow for a strong cryptographic algorithm to be employed that is internationally applicable.	SEC
R22	8.3	Facilities SHOULD also be defined in the protocol for the use of alternate cryptographic algorithms that can be used in certain localities and that can replace algorithms as they are obsoleted or “legalized” for international use.	SEC
R23	9	802.16.1 SHOULD strive to fit into the 802 system model.	All

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A.3 Optional (O)

It is optional that the 802.16.1 standard support or specify the items in Table 4.

Table 4: Optional Requirements

#	Section	Requirement	Affects Mostly
O1	3.1.1	Digital audio/video transport MAY bypass the MAC protocol layer.	MAC PHY
O2	3.1.2	802.16.1 protocols MAY transport any layer in the nationally- and internationally-defined digital telephony service hierarchies.	MAC
O3	3.1.3	802.16.1 MAY provide a direct ATM addressing mode for 802.16.1 nodes, or MAY provide a means to translate ATM addresses to 802 addresses.	MAC
O4	3.1.5	The 802.16.1 protocols MAY support bridged LAN services, whether directly or indirectly.	MAC
O5	4	To best support DAV services, the PHY MAY provide TDM-based encapsulation of DAV streams in TDM MPEG-II frames	PHY
O6	5.7	The MAC and PHY standards MAY allow subscribers to hop between channels.	MAC PHY
O7	5.7	Flexible modulation types, power level adjustment, and bandwidth reservation schemes MAY be employed.	MAC PHY
O8	6	The MAC layer MAY employ TDM allocation of bandwidth within a channel for SDH/PDH services.	MAC
O9	6	The MAC protocol MAY allocate bursts of time slots to bearer services that require changes in bandwidth allocation.	MAC
O10	8.1	The second level of authentication, between the subscriber and the BWA system, MAY be handled by higher layer protocols.	MAC SEC

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2 # B Vocabulary of Terms

Term	Definition	Reference
Access	End-user connection(s) to core networks NOTE 1 - Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc. NOTE 2 - The end-user may be a single user or a user accessing the services on behalf of multiple users.	Based on Rec. ITU-R F.1399
Accounting	A function which apportions the revenue obtained by the service providers to network operators in line with commercial arrangements.	Rec. ITU-R M.1224
Air interface	The common boundary between the subscriber station and the radio equipment in the network, defined by functional characteristics, common radio (physical) interconnection characteristics, and other characteristics, as appropriate. NOTE 1 – An interface standard specifies the bi-directional interconnection between both sides of the interface at once. The specification includes the type, quantity and function of the interconnecting means and the type, form and sequencing order of the signals to be interchanged by those means.	Based on Rec. ITU-R M.1224
Asynchronous transfer mode	A transfer mode in which the information is transferred within labeled cells; it is asynchronous in the sense that the recurrence of cells containing information from an individual user is not necessarily periodic.	ITU-T Rec. I.113
Authentication	The process of verifying the identity of a user, terminal, or service provider.	Rec. ITU-R M.1224
Authorization	A property by which the rights to resources are established and enforced.	Rec. ITU-R M.1224
Available bit-rate	The ATM layer service category for which the limiting ATM layer transfer characteristics provided by the network may change subsequent to connection establishment.	ATM Forum
Backhaul service	Transport of aggregate communication signals from base stations to the core network.	IEEE 802.16

Bandwidth; communication channel bandwidth	The bandwidth of the information payload capacity of a communication channel available to a user for services (expressed in bit/s or multiples thereof).	
Bandwidth; RF channel bandwidth	The bandwidth of a specified portion of the RF spectrum capable of carrying information over the radio interface (expressed in Hz or multiples thereof).	
Bandwidth; transmission channel bandwidth	The frequency spectrum bandwidth required for the transmission of a specified signal (expressed in Hz or multiples thereof).	
Base station	The common name for all the radio equipment located at one and the same place used for serving one or several cells. (See also “station”).	ITU-R Rec. M.1224
Bearer service	A type of telecommunication service that provides the capability for the transmission of signals between user-network interfaces.	ITU-T Rec. I.112
Broadband wireless access	wireless access in which the connection(s) capabilities are higher than the primary rate.	Rec. ITU-R F.1399
Cell	The radio coverage area of a base station, or of a subsystem (e.g. sector antenna) of that base station corresponding to a specific logical identification on the radio path, whichever is smaller.	Based on Rec. ITU-R M.1224
Cell	A block of fixed length which is identified by a label at the asynchronous transfer mode layer of the B-ISDN protocol reference model.	ITU-T Rec. I.113
Cell delay variation	A component of cell transfer delay, induced by buffering and cell scheduling.	ATM Forum
Cell loss ratio	The proportion of lost cells over the total number of transmitted cells for a connection.	ATM Forum
Channel; communication channel	A specific portion of the information payload capacity, available to the user for services.	ITU-T Rec. I.113
Channel; radio-frequency (RF) channel	A specified portion of the RF spectrum with a defined bandwidth and a carrier frequency and is capable of carrying information over the radio interface.	Rec. ITU-R M.1224
Channel; transmission channel	A means of unidirectional transmission of signals between two points.	ITU-T Rec. I.112
Constant bit rate	An ATM service category which supports a	ATM Forum

	guaranteed rate to transport services such as video or voice as well as circuit emulation which requires rigorous timing control and performance parameters.	
Core network	Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc.	Based on Rec. ITU-R F.1399
Customer premises equipment/network	The equipment/network administered by the user.	Based on ITU-T Rec. H.310
Downstream	The direction from base station to subscriber station(s).	IEEE 802.16
Dynamically variable bandwidth	A capability of a system to be able to change the bandwidth of the information payload capacity of a communication channel available to a user for services according to negotiated user requirements.	
Fixed wireless access	Wireless access application in which the base station and the subscriber station are fixed.	Based on Rec. ITU-R F.1399
Frequency Division Duplex	Separation of upstream and downstream transmission in the frequency domain at the same time.	IEEE 802.16
Internet protocol	Networking protocol defined by IETF standards.	IETF
Interoperability	The ability of multiple entities in different networks or systems to operate together without the need for additional conversion or mapping of states and protocols.	Rec. ITU-R M.1124
Inter-working	The means of supporting communications interactions between entities in different networks or systems.	Rec. ITU-R M.1124
Inter-working function	Mechanism which masks the differences in physical, link, and network technologies by converting or mapping states and protocols into consistent network and user services.	Rec. ITU-R M.1124
Maximum burst size	The number of cells that may be transmitted at the peak rate and still be in conformance with the GCRA.	ATM Forum
Minimum cell rate	An ABR service traffic descriptor, in cells/sec, that is the rate at which the source is always allowed to send.	ATM Forum
Maximum cell transfer delay	The sum of the fixed delay component across the link or node and MCDV.	ATM Forum

Network	A set of nodes and links that provides connections between two or more defined points to facilitate telecommunication between them.	Rec. ITU-R M.1224
Nomadic wireless access	Wireless access application in which the subscriber station may be in different places but must be stationary while in use.	Based on ITU-R Rec. F.1399
Peak cell rate	The limit, in cell/sec, for source transmission.	ATM Forum
plesiochronous mode	A mode where the essential characteristic of time scales or signals such that their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits.	ITU-T Rec. G.810 (96), 4.3.5
Point-to-multipoint system	a system that establishes connections between a single specified point and more than one other specified points.	ITU-R Rec. F.1399
Privacy	The provision of capabilities to prevent access of information by unauthorized parties.	ANSI T1.702-1995
Quality of service	The collective effect of service performance which determine the degree of satisfaction of a user of the service. NOTE 1 - The quality of service is characterized by the combined aspects of service support performance, service operability performance, serveability performance, service security performance and other factors specific to each service. NOTE 2 - The term "quality of service" is not used to express a degree of excellence in a comparative sense nor is it used in a quantitative sense for technical evaluations. In these cases a qualifying adjective (modifier) should be used.	ITU-T Rec. E.800 (94), 2101
Radio interface	See air interface	Rec. ITU-R M.1224
Real-Time (adjective)	Pertaining to the processing or transmission of data according to defined time requirements .	Based on ITU-T Rec. Q.9 (88), 6103
Security	The protection of information availability, integrity and confidentiality, as well as authentication and authorization.	Based on Rec. ITU-R M.1224
Service	A set of functions offered to a user by an organization.	Recs. ITU-R M.1224, M.1308
Station	the common name for all the radio equipment at one and the same place.	Rec. ITU-R M.1224

	NOTE - The term "station" may refer to any end-user radio equipment (“subscriber station”) or network radio equipment (“base station”).	
Subscriber	A person or other entity that has a contractual relationship with a service provider on behalf of one or more users. (A subscriber is responsible for the payment of charges due to that service provider.)	Rec. ITU-R M.1224
Subscriber station	the common name for all the radio equipment at one and the same place serving one or more users. (See also “station”).	Based on Rec. ITU-R M.1224
Supplementary service	A service which modifies or supplements a basic telecommunication service. Consequently, it can not be offered to a customer as a standalone service, rather, it must be offered together with or in association with a basic telecommunication service. The same supplementary service may be common to a number of telecommunication services.	Rec. ITU-R M.1224
Sustainable cell rate	The cell rate which could be sustained for a certain length of time. An upper bound on the conforming average rate of an ATM connection over time scales which are long relative to those for which the PCR is defined.	IEEE 802.16 ATM Forum
Synchronous transfer mode	A transfer mode which offers periodically to each connection a fixed-length block.	Based on ITU-T Rec. I.113
System	A regularly interacting or interdependent group of items forming a unified whole technology.	Recs. ITU-R M.1224, M.1308
Time Division Duplex	Separation of upstream and downstream transmission in the time domain using the same frequency.	IEEE 802.16
Unspecified bit rate	UBR is an ATM service category which does not specify traffic related service guarantees. Specifically, UBR does not include the notion of a per-connection negotiated bandwidth. No numerical commitments are made with respect to the cell loss ratio experienced by a UBR connection, or as to the cell transfer delay experienced by cells on the connection.	ATM Forum

Upstream	The direction from subscriber station(s) to base station.	IEEE 802.16
User	Any entity external to the network which utilizes connections through the network for communication.	ITU-T Rec. E.600
Variable bit rate	An ATM Forum defined service category which supports traffic with average and peak traffic parameters.	ATM Forum
Variable Bit Rate: Non-Real-Time	An ATM Forum defined service category which supports bursty traffic, and is characterized in terms of a PCR, SCR, and MBS.	ATM Forum
Variable Bit rate: Real-Time	An ATM Forum defined service category which supports traffic requiring tightly constrained delay and delay variation, as would be appropriate for voice and video applications.	ATM Forum
Virtual point-to-point connections	Providing a point-to-point connection to a subscriber using a point to multipoint system.	IEEE 802.16
Wireless access	end-user radio connection(s) to core networks. NOTE 1 - Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc. NOTE 2 - The end-user may be a single user or a user accessing the services on behalf of multiple users.	Rec. ITU-R F.1399

B.1 Acronyms and Abbreviations

Acronym/Abbreviation	**Definition**
ABR	Available bit-rate
ATM	Asynchronous transfer mode
BBER	Background block error ratio
BER	Bit Error Ratio
B-ISDN	Broadband aspects of ISDN
BNI	Base station network interface
BWA	Broadband Wireless Access
CBR	Constant bit rate
CDVT	Cell delay variation tolerance
CLR	Cell loss ratio
CPE	Customer premises equipment
DSL	Digital Subscriber Line
FDD	Frequency Division Duplex
HFC	Hybrid fiber coax
IP	Internet protocol

ISDN	Integrated Services Digital Network
IWF	Inter-working function
LAN	Local area network
LLC	Logical link control
MAC	Medium Access Control
MAN	Metropolitan area network
MBS	Maximum burst size
MCR	Maximum cell rate
MCTD	Maximum cell transfer delay
OSI	Open Systems Interconnection
PBX	Private Branch Exchange
PCR	Peak cell rate
PDH	Plesiochronous Digital Hierarchy
PDU	Protocol Data Unit
PHY	Physical layer
P-MP	Point-to-multipoint
PSTN	Public Switched Telephone Network
QoS	Quality of service
SCR	Suitable cell rate
SDH	Synchronous Digital Hierarchy
SNI	Subscriber station network interface
TC	Transmission convergence
TDD	Time Division Duplex
UBR	Unspecified bit rate
VBR	Variable bit rate
VBR-nrt	Variable Bit rate: Non-Real-Time rate
VBR-rt	Variable Bit rate: Real-Time

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[Editor's note: these references are not in a particular order. Some of these references are not cited in the text of this document.]

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