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Re:	This is a draft of a system requirements document which is a collaborative effort by the 802.16 System Requirements Task Group. The editor has collected contributions from the task group and strove to find consensus on many issues while assimilating this document. Please be sure you are reading the most recent published version of this document (802.16s0-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 system requirements that are guidelines for developing an interoperable 802.16 air interface. The 802.16 committee desired to reach an understanding and consensus for system requirements before proceeding with developing standards for 802.16 MAC and PHY protocols and thus formed a System Requirements Task Group to produce this document.
Purpose	The editor requests the 802.16 System Requirements Task Group review this document and that individuals submit suggested insertions, deletions and changes. This document is output from 802.16 session #2. Please note that two ad-hoc groups have been formed: one to complete and correct the QoS/CoS section (particularly the delay sensitivity ~~quidelines~~guidelines) and another to evaluate terminology usage.
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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1999-07-14	802.16s0-99/2	Brian Petry (editor)	Some changes approved by task group in session #1
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Acknowledgements

The content of this document was collected from 802.16 committee members over the period of several months, based on both written contributions, verbal discussion in meetings and activity on the email reflector. For the first draft, the editor took some liberty in discerning consensus and determining compromises on issues dealing with the scope of this document, the extent of requirements, and chosen terminology. While “processing” the contributions by member, the editor did not usually use verbatim text, but attempted to extract the essence of requirements. Changes to subsequent versions of this document were made through a formal comment and change-request submittal process. Many thanks go to the individuals who voiced their opinions and strove for consensus in the IEEE 802.BWA Study Group meetings, the 802.16 System Requirements Task group meetings and on the email reflector. The editor also thanks the following individuals who submitted written contributions (their documents may be found at http://grouper.ieee.org/groups/802/16/sysreq):

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1 Introduction

This document provides system requirements that are guidelines for developing an interoperable 802.16 air interface. The 802.16 committee desired to reach an understanding and consensus for system requirements before proceeding with developing standards for 802.16 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 system 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]. Some unresolved issues, noted by the working group, are described in section 1~~12~~.

The System Requirements will not be published ~~and~~ or sold by the IEEE. The requirements, with possible future amendments, are binding to the future development of 802.16 air interface protocols. This means that the forthcoming air interface standard MUST comply with the system 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 ~~vendor~~ implementation may ~~choose to~~ include the item because a ~~particular~~ the target marketplace requires it or because it enhances the product, for example; another ~~vendor~~ implementation may omit the same item.

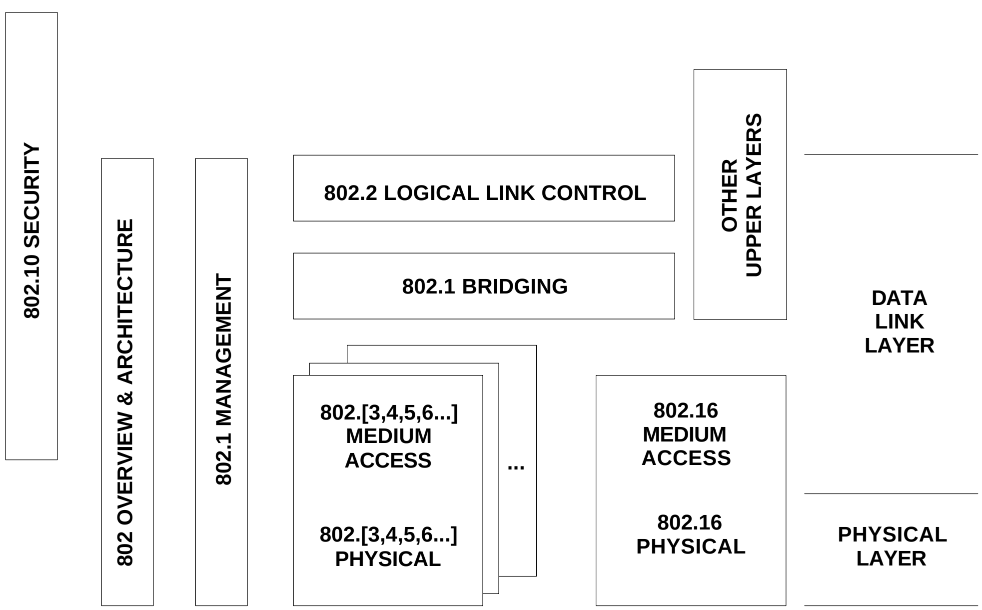
1.1 Scope

For the purposes of this document, a "system" constitutes: an 802.16 MAC and PHY implementation, in which at least ~~two stations communicate~~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, “system requirements” describes the properties of typical systems in terms of how they affect requirements of interoperable 802.16 MAC and PHY protocols. The system requirements describe 802.16 systems and requirements in broad terms: *what* they are, but not *how* they work. The *how* part is left to the forthcoming 802.16 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 ~~interfaces immediately surrounding an 802.16 system, particularly~~ the bearer services that an 802.16 system is required to transport. These *bearer services* ~~impact directly~~ have a direct impact on the requirements of the 802.16 MAC and PHY protocols. ~~Then, w~~When the 802.16 working group produces an interoperable air interface standard that meets these system requirements, ~~an~~ resulting 802.16 system~~ SHALL~~s provide the services required to neatly interface ~~neatly with~~into many conceivable BWA systems. See section 1.2~~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.~~ See sections 3 and 4.~~

The 802.16 air interface interoperability standard SHALL be part of a family of standards for local and metropolitan area networks. The following diagram illustrates the relationship of 802.16 protocols to other 802 standards, and to the OSI reference model. (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 protocols is expected to ~~SHOULD~~ address markets ~~and offer services~~ similar to wired broadband access technologies such as:
~~, especially those wired technologies with which BWA is expected to compete. This includes current high-speed network access markets served by~~

- ~~copper~~ Copper digital subscriber line (DSL) technologies~~,~~
- D~~d~~igital cable TV hybrid fiber/coax (HFC) networks~~,~~
- Integrated Services Digital Network (ISDN)
- ~~and aggregated telephony-oriented connections~~Legacy TDM digital transmission systems (e.g., Full and Fractional T1, E1, ISDN-PRI etc.)
- ~~, and~~ T~~t~~he services that such legacy ~~networks~~ systems carry: data, voice and audio/video [8].

~~The initial target market likely will be small to large businesses and multi-tenant dwellings. BWA SHALL also address broadband network access for the single-family residential market when technology permits.~~The initial target markets to be addressed by the 802.16 protocols in BWA networks are small to large businesses, and multi-tenant dwellings such as high rise buildings. 802.16 protocols in BWA networks may address the target market for single-family residences. [Editor's note: the preceeding rework is a compromise based on two conflicting and overlapping comments that were accepted by the group.]

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 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 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 1-1 and Figure 1-1.

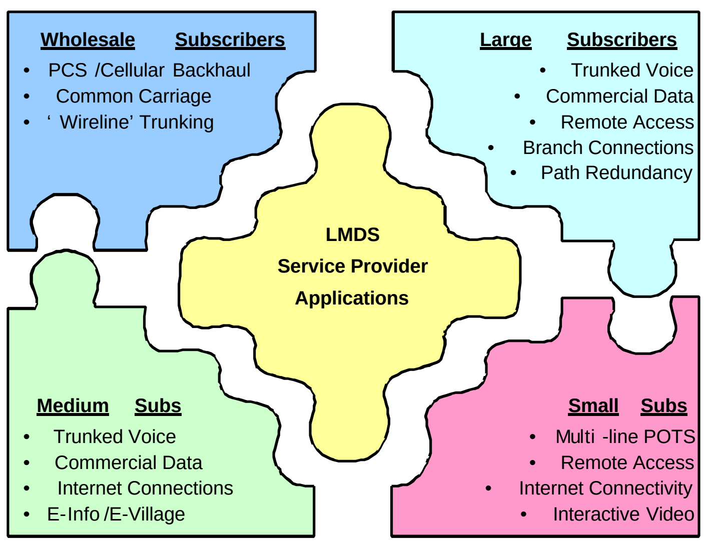


Figure 1~~2~~-1Summary of 802.16 Example Applications and Services

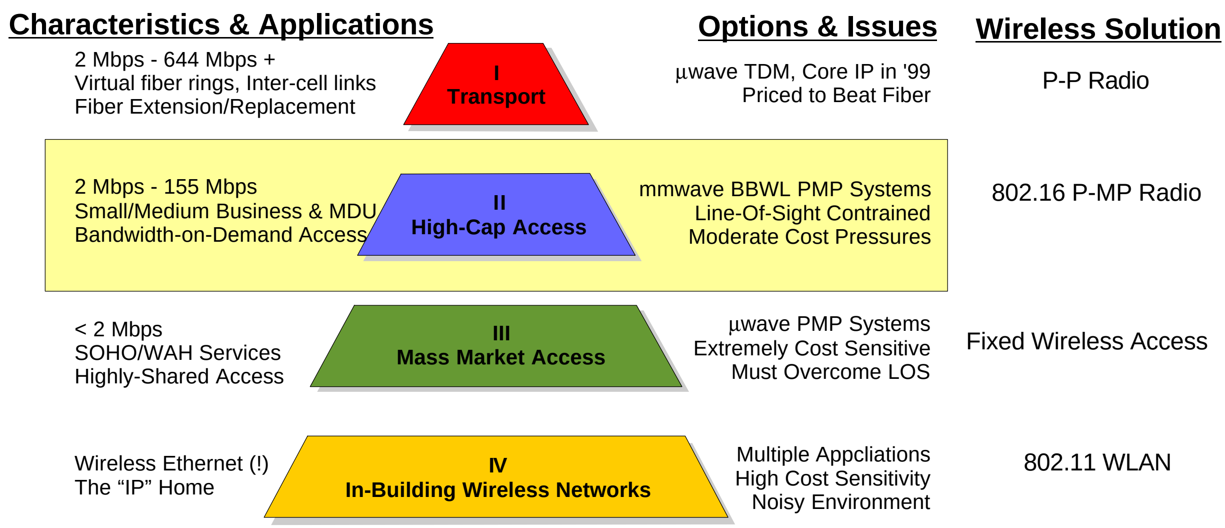


Figure 1~~2~~-2~~22~~ A Multi-Tier Perspective of Wireless Transmission and Distribution Systems

2 802.16 System Model

~~Given the target markets and services described in section , t~~This section presents a high level description of a system model ~~that can~~to be used as a framework for developing 802.16 protocol standards. The model describes some of the ~~basic~~ main features of an 802.16 system, and the terminology ~~that~~ to be used by the 802.16 working group ~~can use~~in the creation of the standards.

As mentioned in section 1.1, an 802.16 "system" constitutes: an 802.16 MAC and PHY implementation, in which ~~at least two stations~~at least one subscriber station communicates with a base station via a radio air interface (an 802.16 system), ~~the interfaces to external networks,~~ and services transported by the MAC and PHY protocol~~ layer~~s. An 802.16 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 ~~transceiver~~ station ~~(BTS) [S. Marin: The terminology association between base station, subscriber terminal, customer premises equipment needs to be clarified.[comment left in (need to resolve terminology throughout document]]~~ to one or more subscriber ~~transceiver~~ stations~~ (STS)~~ [4][9]. Radio communications ~~around 30 Ghz~~in the above range require line-of-sight (LOS) between a ~~BTS~~base station and ~~STS~~subscriber station. LOS blocked by foliage also contributes heavily to signal attenuation~~ [cite ??]~~. Figure 2-1~~Figure 3-1Figure 3-1~~ and Figure 2-2~~Figure 3-2Figure 3-2~~ [13] depict some typical 802.16 systems. 802.16 systems SHALL ~~generally~~ be multiple-cell frequency reuse systems. The range of 802.16 radios varies with transmit power, LOS blockage, availability requirement, and rain fall.

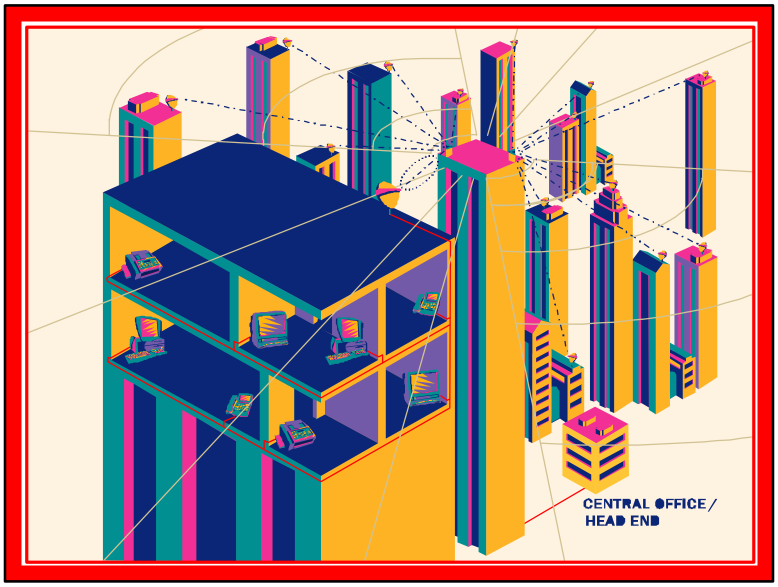


Figure 2~~3~~-1 System Showing a ~~BTS~~Base Station Mounted on a Tall Bulding

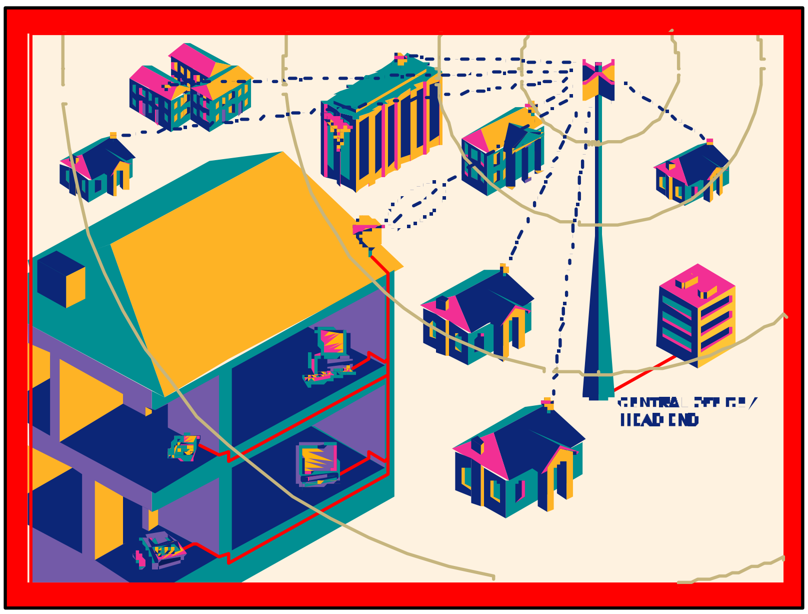


Figure 2~~3~~-2~~22~~ System Showing a ~~BTS~~Base Station Mounted on a Tower

Note that, in concern for simple terminology, an 802.16 *system* consists of one ~~BTS~~base station radio and one or more subscribers. Thus an 802.16 system also defines 802.16 ~~BTS~~base station and ~~STS~~ subscriber station radios that communicate using the 802.16 MAC and PHY protocols. The ~~BTS~~base station radio SHOULD be P-MP, radiating its *downstream* signal with a shaped sector antenna achieving broad azimuthal beamwidth to “cover” a prospective number of subscribers. Each ~~STS~~subscriber station employs a highly directional radio pointed at the ~~BTS~~base station. Note that with this arrangement, direct radio communications between subscriber stations is not possible. Furthermore, the 802.16 system does not define radio communications between base stations. Since the ~~BTS~~base station radios are “sector oriented,” multiple ~~BTS~~base station radios ~~may~~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 systems ~~varies somewhat~~vary among governed geographies [19]. ~~So, to achieve international applicability, 802.16 protocols MUST be frequency-independent.~~ Typical bands allocated for 802.16 use are very wide, allowing for the bands to be *channelized*. ~~To date, the 802.16 working group has not determined channelization requirements. Neither is it known that a chosen, ubiquitous, channel bandwidth will be applicable to all 802.16 systems. For the time being, 802.16 protocols SHOULD remain flexible in their channel parameters. But channels SHALL at least be provisioned in a particular instance of an 802.16 system that allow for:~~

~~– Spectrum allocation in adjacent 802.16 systems~~

~~—~~

- ~~Channel allocation to subscriber(s) based on bandwidth or CoS/QoS requirements~~

2.1 System Reference Model

Figure 2-3~~Figure 3-1Figure 3-1~~ shows the 802.16 system reference points, depicting the relevant elements between a subscriber network and the "core" network (the network to which 802.16 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, ~~BTS~~base station interconnection networks, network management facilities, etc. [1] may be envisaged, but the 802.16 protocols focus on the simplified model shown in the figure. Also not shown are the internal physical characteristics of the ~~BTS~~base station and ~~STS~~subscriber station: the concepts of "indoor" and "outdoor" units. The description of possible separation of ~~BTS~~base station and ~~STS~~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 ~~Transceiver~~ Station Network Interface (BNI) and the Subscriber ~~Transceiver~~ Station Network Interface (SNI). A single SNI may support multiple subscriber networks: LANs, Voice PBXs, etc. And recall from section 1.2~~1.12.1~~ that the SNI may support multiple paying subscribers, such as within a multi-tenant office building or dwelling. A ~~BTS~~base station interfaces to one or more core networks through one or more BNIs. For the purposes of 802.16, 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~~2.12.2~~) on the requirements of 802.16 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).

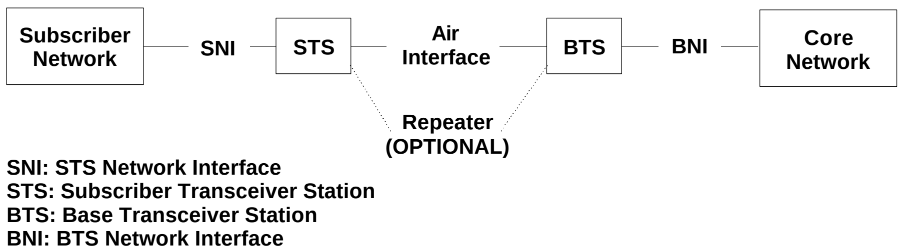


Figure 2~~3~~-3~~33~~ System Reference Points

2.2 Topology

Since all data traffic in ~~an~~ a single cell of an 802.16 network MUST go through the base ~~transceiver~~ station ~~(BTS)~~, ~~it is convenient for the BTS to~~that station SHALL serve as a radio resource supervisor~~, which controls the allocation of bandwidth on the radio channel~~ [10]. The ~~STS~~subscriber stations ~~stations~~ may request bandwidth to achieve QoS objectives (see section 6), but it may be convenient for the ~~BTS~~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 ~~(using LAN terminology)~~, since all transmissions are ~~initiated~~ transmitted by the ~~BTS~~base station, and more than one ~~STS~~subscriber station could share a downstream channel. In the upstream direction, if ~~STS~~subscriber stations share a channel, the topology is similar to a contention-oriented bus, 802.16 protocols MUST provide the means to multiplex traffic from multiple ~~STS~~subscriber stations ~~nodes~~ in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.

The resulting topology is very similar to a Hybrid Fiber Coax (HFC) cable TV network [69][69][3]~~, but with some differences. 802.16 subscribers-per-channel ratio is more flexible and perhaps higher because the BTS can provision its beam width to cover subscribers in a flexible manner. Subscribers with high bandwidth requirements may reside in a narrower beam than subscribers with low bandwidth requirements. Because of the lower subscribers-per-channel ratio, upstream channels may be allocated to achieve higher throughput in the upstream direction~~.

~~2~~3 Supported Services

This section describes the bearer services that an 802.16 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 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 ~~3~~2 if necessary.

~~2.2~~3.1 Bearer Services

This section describes typical services, transported by ~~the MAC and PHY protocols,~~an 802.16 system. In this document,~~ which are important when considering MAC and PHY requirements. The term~~ *bearer servicse* 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-based BWA networks.~~is borrowed from the Integrated Services Digital Network (ISDN) world, which defines a bearer service to be the capability for information transfer involving lower protocol layers at specific access points in the IDSN reference model. In this document, *bearer service* is used more liberally to mean the next layer up the protocol stack from MAC and PHY layers, and the types of networks that interface to the subscriber-side of BWA systems.~~ [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.

~~2.2.1~~3.1.1 Digital Audio/Video Multicast

802.16 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.

~~2.2.2~~3.1.2 Digital Telephony

802.16 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 systems. 802.16 protocols ~~SHOULD~~ 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 section 10~~11~~).

Note that many forms of digital telephony are possible:

- Narrowband/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~~VTOA), and similar services

802.16 systems and protocols MUST support the QoS requirements of these services, as defined in Section 6. ~~As mentioned in section 2.1, it is expected that a significant market for 802.16 systems is connecting a business PBX to an 802.16 system. Most PBXs use channelized SDH/PDH telephony circuits for their connection to the public switched telephone network~~

~~(PSTN), such as T1/E1, and multiples or fractions thereof. A key property of channelized voice trunks is fixed, provisioned, constant bandwidth. Another property is signaling (see section 2.2.2.2)~~

~~2.2.2.1~~3.1.2.1 Telephony Service Properties

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

~~Supervision – monitoring the activity of a user's termination for the ability to accept new incoming calls, or requests from the user to make a new outgoing call.~~

~~Call Signaling – sending messages from a user to request a new call, tear down an existing call, or modify an existing call with other end users.~~

~~Alerting – informing a user of a new incoming call.~~

~~Testing – initiating signals from the central network to troubleshoot possible problems with a user's termination.~~

~~Coding – of user information (e.g., analog voice) to the transmission format (e.g., PCM).~~

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~~28~~ 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. ~~Gain~~Again, the specific amount of delay can vary based on the quality of the service sold to the end user.

Reliability – the network supporting service among end users can be engineered so that downtime (the time when a user cannot get network service due to a network fault) is limited to minutes a year on average. This is yet another metric that can be varied based on the service sold to the end user.

Supplementary Services – There are a number of supplementary services that enable capabilities such as Caller ID, Call Waiting, special dialing plans, three-way/conference calling, etc. These services require additional user-to-network signaling information above that required to request and terminate calls.

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). ~~[confer to ad-hoc QoS group: For synchronous timing, the timing source SHALL be traceable to a Primary Reference Source (PRS). For asynchronous timing, the timing on the circuits at the output of the access network SHALL be +/- 150 ppm for DS1 (ANSI T1.403-1995) and +/- 50 ppm for E1 (ITU-T G.703). Note that the DS1 spec is~~

~~relaxed for older equipment; newer equipment can meet the more stringent +/- 32 ppm spec. In either case, DS1s carried over the acccess network SHALL have jitter and wander characteristics as specified in ITU-T G.823, and E1s as specified in G.824.]~~

~~What do these properties mean to BWA system requirements?~~ 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~~2.2.2.2~~).

~~2.2.2.2~~3.1.2.2 Signaling Systems and Protocols

Telephony and video conferencing signaling protocols may place specific requirements on 802.16 protocols. Some relevant telephony signaling protocols are: Bellcore TR-008, V5.X, Q.931, H.225, H.245, H.323, MGCP, Bellcore GR-303, ISDN PRI, MFC R2, E&M, Q.sig, IETF SIP, etc. [12] [17] [61] [editor's note: protocol references not listed].

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 ~~BWA~~ 802.16 protocols ~~SHOULD~~ MUST meet the transport requirements of such telephony signaling, whether TDM- or message-oriented.

~~2.2.3~~3.1.3 ATM Cell Relay Service

~~Of high speed, connection-oriented services, ATM is the dominant technology.~~ ATM transmits data using ~~small~~, 53-octet, fixed-length cells which are "~~routed~~switched" by ATM switches along virtual connections with an ATM network. ATM cell relay service is carried over a wide variety of links and bit rates, whether copper, optical fiber or wireless. ATM standards define a rich set of quality of service (QoS) guarantees for various service categories [8].

Given the wide deployment of ATM cell relay service within medium to large businesses, even considering the emergence of IP-based QoS, 802.16 protocols SHOULD be defined such that an 802.16 system can efficiently transport ATM cell relay service and preserve its QoS features (see section 6). Thus, 802.16 systems SHALL broadly address the target markets mentioned in section 1.2~~2.1~~.

Also note that, since ATM cell relay service is circuit-based, it employs message-based signaling protocols to establish, maintain and tear down switched virtual circuits as well as signal QoS-based services and perform network management. 802.16 protocols may need to be cognizant of such ATM signaling to enable an 802.16 system to preserve QoS (see also section 3.1.2.2~~2.2.2.2~~).

802.16 SHOULD provide a means to utilize ATM addresses such as ITU-T E.164 [uncited]. For instance, 802.16 may provide a direct ATM addressing mode for 802.16 nodes, or may provide a means to translate ATM addresses to 802 addresses [10].

~~2.2.4~~3.1.4 Internet Protocol Service

The 802.16 system MUST directly transport variable length IP datagrams efficiently. Both IP version 4 and 6 MUST be supported. Especially for efficient transport of IP~~p~~v6, TCP/IP header compression over the air interface SHOULD be supported.

The 802.16 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].

~~2.2.5~~3.1.5 Bridged LAN Service

To an 802.16 system, bridged LAN Service [25] [26] is similar to IP service (section 3.1.4~~2.2.4~~). But whereas IP is classified as a layer 3, “routed” protocol, a bridged LAN is considered layer 2., Bridging is a key component of the IEEE 802 architecture. A bridge connects two or more local area networks (LANs) together, maintaining the concepts of globally addressable nodes, multicast and broadcast procedures. The IEEE 802 has defined protocols (802.1D [25], 802.1Q [28], [26]) to manage topology discovery (Spanning Tree), the concept of virtual LAN membership, “remote” bridging, and multicast domain membership. These protocols allow for the interconnection of 802 LANs, using bridges and switches, regardless of the layer 3 protocols employed.

~~Whereas an 802.16 system is an *access* network rather than a local area network, bridged LAN service over 802.16 may not be optimal in practice. But since it is expected that bridged LAN services places few, if any, additional requirements on 802.16 than IP service, t~~The 802.16 protocols ~~SHALL~~ MAY support bridged LAN services, whether directly or indirectly.

~~2.2.6~~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 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 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 MAC protocol. PPP has some benefits such as simple authentication, privacy/encryption, data compression, and layer 3 network parameter assignment. PPP-over-802.16 ~~SHOULD not~~is not expected to place any additional requirements on 802.16 protocols, and ~~SHOULD~~ 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 and in use. Frame Relay also defines a management protocol. [3] [12].

The 802.16 protocols SHOULD not preclude the transport of the above mentioned services.

4 Protocols

Protocols are the heart of the 802.16 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 protocol stack reference diagram is shown in Figure 4-1~~Figure 4-1~~. In addition to the LLC, MAC and PHY layers suggested by the generic 802 architectures [21] [22], 802.16 protocols transport other categories of "upper protocols" that correspond to the requirements of the bearer services described in section 3.1~~2.2~~.

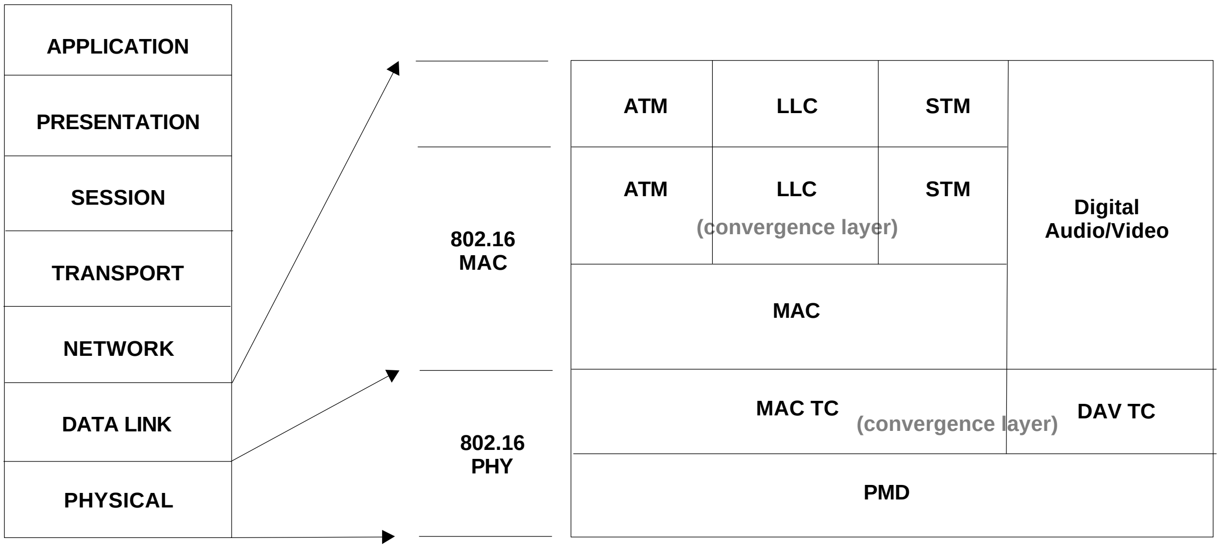


Figure 4-1 Protocol Stack Reference Model

~~The protocol reference diagram may be getting to far into the "how" part of 802.16 protocols, which should be outside the scope of this document, but t~~This protocol stack reference model ~~should ~~is intended to help develop terminology, ~~if not~~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 MAC/PHY PDUs. [17]
- Map an upper layer's addresses into 802.16 addresses
- Translate upper layer CoS/QoS parameters into native 802.16 MAC constructs
- Adapt the asynchronous, synchronous or isochronous (defs) 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 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~~2.2.1~~) 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 is sharing of radio channel resources. The MAC protocol defines how and when a ~~BTS~~base station or ~~STS~~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 ~~BTS~~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 ~~STS~~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 TDM MPEG-II frames [14].

Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16 MAC and PHY task groups while developing the air interface interoperability standard.

5 Performance and Capacity

This section addresses some issues regarding 802.16 system performance and capacity. Specifying protocols such that an 802.16 system can maintain a specified/mandated performance level in the face of rapidly changing channel characteristics (due to rain) will be a difficult problem for the 802.16 working group. This section specifies the target performance levels. Given the target performance levels, planning and provisioning an 802.16 system instance is also a difficult problem. The 802.16 system capacity at the target performance levels for all subscribers, given geographically local LOS obstruction and rain fall will also be difficult. This section also outlines some of the issues for 802.16 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 protocols SHOULD allow for different "scales" of capacity and performance for 802.16 system instances. ~~For instance, large businesses with high throughput and CoS/QoS requirements SHOULD be accommodated as well as small scale systems in dense, limited LOS environments. For instance, a subscriber with high requirements could be dedicated a narrow beam from the BTS with many radio channels. On the other end of the scale are "pico-802.16-systems" in dense metropolitan areas [6] that implement short-radius beams to a few subscribers. Perhaps in the middle of the scale are relatively wide-beam [S. Marin: define (tabled to future session)] 802.16 systems that serve a large number of subscribers on many radio channels.~~

5.2 Delivered Bandwidth

802.16 ~~system carriers are expected~~protocols SHALL be optimized to provide the peak capacity from 2 to 155 Mbps to ~~an~~ a ~~STS~~subscriber station sufficiently close to the ~~BTS~~base station. The

802.16 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond 155 Mbps. However, 802.16 protocols SHALL not preclude the ability of an 802.16 system to deliver less than 2 Mbps peak per-user capacity.

5.3 Flexible Asymmetry

802.16 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---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 system SHOULD be available to transport all services at better than their required maximum error rates (see section 5.5) ~~99.99~~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. This amounts to approximately 53 minutes of outage a year. Note that 99.999% available amounts to approximately 5 minutes of outage a year. ~~[S. Marin change to "from about 99.9 to 99.999" (tabled until next session/comment)]~~ The 802.16 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 in service performance monitoring. An errored block is a block in which one or more bits are in error.

The telephony world also defines availability in terms of "errored seconds" and "severely errored seconds" [15]. For a service with "stringent" QoS requirements, G.826 defines the errored second ratio to be .04 and the severely errored second ratio .002. errored seconds is 99.8% availability. Note that this is below the 99.99% goal.

It is expected that the highest contributor to 802.16 system outage will be excessive attenuation due to rain fall (rain rate and droplet size and other factors) [50] [51] [52] [53] [72]. 802.16 MAC and PHY protocols MUST accommodate rain fall, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements. Since statistical rain rates vary widely in geography, the 802.16 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 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 rain fall.

~~The telephony world also defines availability in terms of "errored seconds" and "severely errored seconds" [15]. For a service with "stringent" QoS requirements, G.826 defines the errored second ratio to be .04 and the severely errored second ratio .002. errored seconds is 99.8% availability. Note that this is below the 99.99% goal.~~

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 rate (BER) is 10E-9. For a BWA system is only one component of a network's end-to-end BER. Additionally, 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) [7]. Note that the size of the data block is TBD.

~~For telephony-oriented bearer services (see section 2.2.2), the 802.16 working group may consider relaxing the 10E-9 BER requirement. ITU requirements for digital voice services are three orders of magnitude less stringent—10E-6 [11] [51] [52]. Thus for digital voice services, 802.16 protocols trade off higher throughput modulation and error correction techniques for less consumed radio bandwidth.~~

~~Other error rate metrics used in the telephony and ATM for what are considered "stringent QoS" are: [15]~~

- ~~Background block error rate (BBER) [51]. 2E-4. One in 5000 blocks is errored. If the block size is approximately that for Ethernet (1522 octets), BBER is roughly equivalent to 16E-6 bit error rate (BER).~~
- ~~Cell Loss Ratio (CLR) [cite I.356]. 3E-7. One in 3.333 Mcells is errored. This is rougly equivalent to 5.6E-9 BER. Note that CLR is not always due to transmission error, but ATM switches dropping cells due to capacity limits.~~

~~Note that the telephony and ATM bit error rates seem far less stringent than LAN error rates.[deleted by QoS ad-hoc group]~~

5.6 Delay

System delay requirements come in several categories:

- Medium Access Delay. The delay imposed by the MAC protocol layer between when a ~~BTS~~base station or ~~STS~~subscriber station becomes ready to transmit and when it actually begins transmission on the channel.
- Transit Delay. The total 802.16 system delay from BNI to SNI and from SNI to BNI (see section 2.1~~3.2~~). This includes the Medium Access Delay.
- End-to-End Delay. The total delay between a terminal in the subscriber network, to the ultimate service beyond the core network. For instance, the total delay between two telephony terminals (handsets). This includes the 802.16 Transit Delay.

In addition to the above categories, 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] [cite G.114].

The budget for the 802.16 system transit delay and access delay MUST be derived. [15] [17]. ~~The radio propagation time is 3.3µsec/km [cite G.114]. If the distance between STS and BTS is 5km, this propagation time is 16.7µsec.~~ 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 transit delay is suggested to be less than 19.5 ms [15] for "stringent QoS" services. ~~[J. Mollenauer: "stringent" should require a "shall" instead of suggested].[confered to ad-hoc group]~~

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 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 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. ~~This~~ The delivered capacity can vary depending on rain attenuation, LOS blockage, transmit power, etc. In a given 802.16 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and maximum error rates are met. Given the rain attenuation statistics in a geographic area, and the development of a channel link budget [11], the following parameters of an 802.16 system SHOULD be addressed by the MAC and PHY protocols [11]:

- Radio range (shaped sector radius)

- Width of the sector
- Upstream/~~Downstream~~ downstream ~~Channels~~channels' data rates
- Allocation of prospective subscriber ~~bandwidth~~ 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 systems, the protocols MUST accommodate them in an automated fashion.

The time-variant impairments, rain fade and multipath 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 equipment (e.g., radios and modems).

6 Class of Service and Quality of Service

~~[Editor's note: Resolution of detail in this section has been conferred to an ad-hoc group.]~~

This section describes the classes of service and quality of service for 802.16 systems. Terminology is borrowed from the ATM and Internet Engineering Task Force (IETF) worlds.

802.16 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the bearer services (see section 9~~5~~) that an 802.16 system MUST transport. Each bearer service defines guarantees that they "expect" to be preserved by an 802.16 system. Thus, 802.16 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 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements [2] (see section 7.1). Table 1 provides a summary of the QoS requirements for various bearer services.

The 802.16 protocols MUST be capable of dedicating ~~fixed~~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 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 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.

Bearer Service	**Bitrate(s)**	**Bit Error Rate**	**Delay (One way)**
	Circuit-Based		
High Quality Narrowband/Voice Frequency Telephony (Vocoder MOS ≥ 4.0)	32 kbps – 64 kbps	10^{-6}	5 msec
Lower Quality Narrowband/Voice Frequency Telephony (Vocoder MOS < 4.0)	6 kbps – 16 kbps	10^{-4}	10-20 ms
Trunking	<=155 Mbps	10^{-6}	5 msec
	Variable Packet [71]		
Time Critical Packet Services	4-13 kbps (voice) and 32-1.5 Mbps (video)	BER 10^{-6}	10 - 20 ms
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}	10-20 ms
ATM Cell Relay - rt-VBR	Same as CBR above	CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}	10-20 ms
ATM Cell Relay – other	<= 155 Mbps	CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}	N.A.

Table 1 Services and QoS Requirements

6.1 Types and Classes of Service

Traffic may be roughly categorized as follows [2] [8] [4] (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: Non-Real-Time Rate (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 consume bandwidth they do.
- Unspecified Bit Rate (UBR). The bandwidth and delay requirements are not specified. Bandwidth is delivered on a "best effort" basis.

The Internet Engineering Task Force (IETF) "Integrated Services" model uses the following terminology to classify network applications [42]:

Elastic. Applications that are tolerant of various bandwidths and/or delay variations:

Interactive burst (Telnet, The X Window System, NFS, Microsoft or Novell File Sharing, etc.)

Interactive bulk (FTP)

Asynchronous bulk (Email, FAX, Remote Printing, Backup, etc.)

Real-Time. Applications that require some level of bandwidth and/or delay variation:

Guaranteed Service. A fixed upper bound on the arrival of data is required. For instance, audio and video conferencing may fall into this category.

Predictive Service. Applications are tolerant of some late data, a higher variation of delay, or may adapt to less available bandwidth. For example, a video playback service may be able to adapt its playback buffer to accommodate variation of delay.

An IETF architecture for differentiated services [43] defines how Internet Protocol-based service classes may be given quality-of-service. Traffic flows are identified in terms of their profiles: rates and burst sizes.

6.2 Parameters

ATM standards describe service categories (see section 6.2) 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 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for both ATM- and IP-based services. (TBD)

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. A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16 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 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 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 is to be a “link” in the IP network, an IWF MUST interface with 802.16 to negotiate resource allocation.

The specification of how IWFs operate is outside the scope of this document and the forthcoming 802.16 interoperable air interface standard [20] [20a]. However, the QoS parameters for 802.16 MUST be chosen and interface primitives defined that allow for bearer services’ IWFs to negotiate QoS “through” an 802.16 system.

The basic mechanism available within BWA systems for supporting QoS requirements is to allocate bandwidth to various services. BWA systems 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:

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

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). ~~The 802.16 standards SHALL consider ISO 15802 for its network management framework.~~

7.1 Service Level Agreements

The 802.16 protocol MUST permit operators (def) 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]

7.2 Malfunctioning ~~STS~~Subscriber Station or Base Station

The operator MUST have means to shut down a~~n~~ ~~STS~~subscriber station if necessary, ~~from the BTS~~remote from the subscriber station, in the face of a malfunction. The operator also MUST have the means to shut down a BTS remotely. The 802.16 protocols SHOULD support a function that automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power exceed limits).

7.3 Accounting and Auditing

The 802.16 system management framework, architecture, protocols and managed object 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 that a single ~~STS~~subscriber station can interface to multiple subscribers that an operator could bill separately.

8 Security

The 802.16 system SHALL enforce security procedures described in this section.

The security system chosen by 802.16 will be added to the protocol stack (Figure 4-1~~Figure 4-1~~) and reference points (Figure 2-3~~Figure 3-3~~) to include security protocols, and "database" servers for authentication, authorization, key management, etc.

8.1 Authentication

There are two levels of authentication for an 802.16 system. The first level of authentication is when the ~~STS~~subscriber station authenticates itself with the ~~BTS~~base station at the ~~STS~~subscriber station's network entry. This initial authentication MUST be very strong in order to prevent 'enemy' ~~STS~~subscriber station from entering the network or an 'enemy' ~~BTS~~base station from emulating a real ~~BTS~~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 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 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 ~~STS~~subscriber station. This is beyond the scope of the 802.16 protocol.

The authentication mechanisms MUST be secure so that an “enemy” ~~STS~~subscriber station is not able to gain access to an 802.16 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 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 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” ~~STS~~subscriber station, ~~BTS~~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 systems.

802.16 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 ~~SHALL~~ 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 MAC supports 802 "universal" 48 bit addresses

An 802.16 system supports MAC multicast in the downstream direction only, not upstream.

The 802.16 protocols support 802.1 bridging services and protocols, including support of the virtual LAN tag and priority ID [25] [26] [28].

The 802.16 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).

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

~~10 MAC Functional Requirements~~

~~[Editor’s note: Bill Myers proposed this section. The group decided to leave its acceptance into the document unresolved.]~~

~~The following describes the functional requirements to be performed by the wireless MAC. In conjunction with the PHY equipment, the MAC assures that QoS requirements for the wireless segment are met such as delay, delay variation, etc. and performs the following tasks:~~

~~10.1Framing and Timing~~

~~10.2Link Acquisition~~

- ~~Download to subscriber the local channel plan, data rate options, modulation options, FEC types, and timeslot arrangement employed at specific cell.~~
- ~~Establishes link at proper upstream power and frequency~~
- ~~Provide timeslot timing calibration.~~
-

~~10.3Link Maintenance~~

- ~~Provide upstream power control and frequency control (OPTIONAL) to maintain specified error rate performance during link dynamics such as rain fades.~~
- ~~Provide timeslot timing control~~
- ~~Interference detection and mitigation~~
- ~~Redundant hardware control~~

~~10.4Resource Allocation~~

~~Admission control for connections based on available resources.~~

- ~~Dynamic allocation of channels and timeslots according to traffic and traffic priority requirements.~~
- ~~Policying of traffic conflicts.~~

~~– Buffer management~~

~~*10.5Link Monitoring*~~

~~– Provide status of link performance (errored seconds, etc)~~
~~– Provide status of hardware~~
~~– Maintain status of bandwidth and resources available~~
~~– Fault detection, isolation and correlation~~

~~11~~10 Definitions and Abbreviations

~~[Editor's note: this section is being reviewed by an ad-hoc committee.]~~

~~BNI – BTS Network Interface. A reference point where one or more core networks interface to a BTS. Also, multiple, co-located BTSs from different 802.16 systems may interface at the BNI.~~

~~BTS – Base Transceiver Station. . Equipment that communicates with one or more subscriber transceiver stations (STS) and includes a BNI, MAC and PHY layer implementation, radio and single shaped sector antenna (or antenna array). More than one BTS may be co-located to allow omnidirectional service. A BTS is designated as one system with a single downstream antenna pattern. A BTS is sometimes called a "hub" or "access point."~~

~~CDMA – Code Division Multiple Access. A multiplexing category where each user or application's signal is "spread" or "scrambled" in a frequency band according to a unique code assigned to the user/application.~~

~~Cell – The radio coverage area of 802.16 systems with co-located BTSs.~~

~~Core Network – A network on the base-station side of an 802.16 system that interfaces to a BTS. Examples could be an IP-based network, ATM, Frame Relay, or public switched telephone network (PSTN).~~

~~Downstream – Flow in the direction of BTS to STS.~~

~~FDD – Frequency Division Duplex. Channels and frequency bands are designated for upstream or downstream use only, but not both.~~

~~Operator – An administrative entity that is responsible for operating, managing and billing for services of 802.16 systems. The operator may or may not "own" the STS components of an 802.16 system. The administrative reach may extend into the subscriber networks and core networks.~~

~~PDH – Plesiochronous Digital Hierarchy. Two signals are plesiochronous if their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits. The traditional telephony digital hierarchies in North America (DS0/64Kbps, DS1/1.544Mbps, DS1C/3.152Mbps, DS2/6.312Mbps, DS3/44.736Mbps, DS4/274.176Mbps) and elsewhere (DS0/64Kbps, E1/2.048Mbps, E2/8.448Mbps, E3/34.368Mbps, E4/139.264Mbps)~~

~~are typically delivered on twisted pair or coaxial cable and are based on plesiochronous clocks in which the user's data and clock are multiplexed up the digital hierachy.~~

~~SDH Synchronous Digital Hierarchy. A telephony network that multiplexes signals, is synchronized to a common clock, and typically delivered on fiber optic cable. In North America, SDH is also refered to as Synchronous Transfer Mode (STM) and implies SONET (Synchronous Optical Network): STS-1/51.840 Mbps, STS-3/155.520 Mbps, STS-9/466.560 Mbps, STS-12/622.080 Mbps, STS-48/2488.320 Mbps). Internationally, the terminology and rates are: STM-1/155.520 Mbps, STM-3/466.560 Mbps, STM-4/622.080 Mbps, STM-16/16.2488.320 Mbps.~~

~~SNI -- STS Network Interface. A reference point where one or more subscriber networks interface to an STS.~~

~~Subscriber – an entity that interfaces to an STS. Multiple subscribers may interface to an STS and are uniquely identified by an 802.16 system.~~

~~Subscriber Network – A network on the subscriber side of an 802.16 system that interfaces to an STS. Examples could be a telephony private branch exchange (PBX), data LAN (e.g., Ethernet), ATM LAN, integrated voice/data network, etc.~~

~~STS – Subscriber Transceiver Station. An 802.16 node that implements the MAC and PHY protocol layers at the subscriber end of an 802.16 system. An STS interfaces with one BTS and one or more subscriber networks through the SNI reference point.~~

~~TDD – Time Division Duplex. A channel or frequency band switches between upstream and downstream modes.~~

~~TDMA – Time Division Multiple Access. A multiplexing category where the medium is divided into time slots, and slots assigned to users or applications.~~

~~Upstream – Flow in the direction of STS to BTS.~~

10.1 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 Rec. ITU-R F.1399
Accounting	A function which apportions the revenue obtained by the service providers to network operators in	Rec. ITU-R M.1224

	line with commercial arrangements.	
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 bidirectional 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 labelled 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 bitrate	An ATM service category which supports a guaranteed rate to transport services such as video or voice as well as circuit emulation which requires rigorous timing control and performance parameters.	ATM Forum
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
Interworking	The means of supporting	Rec. ITU-R

	communications interactions between entities in different networks or systems.	M.1124
Interworking 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	ITU-T Rec. E.800 (94), 2101

	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.	
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. NOTE - The term "station" may refer to any end-user radio equipment ("subscriber station") or network radio equipment ("base station").	Rec. ITU-R M.1224
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	Rec. ITU-R M.1224

	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.	
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	ATM Forum

	parameters.	
Variable Bit rate: Non-Real-Time rate	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

10.2 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	Interworking 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

~~12Issues to Resolve~~

~~This section lists some issues that need to be resolved.~~

~~Note: Two ad-hoc groups were formed at meeting #2: one to resolve QoS, delay and delay variance issues in section 6, and another to propose terminology and update the glossary (section 11) accordingly.~~

~~Issues:~~

- ~~Provide references where applicable (protocol references in section 2.2, 3,~~
- ~~Resolve terminology: system, BTS, STS, Base Station, Subscriber Station, CPE, cell, network, operator, bearer services, fixed, transportable, nomadic, etc.~~
- ~~Define “wide beam” (S. Marin’s comment in section 5.1)~~
- ~~Resolve availablility (e.g., from about 99.9% to 99.999%) in section 5.4.~~
- ~~Resolve W. Myers’ proposed MAC Requirements: section 10. Concise text needed.~~

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