

Project	IEEE 802.16 Broadband Wireless Access Working Group		
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Re:	<p>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:</p> <p><a href="http://grouper.ieee.org/groups/802/16/sysreq">http://grouper.ieee.org/groups/802/16/sysreq</a></p>		
Abstract	<p>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.</p>		
Purpose	<p>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 guidelines) and another to evaluate terminology usage.</p>		
Notice	<p>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.</p>		
Release	<p>The contributor acknowledges and accepts that this contribution may be made publicly available by 802.16.</p>		

## Revision History

1999-07-02	802.16s0-99/1	Brian Petry (editor)	First Draft
1999-07-14	802.16s0-99/2	Brian Petry (editor)	Some changes approved by task group in session #1
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1999-08-09	802.16s0-99/4	Brian Petry (editor)	Output from session #2: Changes approved by task group; Unresolved Issues section added

## 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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## Table of Contents

<b>1</b>	<b>INTRODUCTION.....</b>	<b>1</b>
1.1	SCOPE.....	1
<b>2</b>	<b>SUPPORTED SERVICES .....</b>	<b>3</b>
2.1	TARGET MARKETS .....	3
2.2	BEARER SERVICES .....	5
<b>3</b>	<b>SYSTEM MODEL.....</b>	<b>9</b>
3.1	SYSTEM REFERENCE MODEL.....	11
3.2	TOPOLOGY.....	12
<b>4</b>	<b>PROTOCOLS.....</b>	<b>12</b>
<b>5</b>	<b>PERFORMANCE AND CAPACITY .....</b>	<b>14</b>
5.1	SCALABILITY .....	15
5.2	DELIVERED BANDWIDTH .....	15
5.3	FLEXIBLE ASYMMETRY.....	15
5.4	RADIO LINK AVAILABILITY.....	15
5.5	ERROR PERFORMANCE.....	16
5.6	DELAY.....	17
5.7	CAPACITY ISSUES .....	18
<b>6</b>	<b>CLASS OF SERVICE AND QUALITY OF SERVICE.....</b>	<b>18</b>
6.1	TYPES AND CLASSES OF SERVICE.....	19
6.2	PARAMETERS .....	20
6.3	BEARER SERVICE QoS MAPPINGS .....	20
<b>7</b>	<b>MANAGEMENT .....</b>	<b>21</b>
7.1	SERVICE LEVEL AGREEMENTS.....	21
7.2	MALFUNCTIONING STS .....	21
7.3	ACCOUNTING AND AUDITING.....	22
<b>8</b>	<b>SECURITY .....</b>	<b>22</b>
8.1	AUTHENTICATION .....	22
8.2	AUTHORIZATION .....	22
8.3	PRIVACY.....	23
<b>9</b>	<b>802 CONFORMANCE .....</b>	<b>23</b>
<b>10</b>	<b>MAC FUNCTIONAL REQUIREMENTS.....</b>	<b>23</b>
10.1	FRAMING AND TIMING .....	24
10.2	LINK ACQUISITION.....	24
10.3	LINK MAINTENANCE.....	24
10.4	RESOURCE ALLOCATION .....	24
10.5	LINK MONITORING .....	24
<b>11</b>	<b>DEFINITIONS AND ABBREVIATIONS.....</b>	<b>24</b>
<b>12</b>	<b>ISSUES TO RESOLVE .....</b>	<b>27</b>
<b>13</b>	<b>REFERENCES.....</b>	<b>28</b>

1

## 2 **1 Introduction**

3

4 This document provides system requirements that are guidelines for developing an interoperable  
5 802.16 air interface. The 802.16 committee desired to reach an understanding and consensus for  
6 system requirements before proceeding with developing standards for 802.16 MAC and PHY  
7 protocols and thus formed a System Requirements Task Group to produce this document.

8

9 Please note that this document provides guidelines for the 802.16 working group. Its purpose is  
10 to formulate and facilitate consensus on some general issues prior to plunging into MAC and  
11 PHY details. As such, the system requirements are subject to change as the 802.16 working  
12 group debates the issues, makes revisions, and approves this document as a basis for starting the  
13 "Interoperability Standard" [20]. Some unresolved issues, noted by the working group, are  
14 described in section 12.

15

16 The System Requirements will not be published and sold by the IEEE. The requirements, with  
17 possible future amendments, are binding to the future development of 802.16 air interface  
18 protocols. This means that the forthcoming air interface standard **MUST** comply with the system  
19 requirements.

20

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

23

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

26

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

28

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

32

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

37

38 "MAY" This word or the adjective "OPTIONAL" means that this item is truly optional. One  
39 vendor may choose to include the item because a particular marketplace requires it or because it  
40 enhances the product, for example; another vendor may omit the same item.

41

### 42 **1.1 Scope**

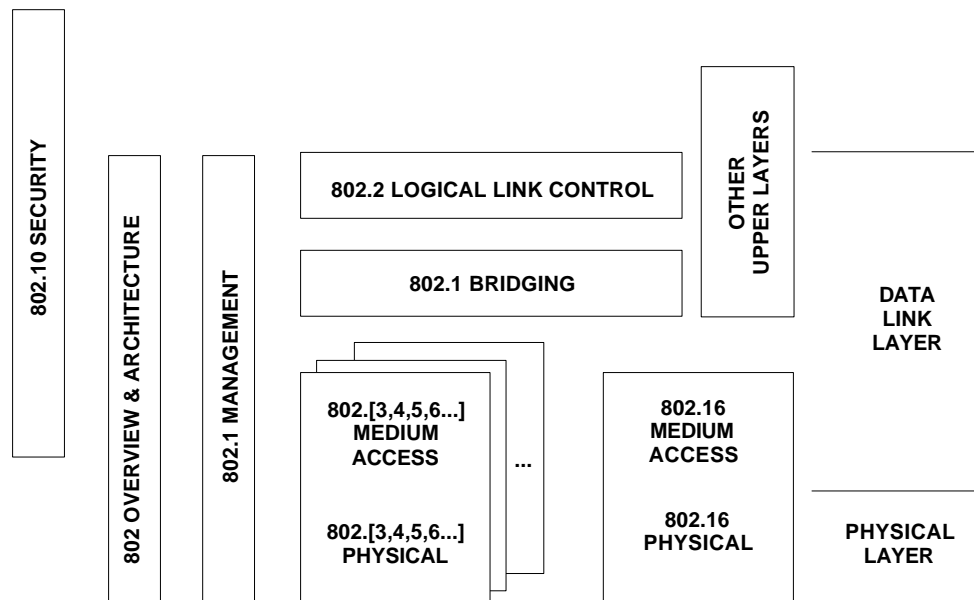
43 For the purposes of this document, a "system" constitutes: an 802.16 MAC and PHY  
44 implementation, in which at least two stations communicate via a point-to-multipoint (P-MP)  
45 radio air interface, the interfaces to external networks, and services transported by the MAC and

1 PHY protocol layers. So, “system requirements” describes the properties of typical systems in  
 2 terms of how they affect requirements of interoperable 802.16 MAC and PHY protocols. The  
 3 system requirements describe 802.16 systems and requirements in broad terms: *what* they are, but  
 4 not *how* they work. The *how* part is left to the forthcoming 802.16 interoperability standard [20],  
 5 which will describe in detail the interfaces and procedures of the MAC and PHY protocols.

6  
 7 Since many BWA *systems* are conceivable, with many possible interconnections, inter-working  
 8 functions [17] and parameters, this document does not specify them all, but focuses on interfaces  
 9 immediately surrounding an 802.16 system, particularly the services an 802.16 system is required  
 10 to transport. These *bearer services* impact directly the requirements of 802.16 MAC and PHY  
 11 protocols. Then, when the 802.16 working group produces an interoperable air interface standard  
 12 that meets these system requirements, an 802.16 system SHALL interface neatly with many  
 13 conceivable systems. See section 2.

14  
 15 Other goals of this document are to formulate reference models and terminology for both network  
 16 topology and protocol stacks that help the 802.16 discuss and develop the MAC and PHY  
 17 protocols. See sections 3 and 4.

18  
 19 The 802.16 air interface interoperability standard SHALL be part of a family of standards for local  
 20 and metropolitan area networks. The following diagram illustrates the relationship of 802.16  
 21 protocols to other 802 standards, and to the OSI reference model. (The numbers in the figure  
 22 refer to IEEE standard numbers.)  
 23



24  
 25  
 26 This family of standards deals with the Physical and Data Link layers as defined by the  
 27 International Organization for Standardization (ISO) Open Systems Interconnection Basic  
 28 Reference Model (ISO 7498: 1984). The access standards define several types of medium access  
 29 technologies and associated physical media, each appropriate for particular applications or system  
 30 objectives. Other types are under investigation.

31  
 32 The standards define the technologies noted in the above diagram are as follows:  
 33

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

3  
4 ANSI/IEEE Std 802.1B [ISO/IEC 15802-2]: LAN/MAN Management. Defines an Open  
5 Systems Interconnection (OSI) management-compatible architecture, environment for performing  
6 remote management.

7  
8 ANSI/IEEE Std 802.1D [ISO/IEC 10038]: MAC Bridging. Specifies an architecture and  
9 protocol for the interconnection of IEEE 802 LANs below the MAC service boundary.

10  
11 ANSI/IEEE Std 802.1E [ISO/IEC 15802-4]: System Load Protocol. Specifies a set of services  
12 and protocols for those aspects of management concerned with the loading of systems on IEEE  
13 802 LANs.

14  
15 ANSI/IEEE Std 802.2 [ISO/IEC 8802-2]: Logical Link Control

16  
17 ANSI/IEEE Std 802.3 [ISO/IEC 8802-3]: CSMA/CD Access Method and Physical Layer  
18 Specifications

19  
20 ANSI/IEEE Std 802.4 [ISO/IEC 8802-4]: Token Bus Access Method and Physical Layer  
21 Specifications

22  
23 IEEE Std 802.10: Interoperable LAN/MAN Security, Secure Data Exchange (SDE)

24

## 25 **2 Supported Services**

26 This section describes the services that an 802.16 system SHOULD support. First, typical target  
27 markets are described, then the particular bearer services which an 802.16 system is expected to  
28 transport.

29  
30 It may be difficult to comprehend services the system supports without first understanding the  
31 system model. Please refer to section 3 if necessary.

32

### 33 **2.1 Target Markets**

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

37  
38 A broadband wireless access (BWA) system SHOULD address markets and offer services similar  
39 to wired broadband access technologies, especially those wired technologies with which BWA is  
40 expected to compete. This includes current high-speed network access markets served by copper  
41 digital subscriber line (DSL) technologies, digital cable TV hybrid fiber/coax (HFC) networks,  
42 Integrated Services Digital Network (ISDN) and aggregated telephony-oriented connections  
43 (e.g., T1, E1, ISDN-PRI etc.), and the services that such networks carry: data, voice and  
44 audio/video [8].

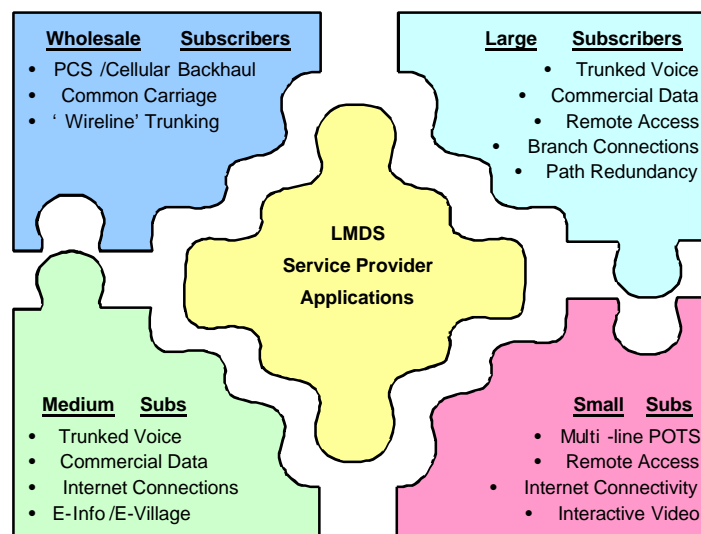
45

1 The initial target market likely will be small to large businesses and multi-tenant dwellings. BWA  
 2 SHALL also address broadband network access for the single-family residential market when  
 3 technology permits.

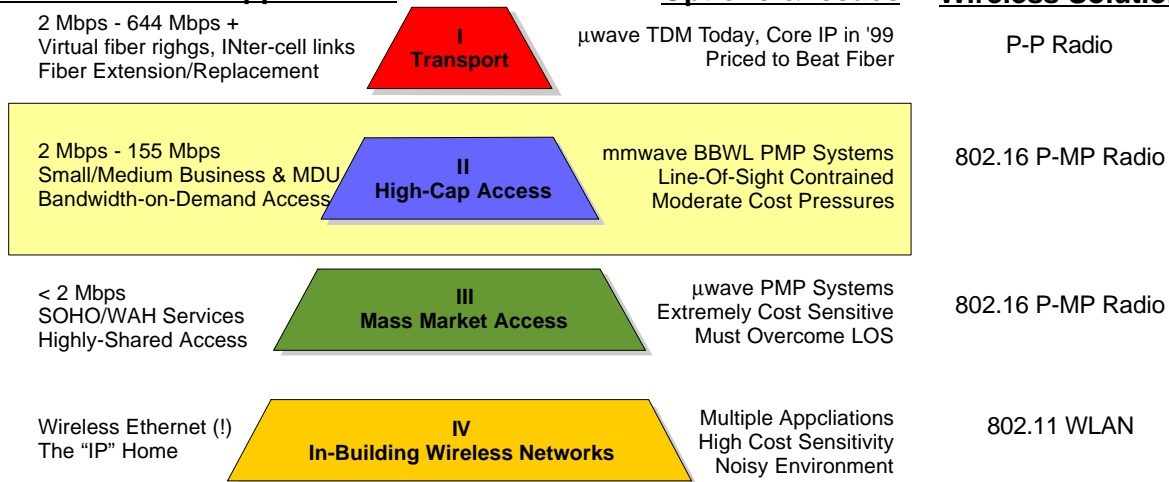
4  
 5 A key word in BWA is “access:” *access* to some other network such as the Internet, a private  
 6 network, a telephony network, etc. An 802.16 access system generally provides access to an  
 7 external network, and by itself is not intended to form an end-to-end communication  
 8 system. 802.16 systems are fixed.

9  
 10 Sometimes, the word *subscriber* is associated with a single customer that is billed for a service.  
 11 But it is important to note that a BWA system SHOULD support more than one paying customer  
 12 at a single access point to a subscriber BWA radio. In other words, the subscriber access point is  
 13 for “wholesale” connection of multiple “retail” subscribers [14]. For instance, an office building  
 14 may be well served by a single BWA radio, but house many tenants who are billed separately.  
 15 This requirement may for instance affect multiplexing in the MAC layer, security (see section 8),  
 16 and accounting (see section 7.3).

17  
 18 The target markets can be further described by [Figure 2-1](#) ~~Figure 2-1~~ and [Figure 2-3](#) ~~Figure 2-2~~.



20  
 21 Figure 2-1 Summary of 802.16 Applications and Services  
 22  
 23

**Characteristics & Applications****Options & Issues****Wireless Solution**

1 Figure 2-32 A Multi-Tier Perspective of Wireless Transmission and Distribution  
2 Systems

## 3 2.2 Bearer Services

4 This section describes typical services, transported by the MAC and PHY protocols, which are  
5 important when considering MAC and PHY requirements. The term *bearer service* is borrowed  
6 from the Integrated Services Digital Network (ISDN) world, which defines a bearer service to be  
7 the capability for information transfer involving lower protocol layers at specific access points in  
8 the ISDN reference model. In this document, *bearer service* is used more liberally to mean the  
9 next layer up the protocol stack from MAC and PHY layers, and the types of networks that  
10 interface to the subscriber-side of BWA systems. [12] [54].

11  
12 The MAC and PHY protocols may not have explicit support for each and every bearer service,  
13 since they SHOULD be handled as data streams in a generic fashion. But it is important to  
14 consider the bearer services for any particular requirements they may have and extract the  
15 "common denominators" that result as generic parameters of MAC and PHY protocols.

### 17 2.2.1 Digital Audio/Video Multicast

18 802.16 protocols SHOULD efficiently transport digital audio/video streams to subscribers. This  
19 form of digital transport may bypass the MAC protocol layer. The streams flow in the direction  
20 of the infrastructure network to subscriber(s) only, and do not originate from subscribers. Digital  
21 Audio/Video Multicast service is thus similar to digital video capabilities of digital broadcast cable  
22 TV, and digital satellite television service.

### 23 2.2.2 Digital Telephony

24 802.16 systems SHOULD support supplying telephony "pipes" to subscribers in a way that eases  
25 the migration of legacy telephony equipment and public switched telephone network (PSTN)  
26 access technologies to 802.16 systems. 802.16 protocols SHOULD transport any layer in the  
27 nationally- and internationally-defined digital telephony service hierarchies: Synchronous Digital  
28 Hierarchy (SDH) or Plesiochronous Digital Hierarchy (PDH) (please see the glossary entries in  
29 section 11).

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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 Telephony over ATM (VtoA), and similar services

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 Telephony Service Properties**

The 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 active, which uses 128 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, 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

1 to minutes a year on average. This is yet another metric that can be varied based on the  
2 service sold to the end user.

3  
4 Supplementary Services – There are a number of supplementary services that enable  
5 capabilities such as Caller ID, Call Waiting, special dialing plans, three-way/conference  
6 calling, etc. These services require additional user-to-network signaling information above  
7 that required to request and terminate calls.

8  
9 Timing - (Fractional) DS1/E1 services require timing to be delivered from the network to the  
10 end user's equipment, whether the timing is synchronous with the network (i.e., based on the  
11 serving network's clock) or asynchronous with the network (based on a clock other than the  
12 serving network's clock). [confer to ad-hoc QoS group: For synchronous timing, the timing  
13 source SHALL be traceable to a Primary Reference Source (PRS). For asynchronous timing,  
14 the timing on the circuits at the output of the access network SHALL be +/- 150 ppm for DS1  
15 (ANSI T1.403-1995) and +/- 50 ppm for E1 (ITU-T G.703). Note that the DS1 spec is  
16 relaxed for older equipment; newer equipment can meet the more stringent +/- 32 ppm spec.  
17 In either case, DS1s carried over the access network SHALL have jitter and wander  
18 characteristics as specified in ITU-T G.823, and E1s as specified in G.824.]

19  
20 What do these properties mean to BWA system requirements? BWA protocols MUST support  
21 efficient transport of encoded voice data in terms of bandwidth, reliability and delay. Other  
22 properties are managed by digital signaling protocols (see section 2.2.2.2).

### 23 24 **2.2.2.2 Signaling Systems and Protocols**

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

29  
30 In digital telephony hierarchies, periodic bits in the time-division-multiplexed data stream,  
31 sometimes “robbed” from encoded voice streams, are used to transport signaling and  
32 troubleshooting information [12]. Other signaling protocols (such as those used in ISDN and B-  
33 ISDN/ATM) are message-oriented and do not utilize periodic bits in a TDM data stream. The  
34 BWA protocols SHOULD meet the transport requirements of such telephony signaling, whether  
35 TDM- or message-oriented.

### 36 37 **2.2.3 ATM Cell Relay Service**

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

43  
44 Given the wide deployment of ATM cell relay service within medium to large businesses, even  
45 considering the emergence of IP-based QoS, 802.16 protocols SHOULD be defined such that an  
46 802.16 system can efficiently transport ATM cell relay service and preserve its QoS features (see

1 section 6). Thus, 802.16 systems SHALL broadly address the target markets mentioned in  
2 section 2.1.

3  
4 Also note that, since ATM cell relay service is circuit-based, it employs message-based signaling  
5 protocols to establish, maintain and tear down switched virtual circuits as well as signal QoS-  
6 based services and perform network management. 802.16 protocols may need to be cognizant of  
7 such ATM signaling to enable an 802.16 system to preserve QoS (see also section 2.2.2.2).

8  
9 802.16 SHOULD provide a means to utilize ATM addresses such as ITU-T E.164 [uncited]. For  
10 instance, 802.16 may provide a direct ATM addressing mode for 802.16 nodes, or may provide a  
11 means to translate ATM addresses to 802 addresses [10].  
12

### 13 **2.2.4 Internet Protocol Service**

14 The 802.16 system MUST transport variable length IP datagrams efficiently. Both IP version 4  
15 and 6 MUST be supported. Especially for efficient transport of Ipv6, TCP/IP header compression  
16 over the air interface SHOULD be supported.

17  
18 The 802.16 IP service MUST provide support for real-time and non-real-time services. It  
19 SHOULD be possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated  
20 Services [43, 44] and Integrated Services [42].  
21

### 22 **2.2.5 Bridged LAN Service**

23 To an 802.16 system, bridged LAN Service [25] [26] is similar to IP service (section 2.2.4). But  
24 whereas IP is classified as a layer 3, “routed” protocol, a bridged LAN is considered layer 2.,  
25 Bridging is a key component of the IEEE 802 architecture. A bridge connects two or more local  
26 area networks (LANs) together, maintaining the concepts of globally addressable nodes, multicast  
27 and broadcast procedures. The IEEE 802 has defined protocols (802.1D [25], 802.1Q [28], [26])  
28 to manage topology discovery (Spanning Tree), the concept of virtual LAN membership,  
29 “remote” bridging, and multicast domain membership. These protocols allow for the  
30 interconnection of 802 LANs, using bridges and switches, regardless of the layer 3 protocols  
31 employed.  
32

33 Whereas an 802.16 system is an *access* network rather than a local area network, bridged LAN  
34 service over 802.16 may not be optimal in practice. But since it is expected that bridged LAN  
35 services places few, if any, additional requirements on 802.16 than IP service, the 802.16  
36 protocols SHALL support bridged LAN services.  
37

### 38 **2.2.6 Other Services**

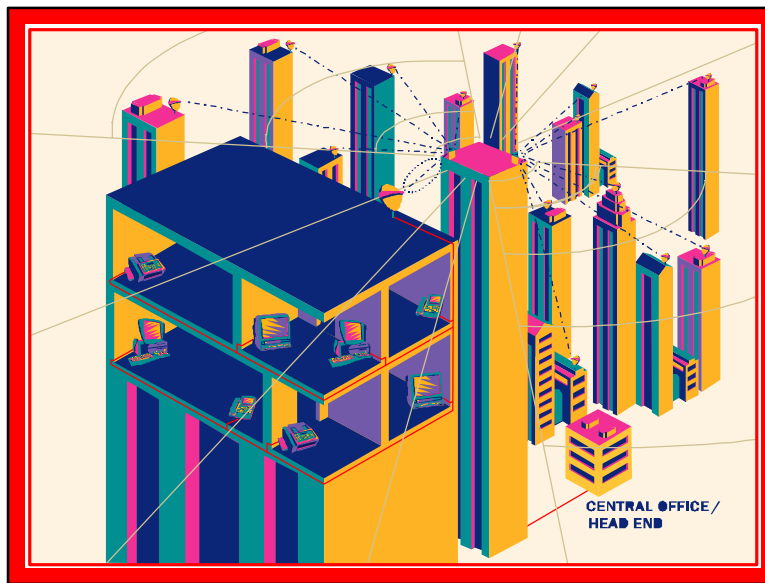
39 Other services that for instance require QoS-based delivery of the MAC services similar to  
40 channelized SDH/PDH telephony, cell relay service, IP service or bridging service (see above  
41 sections), are envisaged. These services do not place any special requirements on 802.16 systems  
42 (MAC and PHY protocols) not already covered in the above sections. Some services are:  
43

- 1 • **Back-haul service** for cellular or digital wireless telephone networks. An 802.16 system may  
2 be a convenient means to provide wireless trunks for wireless telephony base stations. The  
3 channelized SDH/PDH services or ATM cell relay service may be appropriate.  
4
- 5 • **Virtual point-to-point connections** for subscriber access to core network services [9]. In  
6 the example system described in [9], the Internet-oriented point-to-point protocol (PPP) is  
7 employed to make virtual connections between subscribers and service providers and PPP is  
8 encapsulated directly in the 802.16 MAC protocol. PPP has some benefits such as simple  
9 authentication, privacy/encryption, data compression, and layer 3 network parameter  
10 assignment. PPP-over-802.16 SHOULD not place any additional requirements on 802.16  
11 protocols, and SHOULD be similar to IP or bridged LAN service.  
12
- 13 • **Frame Relay Service** Frame Relay is a packet/frame-based protocol, circuit-based data  
14 service that uses a simple variable-length frame format. Some basic QoS guarantees are  
15 defined for frame relay, but not as rich as ATM. Frame relay networks typically use  
16 provisioned permanent virtual circuits (PVCs), although a signaling protocol for switched  
17 virtual circuits (SVCs) is defined and in use. Frame Relay also defines a management  
18 protocol. [3] [12].  
19

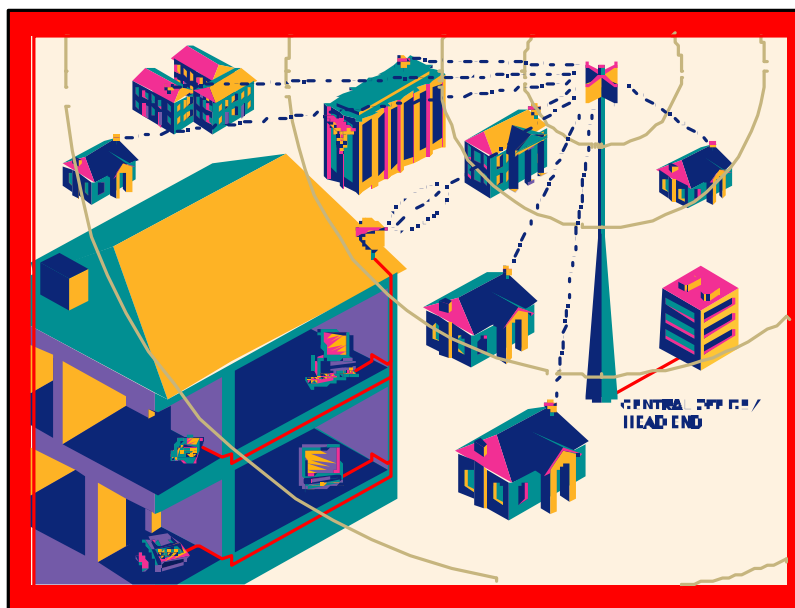
### 20 3 System Model

21 Given the target markets and services described in section 2, this section presents a high level  
22 description of a system model that can be used as a framework for developing 802.16 protocol  
23 standards. The model describes some of the basic features of an 802.16 system, and terminology  
24 that the 802.16 working group can use.  
25

26 As mentioned in section 1.1, an 802.16 “system” constitutes: an 802.16 MAC and PHY  
27 implementation, in which at least two stations communicate via a radio air interface (an 802.16  
28 system), the interfaces to external networks, and services transported by the MAC and PHY  
29 protocol layers. An 802.16 system employs point-to-multipoint (P-MP) radios operating in the  
30 vicinity of 30 GHz, but generally in the range from 10 GHz to 66 GHz, to connect a base  
31 transceiver station (BTS) [S. Marin: The terminology association between base station, subscriber  
32 terminal, customer premises equipment needs to be clarified.[comment left in (need to resolve  
33 terminology throughout document)] to one or more subscriber transceiver stations (STS) [4][9].  
34 Radio communications around 30 GHz require line-of-sight (LOS) between a BTS and STS.  
35 LOS blocked by foliage also contributes heavily to signal attenuation [cite ??]. [Figure 3-1](#)  
36 [3-1](#) and [Figure 3-3](#)~~Figure 3-2~~ [13] depict some typical 802.16 systems. 802.16 systems SHALL  
37 generally be multiple-cell frequency reuse systems. The range of 802.16 radios varies with  
38 transmit power, LOS blockage, and rain fall.  
39  
40



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



4  
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16  
Figure 3-32 System Showing a BTS Mounted on a Tower

Note that, in concern for simple terminology, an 802.16 *system* consists of one BTS radio and one or more subscribers. Thus an 802.16 system also defines 802.16 BTS and STS radios that communicate using the 802.16 MAC and PHY protocols. The BTS 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 employs a highly directional radio pointed at the BTS. 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 radios are “sector oriented,” multiple BTS radios may, in practice, be co-located (subject to frequency re-use requirements), and even share physical hardware.

1  
2 The frequency bands used by 802.16 systems varies somewhat among governed geographies [19].  
3 So, to achieve international applicability, 802.16 protocols MUST be frequency-independent.  
4 Typical bands allocated for 802.16 use are very wide, allowing for the bands to be *channelized*.  
5 To date, the 802.16 working group has not determined channelization requirements. Neither is it  
6 known that a chosen, ubiquitous, channel bandwidth will be applicable to all 802.16 systems. For  
7 the time being, 802.16 protocols SHOULD remain flexible in their channel parameters. But  
8 channels SHALL at least be provisioned in a particular instance of an 802.16 system that allow  
9 for:

10

- 11 • Spectrum allocation in adjacent 802.16 systems
- 12 •
- 13 • Channel allocation to subscriber(s) based on bandwidth or CoS/QoS requirements

14

15

16

17

18

### 19 **3.1 System Reference Model**

20 **Figure 3-1** shows the 802.16 system reference points, depicting the relevant elements  
21 between a subscriber network and the “core” network (the network to which 802.16 is providing  
22 *access*). The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and  
23 extend cell coverage. A greater system encompassing user terminals, BTS interconnection  
24 networks, network management facilities, etc. [1] may be envisaged, but the 802.16 protocols  
25 focus on the simplified model shown in the figure. Also not shown are the internal physical  
26 characteristics of the BTS and STS: the concepts of “indoor” and “outdoor” units. The  
27 description of possible separation of BTS and STS into indoor and outdoor units is beyond the  
28 scope of this document. One addition to this model to be considered are security systems (see  
29 section 8). Two key interfaces “to the outside world” are shown in the figure: the Base  
30 Transceiver Station Network Interface (BNI) and the Subscriber Transceiver Station Network  
31 Interface (SNI). A single SNI may support multiple subscriber networks: LANs, Voice PBXs,  
32 etc. And recall from section 2.1 that the SNI may support multiple paying subscribers, such as  
33 within a multi-tenant office building or dwelling. A BTS interfaces to one or more core networks  
34 through one or more BNIs. For the purposes of 802.16, the SNI and BNI are abstract concepts.  
35 The details of these interfaces, which are sometimes called inter-working functions (IWFs), are  
36 beyond the scope of this document and are not specified by the forthcoming interoperability  
37 standard [20] [17]. Since many subscriber and core network technologies are possible, many  
38 different IWFs are conceivable. The simplified reference model, serves to discuss the impact of  
39 core network technologies and bearer services (see section 2.2) on the requirements of 802.16  
40 protocols by drawing focus to the air interface and the immediate requirements imposed by the  
41 surrounding networks. The standard (e.g., MAC/PHY protocols) SHALL describe common  
42 access protocol(s) and common modulation technique(s).

43

44

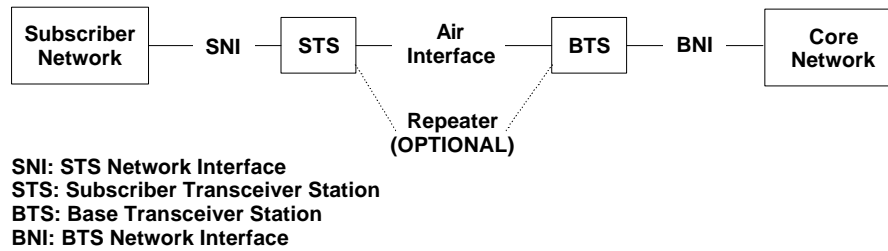


Figure 3-53 System Reference Points

### 3.2 Topology

Since all data traffic in an 802.16 network MUST go through the base transceiver station (BTS), it is convenient for the BTS to serve as a radio resource supervisor, which controls the allocation of bandwidth on the radio channel [10]. The STS stations may request bandwidth to achieve QoS objectives (see section 6), but it may be convenient for the BTS to implement the “smarts” of bandwidth allocation.

In the downstream direction, within a channel, the network topology is similar to a contentionless broadcast bus (using LAN terminology), since all transmissions are initiated by the BTS, and more than one STS could share a downstream channel. In the upstream direction, if STSs 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 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.

## 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.

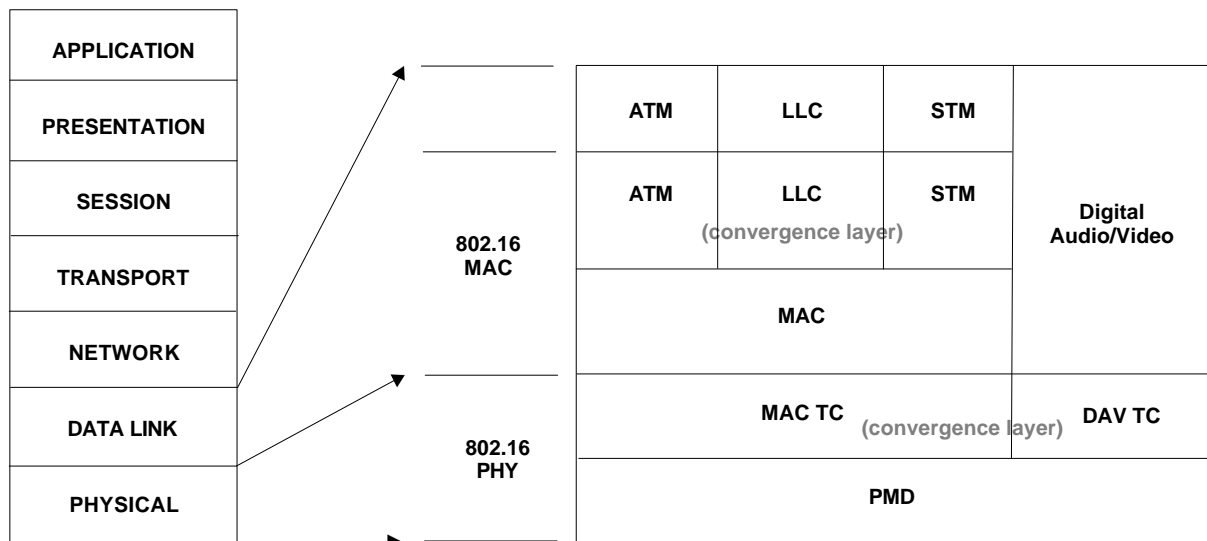
1 With type 2 operation, a logical link is established between pairs of LLC entities prior to any exchange of  
 2 information frames. In the data transfer phase of operation, information frames are transmitted and delivered in  
 3 sequence. Error recovery and flow control are provided.

4 With type 3 operation, information frames are exchanged between LLC entities without the need for the prior  
 5 establishment of a logical link between peers. However, the frames are acknowledged to allow error recovery and  
 6 proper ordering. Further, type 3 operation allows one station to poll another for data.”

7  
 8 “The MAC Sublayer performs access control functions for the shared medium in support of the LLC Sublayer. For  
 9 different applications, different MAC options may be required. The MAC Sublayer performs the addressing and  
 10 recognition of frames in support of LLC. MAC also performs other functions, such as frame check sequence  
 11 generation and checking, and LLC protocol data unit (PDU) delimiting.”

12  
 13 “The Physical Layer provides the capability of transmitting and receiving bits between Physical Layer Entities. A  
 14 pair of Physical Layer Entities identifies the peer-to-peer unit exchange of bits between to MAC users. The  
 15 Physical Layer provides the capability of transmitting and receiving modulated signals assigned to specific  
 16 frequency channels, in the case of broadband, or to a single-channel band, in the case of baseband.”

17  
 18 The 802.16 protocol stack reference diagram is shown in [Figure 4-1](#). In addition to the  
 19 LLC, MAC and PHY layers suggested by the generic 802 architectures [21] [22], 802.16  
 20 protocols transport other categories of “upper protocols” that correspond to the requirements of  
 21 the bearer services described in section 2.2.



25 **Figure 4-1 Protocol Stack Reference Model**

26 The protocol reference diagram may be getting to far into the “how” part of 802.16 protocols,  
 27 which should be outside the scope of this document, but this protocol stack reference model  
 28 should help develop terminology, if not protocol architecture. Each of the “special” protocols  
 29 above the MAC and PHY are given “convergence sub-layers.”. The convergence sub-layers [2]  
 30 [17] may be necessary to:

- 31
- 32 • Encapsulate PDU framing of upper layers into the native 802.16 MAC/PHY PDUs. [17]
  - 33 • Map an upper layer’s addresses into 802.16 addresses
  - 34 • Translate upper layer CoS/QoS parameters into native 802.16 MAC constructs
  - 35 • Adapt the asynchronous, synchronous or isochronous (defs) data pattern of the upper layer
  - 36 into the equivalent MAC service

- 1 • Reduce the need for complex inter-working functions (IWFs) [17]

2  
3 For instance, in the ATM world a Transmission Convergence (TC) layer is defined for each link  
4 type that carries ATM cells. The purpose of this layer is to delimit cells using the particular link  
5 technology, and to signal idle time, or insert idle ATM cells on the link. 802.16 borrows this  
6 terminology to accommodate “special” requirements of the multiple upper layer protocols.  
7

8 Another assumption made in the diagram is that digital audio/video (DAV) service bypasses the  
9 MAC protocol layer and accesses the PHY layer directly. This assumption is made because the  
10 DAV multicast bearer service (see section 2.2.1) is transmitted in the downstream direction only,  
11 and does not require the main service of the MAC: channel contention (access control).  
12

13 The central purpose of the MAC protocol layer in 802.16 is sharing of radio channel resources.  
14 The MAC protocol defines how and when a BTS or STS may initiate transmission on the channel.  
15 Since key layers above the MAC, such as ATM and STM, require service guarantees, the MAC  
16 protocol MUST define interfaces and procedures to provide guaranteed service to the upper  
17 layers. In the downstream direction, since only one BTS is present, and controls its own  
18 transmission, the MAC protocol is simple. But in the upstream direction, if one radio channel is  
19 allocated to more than one STS, the MAC protocol MUST efficiently resolve contention and  
20 bandwidth allocation. Note that the function of the MAC layer is not to provide error correction  
21 by retransmission, or automatic repeat request (ARQ). In the 802 model, those functions if  
22 necessary, are provided by the LLC layer  
23

24 The PHY layer is similarly subdivided between a convergence layer and a physical medium-  
25 dependent (PMD) layer. The PMD is the “main” part of the PHY. Like the MAC convergence  
26 layers, the PHY convergence layers adapt/map the “special” needs of the MAC and DAV services  
27 to generic PMD services. For instance, to best support DAV services, the PHY may provide  
28 TDM-based encapsulation of DAV streams TDM MPEG-II frames [14].  
29

30 Further details, and finalization of the protocol reference model, SHALL be worked out by the  
31 802.16 MAC and PHY task groups while developing the air interface interoperability standard.  
32

## 33 **5 Performance and Capacity**

34  
35 This section addresses some issues regarding 802.16 system performance and capacity.  
36 Specifying protocols such that an 802.16 system can maintain a specified/mandated performance  
37 level in the face of rapidly changing channel characteristics (due to rain) will be a difficult problem  
38 for the 802.16 working group. This section specifies the target performance levels. Given the  
39 target performance levels, planning and provisioning an 802.16 system instance is also a difficult  
40 problem. The 802.16 system capacity at the target performance levels for all subscribers, given  
41 geographically local LOS obstruction and rain fall will also be difficult. This section also outlines  
42 some of the issues for 802.16 capacity planning.  
43

44 Note that ITU-R (WP 9A) has presented several questions regarding the need for performance  
45 objectives for fixed wireless access radio systems. [16]  
46

## 1 **5.1 Scalability**

2 The 802.16 protocols SHOULD allow for different “scales” of capacity and performance for  
3 802.16 system instances. For instance, large businesses with high throughput and CoS/QoS  
4 requirements SHOULD be accommodated as well as small scale systems in dense, limited LOS  
5 environments. For instance, a subscriber with high requirements could be dedicated a narrow  
6 beam from the BTS with many radio channels. On the other end of the scale are “pico-802.16-  
7 systems” in dense metropolitan areas [6] that implement short-radius beams to a few subscribers.  
8 Perhaps in the middle of the scale are relatively wide-beam [S. Marin: define (tabled to future  
9 session)] 802.16 systems that serve a large number of subscribers on many radio channels.

10  
11

12

## 13 **5.2 Delivered Bandwidth**

14 802.16 system carriers are expected to provide the peak capacity from 2 to 155 Mbps to an STS  
15 sufficiently close to the BTS. The 802.16 MAC protocol SHOULD allow the upper range of  
16 delivered bandwidth to scale beyond 155 Mbps.

17

## 18 **5.3 Flexible Asymmetry**

19 802.16 protocols SHOULD allow for flexibility between delivered upstream and downstream  
20 bandwidth and CoS/QoS. Some target markets utilize naturally asymmetrical bandwidth, such as  
21 for generic Internet access---most of the bandwidth is consumed in the downstream direction.  
22 Some markets utilize asymmetrical bandwidth, using more in the upstream direction, such as a  
23 video multicast from a corporate or distance-learning source. Other markets and applications  
24 require symmetrical bandwidth, such as telephony and video conferencing [17].

25

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

28

## 29 **5.4 Radio Link Availability**

30

31 An 802.16 system SHOULD be available to transport all services at their required maximum  
32 error rates (see section 5.5) 99.99% of the time [2, 11] , assuming that the system and radios  
33 receive adequate power 100% of the time and not counting equipment availability. This amounts  
34 to approximately 53 minutes of outage a year. Note that 99.999% available amounts to  
35 approximately 5 minutes of outage a year. [S. Marin change to “from about 99.9 to 99.999”  
36 (tabled until next session/comment)] The 802.16 specifications SHALL not preclude the ability of  
37 the radio link to be engineered for different link availabilities, based on the preference of the  
38 system operator.

39

40

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

1  
2 Severely Errored Second (SES) is defined as a one-second period which contains (30% errored  
3 blocks.

4  
5 Errored Block (EB): A block is defined as a set of consecutive bits associated with the path.  
6 Consecutive bits may not be contiguous in time. A block is typified as data block containing an  
7 error detection code for in service performance monitoring. An errored block is a block in which  
8 one or more bits are in error.

9  
10 It is expected that the highest contributor to 802.16 system outage will be excessive attenuation  
11 due to rain fall (rain rate and droplet size) [50] [51] [52] [53]. 802.16 MAC and PHY protocols  
12 MUST accommodate rain fall, perhaps consuming more radio bandwidth and/or requiring smaller  
13 radio propagation distance (radius) to meet the availability requirements. Since statistical rain  
14 rates vary widely in geography, the 802.16 protocols MUST be flexible in consumed radio  
15 bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance  
16 that varies with geography [11]. Bandwidth and cell radius are critical components of system/cell  
17 capacity planning (also see section 5.7).

18  
19 802.16 MAC and PHY protocols SHOULD specify functions and procedures to adjust power,  
20 modulation, or other parameters to accommodate rapid changes in channel characteristics due to  
21 rain fall.

22  
23 The telephony world also defines availability in terms of “errored seconds” and “severely errored  
24 seconds” [15]. For a service with “stringent” QoS requirements, G.826 defines the errored  
25 second ratio to be .04 and the severely errored second ratio .002. errored seconds is 99.8%  
26 availability. Note that this is below the 99.99% goal.

27

## 28 **5.5 Error Performance**

29 The error rate, after application of the appropriate error correction mechanism (e.g., FEC),  
30 delivered by the PHY layer to the MAC layer SHALL meet IEEE 802 functional requirements:  
31 The bit error rate (BER) is  $10E-9$ . Additionally, each block of data delivered by the PHY to the  
32 MAC layer MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3  
33 errored bits (a Hamming Distance of 4) [7]. Note that the size of the data block is TBD.

34  
35 For telephony-oriented bearer services (see section 2.2.2), the 802.16 working group may  
36 consider relaxing the  $10E-9$  BER requirement. ITU requirements for digital voice services are  
37 three orders of magnitude less stringent— $10E-6$  [11] [51] [52]. Thus for digital voice services,  
38 802.16 protocols trade off higher throughput modulation and error correction techniques for less  
39 consumed radio bandwidth.

40  
41  
42  
43 Other error rate metrics used in the telephony and ATM for what are considered “stringent QoS”  
44 are: [15]

- 1 • Background block error rate (BBER) [51]. 2E-4. One in 5000 blocks is errored. If the block  
 2 size is approximately that for Ethernet (1522 octets), BBER is roughly equivalent to ~~16E-6~~ [R  
 3 Sanders: Conferred to ad-hoc QoS group bit error rate (BER).  
 4 • Cell Loss Ratio (CLR) [cite I.356]. 3E-7. One in 3.333 Mcells is errored. This is roughly  
 5 equivalent to ~~5.6E-97.1E-10~~ [R. Sanders] [conferred to ad-hoc QoS group] BER. Note that  
 6 CLR is not always due to transmission error, but ATM switches dropping cells due to  
 7 capacity limits.  
 8 Note that the telephony and ATM bit error rates seem far less stringent than LAN error rates.  
 9 Also note that BER for a BWA system is only one component of a network's end-to-end BER.  
 10 [R. Sanders] [conferred to ad-hoc QoS group]  
 11

## 12 **5.6 Delay**

13 System delay requirements come in several categories:  
 14

- 15 • Medium Access Delay. The delay imposed by the MAC protocol layer between when a BTS  
 16 or STS becomes ready to transmit and when it actually begins transmission on the channel.
- 17 • Transit Delay. The total 802.16 system delay from BNI to SNI and from SNI to BNI (see  
 18 section 3.2). This includes the Medium Access Delay.
- 19 • End-to-End Delay. The total delay between a terminal in the subscriber network, to the  
 20 ultimate service beyond the core network. For instance, the total delay between two  
 21 telephony terminals (handsets). This includes the 802.16 Transit Delay.  
 22

23 In addition to the above categories, variation of delay, or jitter, is important to consider. For  
 24 example, a high variation of delay can severely impact telephony services. But generic Internet  
 25 access can tolerate a high degree of delay variation.  
 26

27 The end-to-end delay is a subjective metric and depends on an entire application-specific network  
 28 encompassing all 7 layers of the OSI model. In a telephony network, for example, the maximum  
 29 acceptable end-to-end delay for the longest path is RECOMMENDED to be less than 300ms [15]  
 30 [17] [cite G.114].  
 31

32 The budget for the 802.16 system transit delay and access delay MUST be derived. [15] [17].  
 33 The radio propagation time is 3.3μsec/km [cite G.114]. If the distance between STS and BTS is  
 34 5km, this propagation time is 16.7μsec. The MAC layer may have different requirements for each  
 35 direction, upstream and downstream. In the upstream direction, time MUST be budgeted for  
 36 requesting bandwidth and contending among nodes. The budget for 802.16 transit delay is  
 37 suggested to be 19.5 ms [15] for “stringent QoS” services. [J. Mollenauer: \_\_\_\_\_  
 38 ~~require a “shallSHALL” instead of suggested~~ conferred to ad-hoc QoS group].  
 39

40 ITU I.356 recommends end-to-end variation (jitter) for “stringent QoS class” to be less than 3 ms.  
 41 Multimedia videoconferencing requires delay variation to be less than 200 ms end-to-end to allow  
 42 for reasonable synchronization of audio and video streams [17]. It is suggested that the budget  
 43 for 802.16 systems be 1.5ms [15] for “stringent QoS” services.  
 44

45 Please refer to section 6.2, descriptions of QoS parameters.  
 46

## 1 **5.7 Capacity Issues**

2 802.16 system capacity is defined as the product of the number of subscribers, their peak  
3 bandwidth requirements and quality of service guarantees. This capacity can vary depending on  
4 rain attenuation, LOS blockage, transmit power, etc. In a given 802.16 system instance, capacity  
5 **MUST** be carefully planned to ensure that subscribers' quality of service guarantees and  
6 maximum error rates are met. Given the rain attenuation statistics in a geographic area, and the  
7 development of a channel link budget [11], the following parameters of an 802.16 system  
8 **SHOULD** be addressed by the MAC and PHY protocols [11]:  
9

- 10 • Radio range (shaped sector radius)
- 11 • Width of the sector
- 12 • Upstream/Downstream Channels
- 13 • Allocation of prospective subscriber bandwidth to channels. Note: the MAC and PHY  
14 standards may allow subscribers to hop between channels
- 15 • Types of modulation

16

17

18 The MAC and PHY protocols **MUST** accommodate channel capacity issues and changes in  
19 channel capacity to meet contracted service levels with customers. For example, flexible  
20 modulation types, power level adjustment, and bandwidth reservation schemes may be employed.

21 Also, as subscribers are added to 802.16 systems, the protocols **MUST** accommodate them in an  
22 automated fashion.

23

24 The time-variant impairments, rain fade and multipath interference, are expected to be the most  
25 significant contributors to channel impairments and complexity in cell capacity planning [7] [37]  
26 [38] [39] [40] [11] [50] [51] [52] [53]. Common metrics, such as dispersive fade margin (DFM)  
27 [7] for frequency-selective fading environments, may be employed to compare the performance of  
28 802.16 equipment (e.g., radios and modems).

29

30

## 31 **6 Class of Service and Quality of Service**

32

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

34

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

37

38 802.16 protocols **MUST** support classes of service (CoS) with various quality of service (QoS)  
39 guarantees to support the bearer services (see section 5) that an 802.16 system **MUST** transport.

40 Each bearer service defines guarantees that they "expect" to be preserved by an 802.16 system.

41 Thus, 802.16 protocol standards **MUST** define interfaces and procedures that accommodate the  
42 needs of the bearer services: allocation of prioritization of bandwidth. Additionally, 802.16

43 protocols **MUST** provide the means to enforce QoS contracts and Service Level Agreements [2]  
44 (see section 7.1).

45

1 The 802.16 protocols MUST be capable of dedicating fixed, provisioned, bandwidth for bearer  
 2 services such as SDH/PDH. For instance, the MAC layer may employ TDM allocation of  
 3 bandwidth within a channel for these services. TDM bandwidth allocation may be performed  
 4 dynamically to allow for both 1) turning up fixed bandwidth Permanent Virtual Circuits (PVCs)  
 5 and 2) for dynamically changing bandwidth of a virtual circuit once it has been established. [R.  
 6 Sanders] ~~This form of allocation may be provisioned in advanced, or dynamically “signaled” as~~  
 7 ~~virtual circuits are set up.~~ [conferred to ad-hoc QoS group]

8  
 9 For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16 protocols  
 10 MUST support bandwidth negotiation “on-demand” [9]. For instance, the MAC protocol may  
 11 allocate bursts of time slots to bearer services that require changes in bandwidth allocation. Such  
 12 allocation is thus performed in a semi-stateless manner. A connection-oriented bearer service may  
 13 require “state” information to be maintained for the life of a connection. But the 802.16 MAC  
 14 layer interface may provide a connection-less service interface that requires a higher-layer  
 15 “adaptation” to maintain the “state” of a connection and periodically allocate bandwidth. For  
 16 instance, the MAC may need to maintain “state” information about a QoS data flow only for the  
 17 duration of an allocation.

18  
 19 [Insert sections 3 and 4 of contribution 28 (lots of text and tables) A. Arunachalam.][conferred to  
 20 ad-hoc QoS group]

## 21 **6.1 Types and Classes of Service**

22 [A. Arunachalam: Move sections 6.1 and 6.2 into 6.3 (simply merge together?)] [conferred to ad-  
 23 hoc QoS group]

24 Traffic may be roughly categorized as follows [2] [8] [4] (ATM terminology):

- 26 • Constant Bit Rate (CBR). The bearer service requires a constant, periodic access to  
 27 bandwidth. SDH/PDH falls into this category.
- 28 • Variable Bit Rate: Real-Time (VBR-rt). The bandwidth requirements vary over time, within a  
 29 specified range, but delay and delay variance limits are specified. Examples that fall into this  
 30 category are voice-over-IP (VoIP), videoconferencing, video on demand [R. Sanders]  
 31 [conferred to ad-hoc QoS group] and other “multimedia” applications.
- 32 • Variable Bit: Non-Real-Time Rate (VBR-nrt). The bandwidth varies, within a specified  
 33 range, but has loose delay and delay variance requirements. Applications, which are limited in  
 34 their bandwidth usage, may fall into this category. In one example, corporate database  
 35 transactions could be relegated to this category.
- 36 • Available Bit Rate (ABR). The bandwidth varies within a wide range, and is allowed to burst  
 37 up to the maximum link bandwidth when CBR and VBR traffic are not using bandwidth.  
 38 Higher variations of delay may be tolerable since applications that fall into this category allow  
 39 for priority traffic to consume bandwidth they do.
- 40 • Unspecified Bit Rate (UBR). The bandwidth and delay requirements are not specified.  
 41 Bandwidth is delivered on a “best effort” basis.
- 42 • [I Frigui: UBR+. (Text coming from Imed)] [conferred to ad-hoc QoS group]

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

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

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

2  
3 Interactive bulk (FTP)

4  
5 Asynchronous bulk (Email, FAX, Remote Printing, Backup, etc.)

6  
7 **Real-Time.** Applications that require some level of bandwidth and/or delay variation:

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

10  
11 Predictive Service. Applications are tolerant of some late data, a higher variation of delay, or may adapt  
12 to less available bandwidth. For example, a video playback service may be able to adapt its playback  
13 buffer to accommodate variation of delay.

14  
15 An IETF architecture for differentiated services [43] defines how Internet Protocol-based service  
16 classes may be given quality-of-service. Traffic flows are identified in terms of their profiles: rates  
17 and burst sizes.

## 18 19 **6.2 Parameters**

20 ATM standards describe service categories (see section 6.2) in terms of traffic descriptors [9] [12]  
21 [54]:

- 22
- 23 • Peak Cell Rate (PCR). The maximum rate at which cells will be transmitted.
- 24 • Sustainable Cell Rate (SCR). The cell rate which could be sustained for a certain length of  
25 time.
- 26 • Maximum Burst Size (MBS). The maximum number of cells that could be transmitted “back-  
27 to-back.”
- 28 • Minimum Cell Rate (MCR). The minimum cell rate supported by a connection (applies to  
29 ABR service only)]D. Jarrett]Maximum Cell Rate (MCR). The maximum cell rate supported  
30 by a link[conferred to ad-hoc QoS group]

31  
32 Other ATM QoS parameters are:

- 33
- 34 • Cell Loss Ratio (CLR)
- 35 • Maximum Cell Transfer Delay (MCTD)
- 36 • Cell Delay Variation Tolerance (CDVT)

37  
38 802.16 protocols SHALL define a set of parameters that preserve the intent of QoS parameters  
39 for both ATM- and IP-based services. (TBD)

## 40 41 **6.3 Bearer Service QoS Mappings**

42 The classes of service and QoS parameters of bearer services SHALL be translated into a  
43 common set of parameters defined by 802.16. A network node that serves as an inter-working  
44 function (IWF) between a QoS-capable LAN or WAN and an 802.16 system MUST participate in  
45 signaling protocols to set up QoS parameters for connection-oriented services.

1 For example, if an ATM network is to be transported over an 802.16 system, ATM switched  
2 virtual circuits negotiate QoS parameters for the circuit. The IWF MUST participate in the ATM  
3 signaling protocol that sets up the circuit. It also MUST utilize 802.16 interface primitives (e.g.,  
4 MAC layer user interface primitives) to request QoS.

5  
6 Similarly, a QoS-based IP network may employ the Resource Reservation Protocol (RSVP) [70]  
7 to “signal” the allocation of resources along a routed IP path. If 802.16 is to be a “link” in the IP  
8 network, an IWF MUST interface with 802.16 to negotiate resource allocation.

9  
10 The specification of how IWFs operate is outside the scope of this document and the forthcoming  
11 802.16 interoperable air interface standard [20] [20a]. However, the QoS parameters for 802.16  
12 MUST be chosen and interface primitives defined that allow for bearer services’ IWFs to  
13 negotiate QoS “through” an 802.16 system.

14  
15 The basic mechanism available within BWA systems for supporting QoS requirements is to  
16 allocate bandwidth to various services. BWA systems SHOULD include a mechanism that can  
17 support dynamically-variable-bandwidth channels and paths (such as those defined for ATM and  
18 IP environments). [R. Sanders][conferred to ad-hoc QoS group]

## 19 **7 Management**

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

- 24
- 25 • Configuration management
  - 26 • Fault management
  - 27 • Performance management (see also section 5)
  - 28 • Security management (see also section 8)
  - 29 • Accounting management
- 30

31 The 802 standards define a framework for LAN/MAN management in ISO/IEC 15802-2:  
32 1995(E) [24]. The framework contains guidelines for managed objects, management protocol,  
33 and the relationship to ITU management protocols (CMIP/CMIS). The 802.16 standards SHALL  
34 consider ISO 15802 for its network management framework.

### 35 **7.1 Service Level Agreements**

36 The 802.16 protocol MUST permit operators (def) to enforce service level agreements (SLAs)  
37 with subscribers by restricting access to the air link, discarding data, dynamically controlling  
38 bandwidth available to a user or other appropriate means. [3]

### 39 **7.2 Malfunctioning STS**

40 The operator MUST have means to shut down an STS if necessary, from the BTS, in the face of a  
41 malfunction.

### 1 **7.3 Accounting and Auditing**

2 The 802.16 system management framework, architecture, protocols and managed object MUST  
3 allow for operators to effectively administer accounting and auditing. An operator MUST be able  
4 to account for time- and bandwidth-utilization and the various QoS parameters for each  
5 subscriber. Also recall that a single STS can interface to multiple subscribers that an operator  
6 could bill separately.

## 7 **8 Security**

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

9  
10 The security system chosen by 802.16 will be added to the protocol stack (~~Figure 4-1~~~~Figure 4-1~~)  
11 and reference points (~~Figure 3-5~~~~Figure 3-3~~) to include security protocols, and “database” servers  
12 for authentication, authorization, key management, etc.  
13

### 14 **8.1 Authentication**

15 There are two levels of authentication for an 802.16 system. The first  
16 level of authentication is when the STS authenticates itself with the BTS at  
17 the STS's network entry. This initial authentication MUST be very strong in  
18 order to prevent 'enemy' STS from entering the network or an 'enemy' BTS from  
19 emulating a real BTS. Once the initial authentication at this level is  
20 complete, future authentication at this level can be a little more relaxed.  
21 This level of authentication MUST be supported by the 802.16 MAC layer.  
22

23 The second level of authentication is between the subscriber and the BWA  
24 system. This may or may not be the responsibility of the 802.16 protocols.  
25 It may be handled by higher layer protocols.  
26

27 An additional level of authentication may exist between the other two. This  
28 additional layer is the authentication of the subscriber with the STS. This  
29 is beyond the scope of the 802.16 protocol.  
30

31 The authentication mechanisms MUST be secure so that an “enemy” STS is not able to gain  
32 access to an 802.16 system, or to the core network beyond. Passwords and secrets MUST NOT  
33 be passed “in the clear” through the air interface.  
34

### 35 **8.2 Authorization**

36 Authorization is a security process that determines what services an authenticated subscriber is  
37 permitted to invoke. Each subscriber has a set of credentials that describe what the subscriber is  
38 “allowed” to do. The 802.16 standard SHALL identify a standard set of credentials and allow for  
39 vendors to extend the defined credentials with non-standard credentials. Some possible  
40 credentials are:

41  
42       Permission to access the 802.16 system  
43

1 Permission to request up to a defined QoS profile (bandwidth, delay, etc.)

2  
3 Permission to operate certain bearer services (ATM, IP, Remote Bridging, Digital  
4 Audio/Video, etc.)

5  
6 Subscriber authorization requests and responses MUST be transacted securely.  
7

### 8 **8.3 Privacy**

9  
10 Privacy is a security concept that protects transmitted data from being intercepted and understood  
11 by third parties (e.g., an “enemy” STS, BTS or passively “listening” radio). Wire-equivalent  
12 privacy (WEP) [10] and shared private key [10] privacy have been suggested as minimum  
13 required privacy levels for 802.16 systems.

14  
15 802.16 standards SHOULD allow a strong cryptographic algorithm to be employed that is  
16 internationally applicable. Facilities SHOULD also be defined in the protocol for the use of  
17 alternate cryptographic algorithms that can be used in certain localities and that can replace  
18 algorithms as they are obsoleted or “legalized” for international use.  
19

## 20 **9 802 Conformance**

21 As mentioned in some earlier sections of this document, 802.16 SHALL strive to fit into the 802  
22 system model. Some particulars with the 802 model (see *IEEE Standards for Local and*  
23 *Metropolitan Area Networks: Overview and Architecture* (IEEE Std 802-1990) [21]) are:

24  
25 The 802.16 MAC supports 802 “universal” 48 bit addresses

26  
27 An 802.16 system supports MAC multicast in the downstream direction only, not upstream.

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

31  
32 The 802.16 protocols support encapsulation of 802.2 (LLC) [67] by the MAC protocol .

33  
34 Conform to the 802 conventions and structures for “interface primitives:” logical structures  
35 that are passed between protocol layers to invoke processes and transact data.

36  
37 Address the 802 system management guidelines (see section 7).

38  
39 Provide a MAC service interface that complies to 802 conventions [22].

## 40 **10 MAC Functional Requirements**

41  
42 [Editor’s note: Bill Myers proposed this section. The group decided to leave its acceptance into  
43 the document unresolved.]  
44

1 The following describes the functional requirements to be performed by the wireless MAC. In  
2 conjunction with the PHY equipment, the MAC assures that QoS requirements for the wireless  
3 segment are met such as delay, delay variation, etc. and performs the following tasks:  
4

### 5 **10.1 Framing and Timing**

### 6 **10.2 Link Acquisition**

7 □ Download to subscriber the local channel plan, data rate options, modulation options, FEC  
8 types, and timeslot arrangement employed at specific cell.

9 □ Establishes link at proper upstream power and frequency

10 - Provide timeslot timing calibration.

11 -

### 12 **10.3 Link Maintenance**

13 □ Provide upstream power control and frequency control (OPTIONAL) to maintain specified  
14 error rate performance during link dynamics such as rain fades.

15 □ Provide timeslot timing control

16 □ Interference detection and mitigation

17 □ Redundant hardware control

### 18 **10.4 Resource Allocation**

19 Admission control for connections based on available resources.

20 □ Dynamic allocation of channels and timeslots according to traffic and traffic priority  
21 requirements.

22 □ Policing of traffic conflicts.

23 □ Buffer management

### 24 **10.5 Link Monitoring**

25 □ Provide status of link performance (errored seconds, etc)

26 □ Provide status of hardware

27 □ Maintain status of bandwidth and resources available

28 □ Fault detection, isolation and correlation

## 29 **11 Definitions and Abbreviations**

30  
31 [Editor's note: this section is being reviewed by an ad-hoc committee.]  
32

33 BNI – BTS Network Interface. A reference point where one or more core networks interface to  
34 a BTS. Also, multiple, co-located BTSs from different 802.16 systems may interface at the BNI.  
35

36 BTS – Base Transceiver Station. . Equipment that communicates with one or more subscriber  
37 transceiver stations (STS) and includes a BNI, MAC and PHY layer implementation, radio and  
38 single shaped sector antenna (or antenna array). More than one BTS may be co-located to allow

1 omnidirectional service. A BTS is designated as one system with a single downstream antenna  
2 pattern. A BTS is sometimes called a “hub” or “access point.”  
3

4 CDMA – Code Division Multiple Access. A multiplexing category where each user or  
5 application’s signal is “spread” or “scrambled” in a frequency band according to a unique code  
6 assigned to the user/application.  
7

8 Cell – The radio coverage area of 802.16 systems with co-located BTSs.  
9

10 Core Network – A network on the base-station side of an 802.16 system that interfaces to a  
11 BTS. Examples could be an IP-based network, ATM, Frame Relay, or public switched telephone  
12 network (PSTN).  
13

14 Downstream – Flow in the direction of BTS to STS.  
15

16 FDD – Frequency Division Duplex. Channels and frequency bands are designated for upstream or  
17 downstream use only, but not both.  
18

19 Operator – An administrative entity that is responsible for operating, managing and billing for  
20 services of 802.16 systems. The operator may or may not “own” the STS components of an  
21 802.16 system. The administrative reach may extend into the subscriber networks and core  
22 networks.  
23

24 PDH – Plesiochronous Digital Hierarchy. Two signals are plesiochronous if their corresponding  
25 significant instants occur at nominally the same rate, any variation in rate being constrained within  
26 specified limits. The traditional telephony digital hierarchies in North America (DS0/64Kbps,  
27 DS1/1.544Mbps, DS1C/3.152Mbps, DS2/6.312Mbps, DS3/44.736Mbps, DS4/274.176Mbps)  
28 and elsewhere (DS0/64Kbps, E1/2.048Mbps, E2/8.448Mbps, E3/34.368Mbps, E4/139.264Mbps)  
29 are typically delivered on twisted pair or coaxial cable and are based on plesiochronous clocks in  
30 which the user’s data and clock are multiplexed up the digital hierarchy.  
31

32 SDH Synchronous Digital Hierarchy. A telephony network that multiplexes signals, is  
33 synchronized to a common clock, and typically delivered on fiber optic cable. In North America,  
34 SDH is also referred to as Synchronous Transfer Mode (STM) and implies SONET (Synchronous  
35 Optical Network): STS-1/51.840 Mbps, STS-3/155.520 Mbps, STS-9/466.560 Mbps, STS-  
36 12/622.080 Mbps, STS-48/2488.320 Mbps). Internationally, the terminology and rates are:  
37 STM-1/155.520 Mbps, STM-3/466.560 Mbps, STM-4/622.080 Mbps, STM-16/16.2488.320  
38 Mbps.  
39

40 SNI -- STS Network Interface. A reference point where one or more subscriber networks  
41 interface to an STS.  
42

43 Subscriber – an entity that interfaces to an STS. Multiple subscribers may interface to an STS  
44 and are uniquely identified by an 802.16 system.  
45

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

- 1  
2 STS – Subscriber Transceiver Station. An 802.16 node that implements the MAC and PHY  
3 protocol layers at the subscriber end of an 802.16 system. An STS interfaces with one BTS and  
4 one or more subscriber networks through the SNI reference point.  
5  
6 TDD – Time Division Duplex. A channel or frequency band switches between upstream and  
7 downstream modes.  
8  
9 TDMA – Time Division Multiple Access. A multiplexing category where the medium is divided  
10 into time slots, and slots assigned to users or applications.  
11  
12 Upstream – Flow in the direction of STS to BTS.  
13

## 1 **12 Issues to Resolve**

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

3

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

7

8 Issues:

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

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## 13 References

[Editor's note: these references are not in a particular order.]

[1] Margarete Ralston, 802.16sc-99/3, 802.16sc-99/4 Reference Diagram and Notes.

[2] James Mollenauer, 802.16sc-99/5 Functional Requirements for Broadband Wireless Access Networks.

[3] Jim Mollenauer, 802.16sc-99/7 Functional Requirements for the 802.16 Standard.

[4] Brian Petry, 802.16sc-99/8 System Requirements Agenda and On-the-fly Notes from 5/99 Boulder Meeting.

[5] Brian Petry, 802.16sc-99/9 ITU-R 9B/134E (cable modem over BWA) Requirements.

[6] Hossein Izadpanah, 802.16sc-99/10 LMDS Technologies For Broadband Wireless Local Loop Applications.

[7] John Liebetreu, 802.16sc-99/13 Dispersive Fade Margin: A Physical Layer Performance Metric.

[8] Jung Yee, 802.16sc-99/14 A Multi-Service LMDS System.

[9] Willie Lu, 802.16sc-99/15 System Reference Model and Protocol Stack for Broadband Wireless Access.

[10] Marianna Goldhammer, 802.16sc-99/16 MAC Services.

[11] Robert Duhamel, 802.16sc-99/17 LMDS Cell Sizing and Availability.

[12] David Jarrett, 802.16sc-99/18 Definition of Bearer Services and Teleservices, and Services.

[13] Scott Marin, 802.16sc-99/19 The Network Topology of Point to Multipoint Radio Systems.

[14] Scott Marin, 802.16sc-99/20 802.16 Services and Applications.

[15] Scott Marin, 802.16sc-99/21 Quality of Service.

[16] George Fishel, 802.16sc-99/22 Interface to MAC and LLC Protocols.

[17] Imed Frigui, 802.16sc-99/23 Services and Performance requirements for Broadband Fixed Wireless Access.

[18] James F Mollenauer, 802.16sc-99/24 Supporting STM in the IEEE 802.16 Standard.

- 1 [19] Doug Gray, 802.16cc-99/04 WW Spectrum Allocations for BWA.  
2
- 3 [20] 802.16 PAR: Telecommunications and Information Exchange Between Systems -  
4 LAN/MAN Specific Requirements - Air Interface for Fixed Broadband Wireless Access Systems.  
5
- 6 [20] 802.16 Rationale for a Broadband Wireless Access Air Interface Standard: Meeting the Five  
7 Criteria.  
8
- 9 [21] IEEE Std 802-1990 "IEEE Standards for Local and Metropolitan Area Networks: Overview  
10 and Architecture. IEEE 1990.  
11
- 12 [22] ISO/IEC 10039: 1991. Information technology -- Open Systems Interconnection -- Local  
13 area networks -- MAC service definition.  
14
- 15 [23] ISO 7498-1:1984. Information technology -- Open Systems Interconnection -- Basic  
16 Reference Model.  
17
- 18 [24] ISO/IEC 15802-2:1995. Information technology -- Telecommunications and information  
19 exchange between systems -- Local and metropolitan area networks -- Common specifications --  
20 Part 2: LAN/MAN management.  
21
- 22 [25] ISO 15802-3:1998. Information technology -- Telecommunications and information  
23 exchange between systems -- Local and metropolitan area networks -- Common specifications --  
24 Part 3: Media Access Control (MAC) bridging.  
25
- 26 [26] ISO/IEC 15802-5:1998. Information technology -- Telecommunications and information  
27 exchange between systems -- Local and metropolitan area networks -- Common specifications --  
28 Part 5: Remote Media Access Control (MAC) bridging.  
29
- 30 [27] IEEE 802.1F-1993. IEEE Standards for Local and Metropolitan Area Networks: Common  
31 Definitions and Procedures for IEEE 802 Management Information.  
32
- 33 [28] IEEE 802.1Q-1998. IEEE Standards for Local and Metropolitan Area Networks: Virtual  
34 Bridged Local Area Networks.  
35
- 36 [29] IEEE 802.10-1998. IEEE Standards for Local and Metropolitan Area Networks: Standard  
37 for Interoperable LAN/MAN Security (SILS).  
38
- 39 [30] IEEE 802.10c-1998. IEEE Standards for Local and Metropolitan Area Networks:  
40 Supplement to Standard for Interoperable LAN/MAN Security (SILS) -- Key Management  
41 (Clause 3).  
42
- 43 [31] J. Costa ITU-R 9B/134E Broadband Wireless Access Draft New Recommendation ITU-R  
44 F.BWA Radio Transmission Systems for Fixed Broadband Wireless Access (BWA) Based on  
45 Cable Modem Standards" Apr. 1999.  
46
- 47 [32] D. Gray, "A Broadband Wireless Access System at 28 GHz" IEEE Radio and Wireless  
48 Conference, Boulder, CO, pp. 1-7, Aug. 1997.

- 1  
2 [33] H. D. Graves, "A Detailed Analysis of MMDS and LMDS", February 23-26, 1997 IEEE  
3 MTT-S Wireless Technology Symposium, Vancouver, Canada, pp. 7-10, Feb 1997.  
4  
5 [34] H. Izadpanah, "LMDS: A Broadband Wireless Access Technology: An Overview", The 3rd  
6 IAA Annual Conference on "Computers and Communications", The City University of New  
7 York, New York, Sept. 1998.  
8  
9 [35] H. Izadpanah, D. Gregoire, J. Schaffner, and HP Hsu, "MM-Wave Wireless Access  
10 Technology For The Wideband Wireless Local Loop Applications", 1998 IEEE Radio and  
11 Wireless Conference (RAWCON'98) Colorado Springs, CO, pp. ,Aug., 1998.  
12  
13 [36] J. Schaffner, H. Izadpanah, and HP Hsu, "MM-Wave Wireless Technology and Testbed  
14 Development for Wideband Infrastructure Access", WCC'98, San Diego, CA, Nov. 1998.  
15  
16 [37] C.W. Lundgren and W.D. Rummler, "Digital radio outage due to selective fading  
17 observation vs. prediction from laboratory simulation," Bell System Technical Journal, pp.1073-  
18 1100, May-June 1979.  
19  
20 [38] M. Emshwiller, "Characterization on the performance of PSK digital radio transmission in  
21 the presence of multipath fading," ICC'78 Conference Record, Toronto, Ontario, CANADA,  
22 Paper 47.3.  
23  
24 [39] Microwave digital radio systems criteria, Bellcore Technical Reference TR-TSY-000752,  
25 October 1989.  
26  
27 [40] W.D. Rummler, R.P. Coutts, and M. Linger, "Multipath fading channel models for  
28 microwave digital radio," IEEE Communications Magazine, November 1986, pp.30-42.  
29  
30 [41] M. Taylor, "LAN emulation over ATM", Computer Commun., Vol. 20, No. 1, January  
31 1997.  
32  
33 [42] R. Braden et al., "Integrated Services in the Internet Architecture: An Overview", RFC 1633,  
34 June 1994.  
35  
36 [43] S. Blake et al, "An Architecture for Differentiated Services", RFC 2475, December, 1998.  
37  
38 [44] S. Blake et al, "A Framework for Differentiated Services", Internet Draft, October, 1998.  
39  
40 [45] "Broadband Radio Access Networks (BRAN); Requirements and architectures for  
41 broadband fixed radio access networks (HIPERACCESS)", ETSI Technical Report TR 101 177  
42 V1.1.1 (1998-05).  
43  
44 [46] A. Azcorra et al., "IP/ATM Integrated Services over Broadband Access Copper  
45 Technologies" IEEE Communications, pp. 90-97, Vol. 37, No. 5, May 1999.  
46  
47 [47] Proc. Of 1999 IMT-2000 3rd Generation Wireless Technology Conference. Feb 10-12,  
48 1999. New Orleans, USA.

- 1  
2 [48] Lou Dellaverson, Evolution of a Global Standard on WATM. ATM Forum, 1999.  
3  
4 [49] Proceedings of 1999 Wireless Symposium. Feb. 22-26, 1999. San Jose, USA.  
5  
6 [50] R. K. Crane, "Prediction of Attenuation by Rain" IEEE, 1980.  
7  
8 [51] ITU-T G.826: Error performance parameters and objectives for international, constant bit  
9 rate digital paths at or above the primary rate (2/99).  
10  
11 [52] ITU-R F.1189-1 Error performance objectives for constant bit rate digital paths at or above  
12 the primary rate carried by digital radio-relay systems which may form part or all of the national  
13 portion of a 27500 km hypothetical reference path. (1995-1997).  
14  
15 [53] CCIR Recommendation 749, Radio-Frequency channels arrangements for radio-relay  
16 systems operating in the 36.0 to 40.5 GHz band. (1992).  
17  
18 [54] ITU-T Recommendation I.210 (1993) - "ISDN Service Capabilities Principles of  
19 Telecommunications Services Supported by an ISDN and the Means to Describe Them".  
20  
21 [55] W. Stallings, Data and Computer Communications, 5th ed., Prentice Hall, 1996.  
22  
23 [56] G. Almes et. al. "A One-way Delay Metric for IPPM". Internet Draft, May 1999.  
24  
25 [57] G. Almes et. al. "A Round-trip Delay Metric for IPPM". Internet Draft, May 1999.  
26  
27 [58] G. Almes et. al. "A One-way Packet Loss Metric for IPPM". Internet Draft, May 1999.  
28  
29 [59] ITU-T Recommendation I.35IP. Internet Protocol Data Communication Service IP Packet  
30 Transfer Performance Parameters.  
31  
32 [60] C. Demichelis. "Packet Delay Variation: Comparison between ITU-T and IETF draft  
33 definitions". Draft, carlo.demichelis@cse.it.  
34  
35 [61] M. Hamdi et. al. "Voice Service Interworking for PSTN and IP Networks". IEEE Comm.  
36 Magazine, Vol. 37 No. 5, May 1999.  
37  
38 [62] J. Russell. "Multimedia Networking Performance Requirements". ATM Networks, I. Viniotis  
39 and R. O. Onvural, Eds., New York; Plenum, 1993, pp. 187-198.  
40  
41 [63] A. Dutta-Roy. "Cable it's not just for TV". IEEE Spectrum, Vol. 36 No. 5, May 1999.  
42  
43 [64] K. Dubose and H.S. Kim. "An Effective Bit Rate/Table Lookup Based Admission Control  
44 Algorithm for the ATM B-ISDN." In: Proc of the 17 th IEEE Conf. On Local Computer  
45 Networks, Sept. 1992.  
46  
47 [65] L. P. Bermejo et. al. "Service Characteristic and Traffic Models in Broadband ISDN".  
48 Electrical Communication, Vol. 64-2/3, 1990, pp.132-138.

- 1  
2 [66] G. Galassi et. al. "Resource Management and Dimensioning in ATM Networks". IEEE  
3 Network Magazine, May 1990, pp. 8-17.  
4  
5 [67] ISO/IEC 8802-2:1998. Information technology -- Telecommunications and information  
6 exchange between systems -- Local and metropolitan area networks -- Common specifications --  
7 Part 2: Logical Link Control.  
8  
9 [68]IEEE P802.14/a Draft 3 Revision 3, Cable-TV access method and physical layer specification  
10 Oct. 1998. (unpublished draft)  
11  
12 [69] Data-Over-Cable Service Interface Specifications. Radio Frequency Interface Specification  
13 V1.1 SP-RFI-104-980724, Cable Television Labs, 1998.  
14  
15 [70] RFC-2205 Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification.  
16 R. Braden, Ed., L. Zhang, S. Berson, S. Herzog, S. Jamin. September 1997. Status: PROPOSED  
17 STANDARD.  
18  
19 [71] Recommendation ITU-R M.1079 (June 1999). Performance and Quality of Service (QoS)  
20 Requirements for International Mobile Telecommunications-2000 (IMT-2000).[editor's note:  
21 confer to ad hoc QoS/CoS/delay/variation, etc. group]