

# Metropolitan and Regional Wireless Networking: 802.16, 802.20 and 802.22

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## Abstract

Over the next few years the need for metropolitan and region-wide wireless Internet access is expected to rise sharply. In order to meet the needs of this emerging market the IEEE has begun forming new working groups to define the wireless standards of the future. This paper provides an overview of the technical aspects of the 802.16, 802.20 and 802.22 standards along with information on their respective markets and the type of service users of these new technologies should expect to receive.

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## 1. Introduction

Over the past ten years, standards published by the IEEE have all but dominated the wireless networking market. Competing technologies such as HiperLAN and WaveLAN have all but vanished, leaving the various flavors of 802.11 as the only wireless network access standards for which supporting products are widely available. In fact, consumers have been willing to adopt products based on the 802.11 wireless standards despite well-documented security and performance/scalability issues [[Borisov01](#), [Bruno05](#)]. In response to

consumer desires, a number of companies have been formed to provide small-scale wireless hotspots and, in some cases, to extend the 802.11 standards to provide fixed-access broadband Internet access in rural areas where it is not practical to run physical lines. These services, however, work intermittently at best and, by virtue of the 802.11 standards they make use of, cannot scale to serve more than ten or twenty simultaneous users [[Goth04](#)].

More recently, with the arrival of 2.5G cellular technology consumers have begun to realize the power of having Internet access anywhere in the world. For the first time, people are now able to check their e-mail from their car and make "micro" purchases directly from their cellular telephones. Cellular standards, however, are by no means universal and the charges for accessing cellular data services can quickly add up. Some of these costs result from the fact that current cellular services were not designed to transmit packetized data, but the most important factor driving up access costs is the fact that no viable competing services exist [[Klerer03](#)].

The IEEE is well aware of these issues and has taken steps to create the 802.16, 802.20 and 802.22 working groups in order to define new wireless standards which can provide the necessary technology to support fully wireless ISP's as well as compete with current and next generation cellular technologies [[Goth04](#), [Santhi06](#)]. The IEEE 802.16 working group, formed in 1999, is the most mature of the next generation wireless standard developing bodies and has developed both fixed (802.16a/d) and low-mobility (802.16e) broadband wireless access systems operating in "metropolitan" areas that are approximately 1 to 5 km in size [[Nichols04](#), [Fong04](#)]. The IEEE 802.20 working group, formed in 2002, seeks to extend the mobility support provided by 802.16e to provide access at speeds up to 250 km/h across metropolitan-sized areas [[Klerer03](#)]. The 802.22 standard, on the other hand, aims to provide broadband access across entire "regions" that are up to 100 km in radius [[Chouinard04](#)]. Figure 1 provides a clear picture of where 802.16, 802.20 and 802.22 fit in with the other IEEE wireless networking standards.

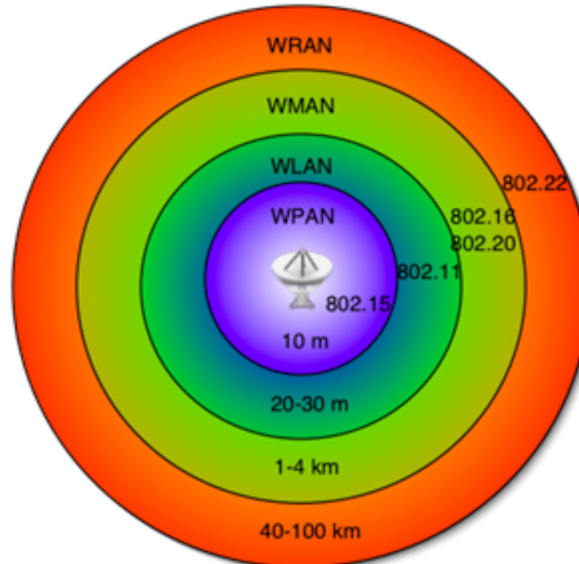


Figure 1: Classifications and Ranges of the Various IEEE Wireless Networking Standards

In all of three of these working groups, committee members are working towards developing flexible and open standards for next-generation wireless networking. In doing so, the IEEE hopes that their work becomes the global standards for long-distance wireless networking in much the same way the 802.11 technologies have become the defacto standards for wireless local area networks (WLANs). In the rest of this paper an overview the of 802.16, 802.20 and 802.22 standards will be provided, along with a discussion of the possible markets for these technologies and the type of service end-users should expect to receive.

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## 2. 802.16: WiMAX and Mobile WiMAX

The 802.16 working group was formed in July 1999 to develop wireless metropolitan area networking (WMAN) standards [Ghosh05]. The original intention of the group was to create a fixed-wireless standard based on line-of-sight (LOS) technology in order to provide T1/T3 levels of service to enterprises operating in locations where it was infeasible to run a physical fiber or copper infrastructure. This standard, known as 802.16, was published in 2002, but has yet to see widespread deployment [Nichols04,Fong04].

From 2002 to 2004, the working group focused on developing a fixed-broadband non-line-of-sight (NLOS) standard referred to as 802.16a/d (depending on the implementation used) intended for use by consumers as a replacement for the 802.11b-based Wireless ISP's that first emerged during the same time period. The standard aims to provide wireless access at DSL-like speeds of 1.5 Mbps downstream and 384 Kbps upstream [Goth04]. In terms of marketability, the install base for the technology is expected to be upwards of 20 Million by 2009 [Pipeline05].

Despite the significant market share projected for 802.16a/d-based products, it is 802.16e that has generated the most industry hype of all the WiMAX variants. This standard was recently approved in December 2005 and builds upon the 802.16d standard to provide low-mobility (60 Km/h or less) wireless Internet access that uses a Cellular-like handoff mechanism to extend the range of the system [Santhi06, Fong04]. Although the standard has just recently been approved, a variant of it called "WiBro" is set to be deployed in Korea in the second-half of 2006 [Robinson06]. Figure 2 provides a summary of the markets that 802.16, 802.16a/d and 802.16e hope to service.

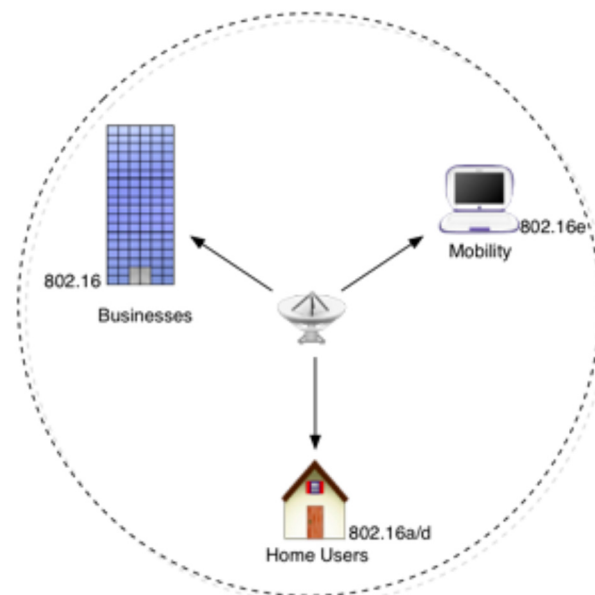


Figure 2: Target Markets for the 802.16, 802.16a/d and 802.16e Standards

To ease consumer confusion in regards to the alphabet soup that the 802.16 standard has become, the WiMAX Forum was founded as a non-profit corporation in June of 2001 by various manufacturers of 802.16-supporting hardware to define interoperability standards and to encourage cooperation between competing hardware vendors. Recently, the forum has begun certifying both provider and end-user devices based on the 802.16d standard from vendors such as Wavesat and Aperto Networks [WiMAXForum06a]. Prior to this, a number of "pre-802.16d" devices have been made available but were not widely deployed [Skylight05]. Certified devices based on the 802.16e standard are expected to be available by the end of 2006.

## 2.1 802.16a/d: WiMAX

The 802.16, 802.16a and 802.16d standards all define the operation of various fixed wireless networking systems. Through the use of both LOS and NLOS connection mechanisms, these standards were created with the intention of providing a solid foundation upon which Wireless Internet Service Providers (WISPs) could be based. The 802.16 standard is intended for use by businesses, while consumer needs are targeted by the 802.16a/d standards. In order to provide a high-speed and scalable wireless service a number of advanced PHY and MAC layer technologies were developed and introduced by the initial 802.16 standard and enhanced in the later 802.16a/d revisions [[Nichols04](#), [Fong04](#)]. These technologies later formed the basis of not only 802.16e, but also the 802.20 and 802.22 standards [[Klerer03](#), [Chouinard04](#)].

### 2.1.1 802.16a/d PHY Layer Overview

The 802.16 Physical (PHY) Layer is designed to make use a wide array of frequency bands in order to support deployment in all regions of the world, while simultaneously providing the necessary technology to support a large number of concurrent users at speeds similar to DSL [[Santhi06](#)]. The main features of the 802.16 PHY Layer include flexible frequency and duplexing support, adaptive coding and modulation, and optional support for various intelligent transmission systems.

#### 2.1.1.1 802.16a/d Frequency Ranges and Duplexing

The 802.16 and 802.16a/d standards operate on distinctly different frequency bands with accordingly varying channel sizes. These differences exist primary due to different target markets of the technologies: 802.16 for business users and 802.16a/d for consumers. Regardless of the frequency band used, however, Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) are both supported [[Santhi06](#)].

The original 802.16 standard operates on licensed bands in the 10 to 66 GHz range over 20, 25 or 28 MHz channel widths and requires LOS between the base station and the user terminal to work properly. The wide channels used by the system allow data rates from 33 up to 134 Mbps to be achieved, but due to the use of high frequency bands the system is limited to a range of 2 to 5 km around the base station [[Legg04](#)]. The decision to make use of licensed and somewhat wide frequency bands clearly illustrates the fact that 802.16 is intended for use at the enterprise level where dedicated high speed access is required and the monetary investment needed to obtain a license would put the cost of service far out of the range of most consumers.

In contrast to 802.16, 802.16a/d operates on both licensed and unlicensed bands in the 2 to 11 GHz range over 1.5 to 20 MHz wide channels. The use of unlicensed and lower frequency bands allows for NLOS access and makes it less expensive to both manufacture equipment and to create the infrastructure required to operate a network. This, in turn, lowers the cost of access for end-users and thus makes the service more appealing to the consumer market that it was designed for. As an added bonus, the lower frequencies utilized by the system increases the range of the service to almost 10 km, therefore allowing a single base station to serve a larger area than is possible with 802.16. An aggregate bandwidth of 75 Mbps is supported if a 20 MHz channel width is used, but the actual amount a single user receives is largely dependant on how many users a base station is supporting [[Nichols04](#)].

Both 802.16 and 802.16a/d have optional support for a channel bonding feature. This allows service providers to chain multiple channels together in an effort to support more users with a single tower or to provide higher access speeds. Up to five channels can be bonded together to provide an aggregate bandwidth of 350 Mbps (in 802.16a/d), but in order to do so both the provider and user equipment need to support the feature [[Nichols04](#)].

#### 2.1.1.2 802.16a/d Transport, Modulation and Coding

The 802.16 and 802.16a/d standard define slightly different transport mechanisms that are closely tied to their target markets. The original 802.16 standard, for instance, defines only a single-carrier transport (known as WirelessMAN SC) mechanism that matches the fact that it was designed to provide LOS access at very high speeds to (typically) a single enterprise class customer. 802.16a/d, on the other hand, both support single carrier (WirelessMAN SCA) and orthogonal frequency division multiplexing (OFDM) modes with 256 sub-carriers (WirelessMAN OFDM). 802.16d also defines an orthogonal frequency division multiple access (OFDMA) mode that supports 2048 sub-carriers, allowing multiple users to simultaneously share the bandwidth of a single logical channel. OFDM and OFDMA both allow a single channel to be split into a number of smaller channels that can each carry a portion of transmitted message. In the case of OFDM, all of the smaller channels are used by the same logical users (TDD is then used to share the channel), while with OFDMA multiple users can simultaneously share a portion of the sub-carriers that are defined [[Fong04](#), [Nichols04](#)].

In terms of modulation, both 802.16 and 802.16a/d support methods from BPSK up to 64QAM. For encoding purposes, Reed-Solomon coding combined with an inner convolutional code is standard, while a variety of turbo-coding mechanisms can optionally be used to increase connection throughput. Due to the hardware complexity of implementing turbo coding, however, not many 802.16a/d products are expected to make use of it [[Ghosh05](#)].

In order to cope with changing airlink conditions such as interference, competing users and user distance from the base station, adaptive modulation and coding techniques are supported. This enables a user to, for instance, switch from higher to lower modulation methods in order to reduce the error rate of packets sent over the connection. The spectral efficiency (coding rate) of the encoding method used can also be manipulated to achieve similar results [[Ghosh05](#)].

### 2.1.1.3 802.16a/d Advanced Transmission Mechanisms

802.16 and 802.16a/d, like most other wireless network access systems, only requires the presence of a single antenna at both the base station and user terminal to work properly. Single antenna systems, however, are not always reliable and are easily susceptible to common problems such as interference and channel fading. As a result, a number of advanced antenna techniques were incorporated into the later 802.16a/d standards as optional PHY-layer features [[Ghosh05](#)].

One such feature supported by the 802.16a/d standard is the adaptive antenna system (AAS). AAS requires OFDM or OFDMA transport modes, and utilizes multiple transmitting antennas to divide the subcarriers transmitted into segmented groups that are then each transmitted over a unique antenna. In doing so, the subcarriers can be assigned on a "geographic" basis and better tune the transmitted signal towards the receiving users in order to reduce their susceptibility to interference. Users can, in turn, provide feedback to the base station in order to properly beam-form their signals and fine-tune the connection [[Ghosh05](#)].

In addition to supporting AAS, the 802.16a/d standard also allows for the use of Space Time Block Codes (STBC). Like AAS, STBC requires the use of multiple transmission antennas to increase the diversity of the signal and reduce susceptibility to interference. Unlike the beamforming used in AAS, however, STBC uses multiple antennas to send out time shifted copies of the same signal. The receiver then stitches together the shifted signals to form their best estimate of the signal that was actually sent [[Ghosh05](#)].

While STBC uses multiple transmitting antennas to increase signal diversity, another supported antenna option known as Spatial Multiplexing (SM) or Multiple-Input/Multiple-Output (MIMO) uses multiple transmitting and receiving antennas to transmit different sub-streams of data and increase throughput. A feedback mechanism similar to the one utilized in AAS is used to fine-tune the transmitted signal. In theory, this method of transmission should increase the data rate of the connection, but in reality due to the reduced resiliency to interference caused by using MIMO, data rates are often lower than those achieved by a

STBC-based system. To combat this, STBC and MIMO can be combined into a single system. Doing so, however, can require an inordinate number of both transmitting and receiving antennas to be effective [[Ghosh05](#)].

### 2.1.2 802.16a/d MAC Layer Overview

The MAC Layer of the 802.16a/d standard is designed to provide support for all of the features defined via the PHY specification. In defining the MAC layer scalability was of the utmost importance. In stark comparison to the small-scale deployments typically associated with WLAN standards such as 802.11, 802.16 networks (especially those based on the a and d variants) are designed to scale to support a hundred or more simultaneous users with a single base station [[Goth04](#)].

The MAC layer itself is actually split into two portions: a convergence-specific sublayer and a common-part sublayer. The convergence-specific sublayer is unique to a particular PHY implementation and differs depending on the type of network the end user wishes to connect to (such as Ethernet or ATM). The common-part sublayer, on the other hand, is the same regardless of what type of network the user wishes to transmit across and is responsible for handling functions such as transmission scheduling and QoS support [[Ghosh05](#)].

#### 2.1.2.1 802.16a/d Connection Establishment and Framing

The MAC defined in the 802.16a/d standard is designed with scalability in mind. Multiple transmission flows are supported per user to maximize bandwidth usage, and, via the use of OFDMA, can support an order of magnitude more users than a typical 802.11b/g-based connection [[Ghosh05](#)]. Data transmission is accomplished by sending and receiving alternating sets of Downlink (DL) and Uplink (UL) frames that carry base station (BS) to user terminal traffic and vice-versa. When TDD duplexing is used, the alternating frames are separated by a small guard time segment, while with FDD separate frequencies are used and the need for guard time is eliminated [[Kwon05](#)]. An example TDD-based OFDMA frame can be seen below in Figure 3.

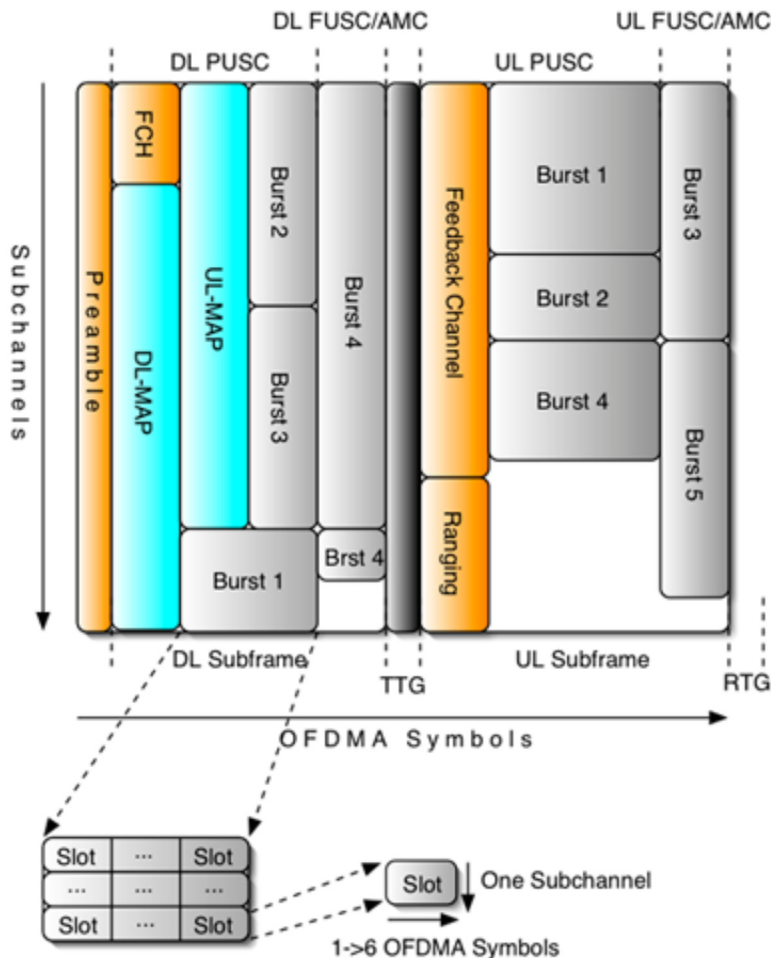


Figure 3: Time Division Duplexed WiMAX OFMDA Frame

When a user terminal is first powered-on it scans a set of known frequencies for a supporting BS. When a BS is found, the user attempts to establish a connection. In order to do so, the user watches for frame transmission preambles that are sent prior to each frame. As can be seen in Figure, the preamble is followed by a ranging period used to tune the power usage of a terminal and associate the user terminal with the base station [Kwon05].

In terms of data transmission, downlink frames from the BS to users are simply broadcast to all user terminals within range [Cho05]. Special care is taken when AAS or MIMO is used to ensure that beam-formed data streams are directed at the proper users. Downlink frames are themselves preceded by a DL-MAP (Downlink Map) that specifies which portions of the transmitted frames are for which users. Each user in range of the BS receives this map and then can selectively copy any data in the proceeding frame that is intended for the user [Kwon05].

For uplink transmission from users to the base station, transmission slots are allocated via a small contention period at the start of the uplink frame. Unlike in 802.11, however, once a user is allocated one or more transmission slots they are allowed to keep them without going through contention again the next time they wish to transmit. Transmission slots are granted exclusively by the BS and the ordering of assignment within a uplink frame is sent via a UL-MAP (Uplink Map) message with a format much like that of the DL-MAP used for downlink connections. The UL-MAP is sent prior to the start of the uplink frame to give user terminals the chance to synchronize their connections and prepare for data transmission [Cho05, Kwon05].

In allowing users to reserve uplink transmission slots, the ability to provide guaranteed bandwidth is provided. In effect, this enables a provider to offer a DSL or Cable-like connection over a wireless medium. This is

much different than is the case with a 802.11b/g-based network where all transmissions are contention based and the BS only plays a passive role in deciding who is allowed to transmit uplink traffic [[Cho05](#), [Goth04](#)].

### 2.1.2.2 802.16a/d QoS Support

In order to provide guaranteed levels of services to both consumers and businesses alike, the 802.16a/d standard was designed from the ground up to provide extensive Quality-of-Service (QoS) Support. The standard defines four levels of QoS: Unsolicited Grant Service (UGS) for Constant Bit Rate Traffic (CBR) like VoIP, a Real-time Polling Service (rtPS) for Real-time Variable Bit Rate (rtVBR) traffic like video, a Non Real-time Polling Service (nrtPS) for Non Real-time Variable Bit Rate (nrtVBR) traffic like FTP data and a Best Effort (BE) service for generic connections. These four mechanisms can be directly mapped to DiffServ (DS) classifications to provide true end-to-end QoS. Support is provided "in-frame" for UGS traffic and bandwidth is pre-allocated to support such connections. UGS traffic can therefore be guaranteed a specific data rate, jitter variance and transmission latency in order to provide true CBR support [[Cho05](#)].

Signaling methods are also provided for requesting rtPS, nrtPS and BE-levels of traffic support but inter-frame support for these transmission classes is not provided. Furthermore, no sort of admission control system is provided for determining which user should be allowed to request what levels of service and how large those requests should be allowed to be. As a result, a large portion of the QoS support defined in 802.16a/d is left up to vendors to implement as they choose [[Cho05](#), [Ghosh05](#)].

### 2.1.2.3 802.16a/d Security Features

The 802.16a/d standard makes use of public-key encryption keys that are exchanged at connection setup time. User terminals are authenticated to the BS via the use of digital certificates that are based on the 56-bit Data Encryption Standard (DES) [[Nichols04](#)]. The security method implemented in the standard, however, does not support BS to user terminal authentication. Furthermore, the system does not provide adequate protection against data forgery or replies, nor does it fully define how operations such as key management will be handled. As a result, security in 802.16a/d remains a major concern [[Johnston04a](#)].

## 2.2 802.16e: Mobile WiMAX

In comparison to the 802.16, 802.16a and 802.16d standards that defined fixed-wireless access mechanisms, 802.16e is designed for low-mobility environments. Mobility is supported at speeds up to 60 km/h and the system can provide a data rate of up to 500 Kbps/user at distances far from the BS [[Santhi06](#)]. In order to provide mobility support, the 802.16e working group had to deal with new issues such as handoff and power management that were non-issues in fixed operating environments. As a result, 802.16e seems somewhat like an entirely different standard than those that came before it.

### 2.2.1 802.16e PHY Layer Overview

The 802.16e PHY is largely based on the PHY layer implementation from the earlier 802.16a/d standards. It therefore inherits support for all of the transport, modulation and advanced transmission systems that are defined by those systems. As a result, the discussion below will focus only on the new features that 802.16e defines.

#### 2.2.1.1 802.16e Frequency Ranges and Duplexing

Like the 802.16a and 802.16d standards, 802.16e operates in NLOS mode in the 2 to 11 GHz spectrum. It operates exclusively over unlicensed bands making it less expensive for operators to create a service



infrastructure over which to provide the service. Regardless of the portion of the frequency spectrum that is used, channel bandwidths of 1.5 to 20 MHz are supported via both TDD and FDD in a similar fashion to 802.16a/d. Data speeds similar to that of 802.16a/d are also achievable, with a maximum aggregate bandwidth of 15 Mbps when moderately sized 5 MHz channels are used. Furthermore, optional channel bonding is supported to increase data rates even further [[Legg04](#)].

### 2.2.1.2 802.16e Transport, Modulation and Coding

The 802.16e standard retains the fixed-access single carrier, OFDM-256 and 2048 sub-carrier OFDMA modes of operations defined in the 802.16, 802.16a and 802.16d standards. Alongside these mechanisms, however, a new Scalable OFDMA (S-OFDMA) mode of operation was also defined. S-OFDMA allows for the use of 128, 512, 1024 or 2048 sub-carriers. The number used can be dynamically determined by the BS to provide 802.16e devices with a further method of adapting to the needs of the environment in which it is deployed [[DailyWireless05](#)].

In accordance with the 802.16a/d standards on which 802.16e is based, support for adaptive modulation and encoding is also provided. To provide for more flexible encoding an advanced Low Density Parity Check (LDPC) method is provided in addition to the convolutional and turbo coding mechanisms that 802.16a/d define. LDPC is designed to provide higher throughput versus typical turbo codes with a minimum complexity. With LDPC codes in place, it is possible to provide up a 5/6 code rate (6 bits coded for every 5 of actual data) which is somewhat better than the 3/4 code rates previously possible [[Classon05](#), [Xu05](#)].

### 2.2.1.3 802.16e Advanced Transmission Mechanisms

802.16e supports all of the advanced antenna mechanisms defined in the 802.16a/d standards such as AAS and STBC. Furthermore, support has been added for enhanced MIMO implementations in an effort to improve data transmission rates without incurring the signal-to-noise ratio penalty that other MIMO configurations often suffer from [[Roh05](#)].

## 2.2.2 802.16e MAC Layer Overview

Like the PHY layer, the MAC layer of 802.16e is largely based on that of the 802.16a/d standards. Significant enhancements, however, were made to support various handoff, power management and inter-communication channels required to add mobility support to the standard [[Xiao05](#), [Santhi06](#)]. For the sake of brevity, the discussion below will focus on these changes in particular.

### 2.2.2.1 802.16e Handoff Support

In order to allow for handoff support in 802.16e, new MAC-level messages that allow for BS selection, BS scanning and handoff request/grant mechanisms were added. These messages seek to allow 802.16e users the sort of automatic mobility that cellular users are accustomed to. Furthermore, both soft (make-before-break) and hard handoffs between two BS's are supported as well as macro-diversity handovers to support handoffs between regions with two different cell sizes [[Kitroser03](#)].

For handoff to work properly, mechanisms for allowing BS-to-BS and BS-to-backhaul (wired network) communications were also added. The BS-to-BS connection links allow for handoff negotiations between cells while the BS-to-backhaul links provide support for roaming user authentication much like in GSM-based cellular networks. By providing a roaming authentication mechanism service providers will be able to provide coast-to-coast support for users of Mobile WiMAX services [[Kitroser03](#)].

### 2.2.2.2 802.16e Power Management

Since 802.16e is the first 802.16-based standard that supports mobility it is also the first to define an efficient power management system for use by mobile (battery powered) devices. In addition to full-power operation, devices that implement 802.16e also support paging (idle) and sleep modes.

Idle mode operation is entered by a mobile user when the device wishes to become temporarily unavailable to receive downlink traffic. In these cases, the mobile user disassociates itself from all BS's, first alerting them of what it intends to do. While in idle mode, the mobile station needs to periodically check for paging messages sent by the BS to see if new downlink frames have been sent to the device. Idle mode is intended to be used in cases when a mobile user is traversing a location where multiple BS's are present and the user wishes to avoid multiple handoffs and connection negotiation sessions [[WiMAXForum06b](#)].

Sleep mode operation, on the other hand, is entered only after the mobile user makes a request to do so to the BS. The BS then responds (if sleep is allowed) with a sleep interval time vector indicating how long the mobile user device is allowed to go into low-power mode and sleep. After the sleep interval expires, the mobile device wakes up and sees if any new frames intended for it have been transmitted. If not the mobile device is allowed to increase its sleep interval, doubling it each time up to a pre-defined maximum period [[Xiao05](#)].

### 2.2.2.3 802.16e Enhanced QoS Support

In addition to the standard QoS support defined by the 802.16a/d standard, 802.16e defines extended support for more flexible usage. While 802.16a/d only defines explicit MAC-level support for UGS mode, 802.16e extends this mechanism to support rtPS, nrtPS and BE classifications. These enhancements allow 802.16e devices to provide true DiffServ (DS) compatibility while supporting a wider array of traffic transmission constraints [[WiMAXForum06b](#)].

### 2.2.2.4 802.16e Enhanced Security Support

In an effort to fix the somewhat flawed security provided by the 802.16a/d standard, 802.16e implements a 128-bit encryption key mode based on the Advanced Encryption Standard (AES). AES is a public key encryption method, much like the DES mechanism it replaces, but is generally considered to be a much stronger standard. The AES mode supported by 802.16 provides support for both BS-to-user and user-to-BS authentication ensuring that man-in-the-middle attacks launched by impersonating BS's are no longer possible. An explicit packet numbering scheme is also implemented to prevent replay attacks [[Johnston04b](#)].

### 2.2.2.5 802.16e Hybrid ARQ Support

Although the 802.16e standard is centered around mobility, some of the additions to the standard such as optional Hybrid ARQ (HARQ) support are simply general performance enhancements. In traditional ARQ systems when a message retransmission is requested the entire packet needs to be re-sent even if only one or two bits of the original message were corrupted in transmission. HARQ refines this methodology so that successive retransmissions of a packet can consist of simply more parity bits (to recover a partially corrupted message) instead of entire messages. Regardless of the re-transmission method used, however, devices that support HARQ combine the successive retransmitted signals with the original to form the entire message. It has been proven that this method of retransmission can greatly improve performance in areas where the signal-to-noise ratio is low [[Ghosh05](#)].

## 2.3 WiMAX vs. Mobile WiMAX Comparison

WiMAX (a/d) and Mobile WiMAX (e) both seek to serve different markets and thus implement WMAN technologies in different ways. Despite this, they share many similar qualities since they were both derived from 802.16. Table 1 summarizes the major features of the 802.16, 802.16a/d and 802.16e standards.

	Market	Frequency Usage and Framing	PHY Features	MAC Features
802.16	Enterprise-class Fixed Wireless Access	10 to 66 GHz Licensed Bands. Line of Sight Operation. Single Carrier and OFDM Support	Adaptive Modulation and Encoding. Support for TDD and FDD. Convolutional Coding.	QoS Support
802.16a/d	Consumer-Class Fixed Wireless Access	2 to 11 GHz Licensed and Unlicensed Bands. Non Line of Sight Operation. Single Carrier, OFDM and OFDMA Support.	All Features from 802.16. AAS, STBC and MIMO Support. Turbo Code Support.	All Features from 802.16. Hybrid ARQ Support. Modified Framing Structure to allow for AAS and MIMO Feedback.
802.16e	Consumer-Class Semi-Mobile Wireless Access	2 to 11 GHz Unlicensed Bands. Line of Sight Operation. Single Carrier, OFDM, and OFDMA Support	All Features from 802.16a/d. BS-to-BS and BS-to-Backend Communication Mechanisms Support for Enhanced LDPC Coding.	All Features from 802.16a/d. Better Defined QoS Support. Power Management. Handoff/Roaming Support.

Table 1: Summary of the 802.16, 802.16a/d and 802.16e Standards [[Goth04](#), [Legg04](#), [Nichols04](#)].

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### 3. 802.20: Mobile Broadband Wireless Access (MBWA)

Much like the recently ratified 802.16e standard, 802.20 (also known as Mobile Broadband Wireless Access, or MBWA) hopes to define a WMAN standard with mobility support. 802.20 differs from 802.16e, however, in that it aims to provide "vehicular" mobility at speeds of up to 250 km/h instead of the much lower 60 km/h speeds offered by Mobile WiMAX [Upton05, Kwon05]. Furthermore, unlike 802.16e which has to carry the baggage of the 802.16, 802.16a and 802.16d standards, 802.20 is a clean-sheet design focused exclusively on providing high-speed mobility at speeds similar to ADSL [MBWA05]. Figure 4 shows how the topology of a typical 802.20 network may be structured.

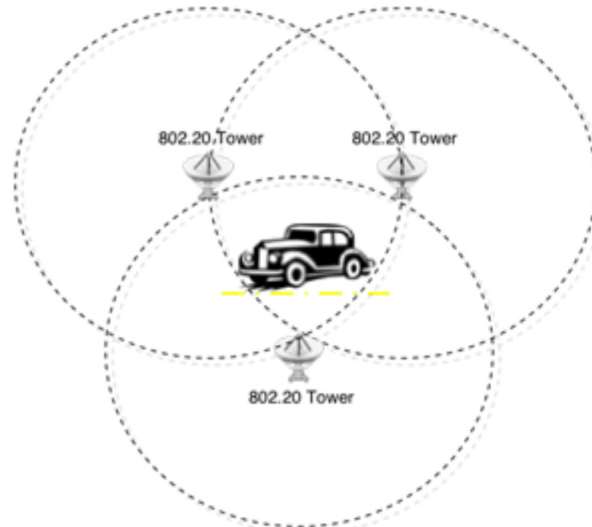


Figure 4: Example 802.20 Network Architecture

The 802.20 standard is being positioned as an alternative to 2.5 and 3G cellular services by virtue of the fact that both technologies support high-speed handoffs and wireless network access. Once ratified, "green-field" providers could use products based on the standard to create highly mobile wireless data networks. In doing so, the high prices that cellular providers currently charge for access to data networks would likely drop due to the emergence of a competing service. [MBWA05].

The 802.20 working group originally started as a small committee within the 802.16 standards group in March of 2002, prior to when work on the 802.16e standard started [Klerer03]. The committee quickly broke off into it's own working group in December of 2002 due to the fact that 802.16 was focusing on fixed-wireless standards during that time period [Fong04]. Since then, minimal progress towards defining the standard has been made, while the entire 802.16e standard has been defined, designed and ratified [Robinson06]. At this point in time, the standard seems to be in limbo, but the IEEE claims that work is ongoing.

In the following sub-sections, what little information is currently known about the 802.20 PHY and MAC layers will be presented. In reading the descriptions please keep in mind that the standard itself is still in the planning stages and that not so much as a preliminary standard has been published at this point.

### 3.1 802.20 PHY Layer Overview

The PHY layer of the 802.20 standard is loosely based on technologies developed in the 802.16 working groups. The standard, however, is more heavily angled towards use in a mobile setting and includes technologies designed to support this type of usage.

#### 3.1.1 802.20 Frequency Ranges and Duplexing

The 802.20 standard is set to operate in licensed bands below 3.5 GHz in a NLOS mode of operation. Licensed bands will be used to provide a packet-switched connection similar to that of the circuit-switched

networks operated by current cellular providers. A wide variety of channel bandwidths from 1.25 MHz to 40 MHz are also expected to be supported with both TDD and FDD duplexing, but nothing is finalized at this point [[Upton05](#)].

A spectral efficiency of at least 1 bps/hz is targeted in order to provide acceptable data rates. Using 1.25 MHz channels speeds similar to ADSL, with 1 Mbps downstream and 300 Kbps upstream, are expected and should scale accordingly with wider channels. In all cases, up to 100 users/cell should be supported although not all of them may be active at once [[Upton05](#)].

### 3.1.2 802.20 Transport, Modulation and Coding

In terms of data transmission, the current partial proposals seem to be leaning towards using OFDMA in a similar fashion to 802.16e [[Tomcik06](#)]. The benefit of using existing technology, of course, is that development time is reduced and products can be brought to market sooner. Some reference, however, has been made to the possibility of using OFDMA on the downlink connection and CDMA on the uplink. The rationale for using CDMA on the uplink is that using OFDMA somewhat limits the benefits that antenna technologies like spatial multiplexing and MIMO can provide. CDMA can help to alleviate this limitation by assigning the same bandwidth resources to all users in a sector and using spatial processing at base station to recover the signal [[Tomcik06](#)].

Modulation and coding in 802.20 is essentially identical to that of 802.16a/d. Modulation rates from BPSK to 64QAM are all supported, along with both convolutional and turbo coding. Both mechanisms are fully adaptable, scaling to support both changing channel conditions and mobility rates. This enables the system to, for instance, provide a faster data connection to walking users than to those moving in automobiles or high-speed trains [[Upton05](#)].

### 3.1.3 802.20 Advanced Transmission Mechanisms

In order to allow flexible high-speed mobility, the 802.20 standard is expected to support essentially all of the advanced transmission options that the 802.16 family of standards defines. These include, but are not limited to, AAS, STBC and various forms of Spatial Multiplexing/MIMO. Support for Space-division Multiple Access (SDMA) is also mentioned in some of the preliminary proposals.

SDMA is forward-link transmission technique used at the BS to signal multiple users via the same time-frequency resources. This method can increase aggregate data rate by grouping transmission recipients together and transmitting signals to "zones" within a cell or cluster. Since directed beams need to be tuned towards their receivers, SDMA requires a feedback channel similar to that used by AAS to operate properly [[Tomcik06](#)].

## 3.2 802.20 MAC Layer Overview

Like the PHY layer, the MAC layer of the 802.20 standard is also loosely based on technologies developed in the 802.16 working groups. Similar to 802.16, the 802.20 MAC is split into both convergence-specific and common-part sublayers. Furthermore, mobility techniques developed in 802.16e such as handoff and power management are also implemented in the 802.20 standard [[Upton05](#)].

### 3.2.1 802.20 Connection Establishment and Framing

The connection establishment mechanism for 802.20 is not yet fully defined, but due to the standards similarities to 802.16e it is likely safe to assume that the mechanisms will be largely similar. One difference

between the two, however, is that CDMA (as opposed to OFDM/OFDMA) may be used on uplink connections. If this ends up being the case, a separate reverse-link access channel (R-ACH) will need to be implemented in order for users to request data transmission slots. This channel, however, will provide essentially the same functionality as the contention/ranging period utilized in 802.16 [Tomcik06].

Transmission and framing mechanisms in 802.20 will also be complicated somewhat if a hybrid OFDMA downlink and CDMA uplink system is implemented. In such a case, users will request transmission resource via the R-ACH over CDMA and then receive feedback from the BS over OFDMA. The OFDMA frame format will remain largely the same as that used in 802.16, with similar UL and DL mapping structures used to indicate when users are allowed to transmit as well as what transmitted data segments are meant for them [Tomcik06].

### 3.2.2 802.20 Handoff Support

Being a fully mobile standard, 802.20 will include support for all sorts of handoff mechanisms to enable users to freely roam between service areas without interruption. Soft handoff support will be fully integrated, as will higher-level handoffs over MobileIPv4, MobileIPv6 and SimpleIP. Since different forward and reverse-link connection mechanisms may be used, handoff will need to occur in both directions. To facilitate this level of support, mechanisms for BS-to-BS and BS-to-backhaul communications will be defined in a similar fashion to those used in 802.16e [Tomcik06, Upton05].

### 3.2.3 802.20 Power Management

In order to conserve power in mobile devices, support for a sleep-like operation mode is described in the current 802.20 partial standard proposal. Before a device enters the idle state it negotiates a paging period with the BS. The device is then allowed to "sleep", only awakening to check for paging messages at pre-negotiated intervals. For extended "sleep" cycles, the interval length can be renegotiated in order to better conserve power [Tomcik06, Upton05].

### 3.2.4 802.20 QoS Support

The level of QoS support that 802.20 will provide is somewhat undecided at this point. The requirements document states, however, that DiffServ (DS) and RSVP will be supported for end-to-end compatibility with existing networks. The specification document also states that some form of UGS via which flows can specify their required data rates, latency, packet error rate and delay variation (jitter) will be incorporated into the final standard [Upton05].

### 3.2.5 802.20 Security Features

Data sent over devices supporting 802.20 will be encrypted with public keys generated by the AES 128-bit algorithms. In combination with AES-128, mechanisms for ensuring that data integrity is preserved will be included in the standard. Further security features will include cross-authentication to prevent user and BS spoofing, as well as some sort of mechanism for preventing and/or avoiding Denial of Service (DoS) attacks [Upton05, Tomcik06].

### 3.2.6 802.20 Hybrid ARQ Support

Although not explicitly mentioned in the original specification document, at least one partial proposal for 802.20 includes support for Hybrid ARQ (HARQ). This support will be along the same lines as that specified in the 802.16e standard, and by making use of the technology users in poor signal strength locations will

achieve a higher rate of transmission than they would have otherwise [[Tomcik06](#)].

### 3.3 802.20 vs 2.5 and 3G Cellular Networks

As was previously mentioned, one of the main goals of the 802.20 standard is to provide a IP-based data service superior to that offered by both current and near-future cellular networks [[MBWA05](#)]. In doing so, the hope is that a viable alternative to cellular data services can be developed which will provide competition for cellular network operators. A comparison of 802.20 to 2.5G/3G cellular networks can be seen below in Table 2.

	Operational Frequencies	Channel Bandwidth	Maximum Data Rate	Network Architecture	Spectral Efficiency
802.20	Less than 3.5 Ghz. Licensed.	Less than 5 Mhz. 1.25 MHz Typical.	1 Mbps downstream and 300 Kbps upstream.	Packet Switched.	0.8 to 1.0 bps/Hz.
2.5G (Typical)	800 to 1900 MHz. Licensed.	Less than 5 Mhz	40 Kbps to 2.5 Mbps downstream.	Circuit Switched	0.3 to 0.6 bps/Hz.
3G (Typical)	Less than 2.7 GHz. Licensed.	Less than 5 Mhz.	1 Mbps or higher downstream.	Circuit Switched, Transitioning to Packet Switched.	0.5 bps/Hz or higher

Table 2: Feature Comparison of 802.20 and 2.5/3G Cellular Networks [[Upton05](#), [MBWA05](#), [Klerer03](#)].

As can be seen in the table, the 802.20 standard offers performance similar to that of typical 2.5G and 3G cellular technologies. 802.20, however, has the distinct benefit of being a fully IP-based packetized network standard. As a result, network throughput is enhanced versus a circuit-switched standard, since messages do not have to be transcoded from pre-allocated circuits into packets and back again each time a request is sent or received. Furthermore, 802.20 offers a higher spectral efficiency than any current or near-future cellular standard and thus can do more with less channel bandwidth and support a higher number of users per cell [[Klerer03](#)].

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## 4. 802.22: Wireless Regional Area Networks (WRAN)

While 802.16a/d/e and 802.20 have focused on providing the infrastructure necessary to create wireless metropolitan area networks approximately 1 to 5 km in radius, 802.22 is seeking to define a standard capable of serving vast regions up to 100 km in size. In doing so, the 802.22 working group hopes to provide fixed-wireless access at speeds comparable to ADSL to people living in remote or rural environments that, up until now, have had but a few other options for broadband Internet access. This, in turn, could enable thousands of people to experience the power of broadband for the first time ever [[Chouinard04](#), [Cordiero05](#)]. Figure 5 shows a map of an area where a WRAN network might be deployed.

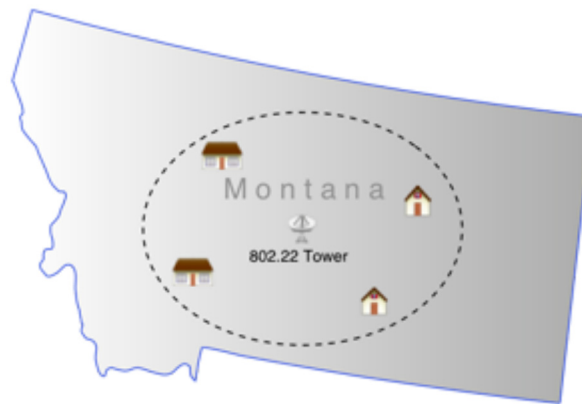


Figure 5: Example Deployment of an 802.22 Network

Work on the 802.22 standard first began in November of 2004 just after the FCC passed an important resolution entitled NPRM 04-186. In a nutshell, NPRM 04-186 defines provisions that allow license-exempt devices to operate in the TV-band so long as they can co-exist with existing services such as broadcasters and wireless microphone operators. The frequencies that the TV-Band covers are well known for their excellent signal propagation rates and appear to be ideal for use in a WRAN. As a result, work towards defining standard based around usage of the TV-band has swiftly progressed [[Chouinard04](#), [Cordiero05](#)].

At this point in time, the 802.22 standard is steadily moving closer towards being finalized, as competing proposals by a variety of small consortiums inside the working group have begun to merge. Once this work and other various technology tests are completed the standard should be ready for market deployment. The next sub-sections of this paper outline the current proposed MAC and PHY layers with special attention paid to unique incumbent-sensing mechanisms being incorporated into the standard.

## 4.1 802.22 PHY Layer Overview

The PHY layer of 802.22 is based on many of the same technologies as the fixed-broadband 802.16a/d standards. The major differences between the two center around the frequency ranges used and the channel sizes supported. Special considerations have been made, however, to better support the unique challenges associated with operating over the TV frequency band.

### 4.1.1 Frequency Ranges and Duplexing

As was mentioned in the introduction, the 802.22 standard is designed to operate in frequencies allocated to the UHF/VHF TV-band. Internationally, this band includes frequencies from 47 to 910 MHz; in the US, however, only frequencies from 54 to 854 MHz are used. Channel bandwidths of 6, 7 and 8 MHz (6 in the US) are supported and mimic those used by television broadcasters around the world. Regardless of the channel configuration used, both TDD and FDD methods of duplexing are supported [[Chouinard04](#)].

Using a 6 MHz channel, an aggregate bandwidth of up to 23 Mbps can be provided. Optionally, 2 or 3 channels, either contiguous or separated, can be bonded together to provide up to 71 Mbps of bandwidth. When channels are bonded, separate sets of OFDMA carriers are used on each channel for a total of 6144 sub-carriers when 3 channels with 2048 sub-carriers each are used. This feature was not included in the original specification, and was added only after a number of committee members raised concerns about whether or not a single channel could meet the needs of an estimated 100 users/cell [[Benko06](#)].

In order to share the spectrum with incumbent users, 802.22 devices are also capable of operating over partial channels from 1 to 8 MHz in size. This allows an 802.22 base station to share a channel with incumbent devices such as wireless microphones that only use 1 or 2 MHz of the total bandwidth allocated to a channel.



Furthermore, this ability allows 802.22 devices to selectively tune out portions of channels where interference and cross-talk make it impossible to transmit and receive a recognizable radio signal [[Benko06](#)].

### 4.1.2 Transport, Modulation and Coding

Data transmitted across an 802.22 network will make use of adaptive OFDMA with 1024 or 2048 subcarriers in both the forward and reverse directions. The ability to adapt the number of sub-carriers used will allow 802.22 to be more resilient to interference and other outside influences [[Benko06](#)]. Furthermore, by making use of the OFDMA technology developed for WiMAX and Mobile WiMAX, products based on the final 802.22 standard will be able to be deployed in a much more timely manner.

In terms of modulation, rates from BPSK up to 64QAM supported with the ability to dynamically adapt the method used as channel conditions change. Coding via convolutional codes is mandatory with optional support for LDPC and turbo coding. Furthermore, a more advanced method of turbo coding known as Shorted Block Turbo Code (SBTC) is expected to be supported as well. SBTC is based on the Turbo Product Code (TPC) used in 802.16 and is said to provide better parity checking mechanisms than the method used in 802.16e [[Benko06](#), [Chouinard04](#)].

### 4.1.3 Advanced Transmission Mechanisms

Much like the 802.16 and 802.20 standards, 802.22 supports a number of advanced transmission options. Among these options are optional support for STBC, adaptive beam forming (AAS), and various forms of MIMO and SDMA. A feedback channel referred to as Uplink Channel Sounding (ULCS) is provided in the OFDMA framing structure to support the feedback paths that mechanisms such as AAS and SDMA require [[Benko06](#)].

## 4.2 802.22 MAC Layer Overview

The MAC Layer of the 802.22 standard has many features inspired by the 802.16e standard such as DiffServ-compatible QoS support and a full-featured OFDMA frame structure. In order to co-exist with incumbent operators and provide better support for channel bonding, however, a number of special features were added to the standard [[Benko06](#)].

### 4.2.1 Connection Establishment and Framing

Connection establishment in 802.22 functions in a somewhat different manner than that of 802.16e or 802.20 because the frequencies on which a BS may reside can optionally be used by other incumbent users. As a result, the BS could be operating on any channel within the UHF/VHF band at any given time, making the task of performing user authentication and registration that much harder. Users account for this when they start-up by first searching all of the channels in the area to see if a BS is present. The presence of a BS is differentiated from other UHF/VHF users by the preamble sent at the start of each OFDMA frame. Once a user locates a BS, authentication and connection setup is done by the user injecting messages into the contention-based connection setup time allocated at the start of each frame [[Benko06](#)].

Data in 802.22 networks is transmitted by an OFDMA frame structure similar to that of 802.16e where the BS controls all downlink traffic and users must request uplink slots before they transmit. Minor additions, however, were made to the 802.16e framing structure to allow for incumbent detection and channel bonding. When channel bonding is used, a "super frame header" is transmitted to indicate to supporting users which channels they should look for and transmit data on (via an enhanced DL/UL map structure). Furthermore, in order to provide support for users that do not support channel bonding a portion of the OFDMA super frame

is reserved for such users to alert the BS of their restrictions so that the BS does not attempt to schedule transmissions and upload slots that the user cannot physically receive or make use of [Benko06].

#### 4.2.2 Incumbent Sensing and Detection

Incumbent sensing and detection is both a unique and vital portion of the 802.22 standard. As can be seen in Figure 6, a multitude of incumbents may be operating in the same region as WRAN network. Therefore, in order to properly share the VHF/UHF bands with television broadcasters or wireless microphones, a foolproof system of incumbent avoidance techniques needs to be implemented. The approach currently being proposed by various members of the 802.22 committee employs a multi-tiered approach to sensing that aims to have a minimal impact on overall system performance [Benko06].

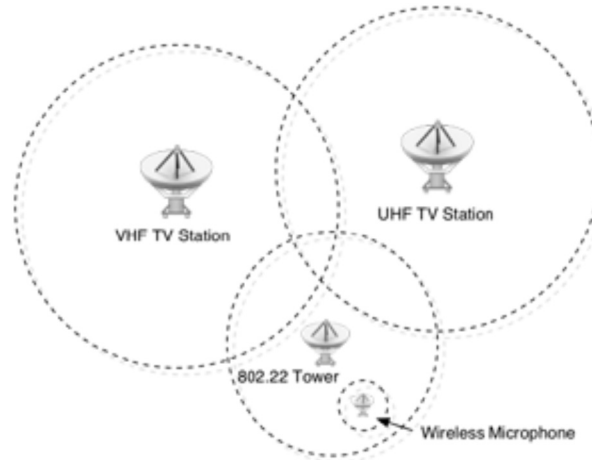


Figure 6: Incumbent Operators in Range of an 802.22 Network

In the proposed sensing method, both the BS and user terminals will participate in incumbent detection. This allows sensing tasks to be distributed and gives the BS a better chance of identifying localized broadcasters (such as wireless microphone operators) that only a user would be able to detect. The BS reserves portions of the OFDMA frame to tell users which channels they should monitor for traffic. Users then collect this data and report it back to the BS at pre-specified intervals. Once all sensing information is collected, the BS then creates a revised list of occupied and unoccupied channels based on the results [Benko06].

Depending on the level of accuracy required sensing can either be done via either "fast" or "fine" mechanisms. Fast sensing is performed in-band during the guard interval portions of OFDMA frames. The advantage of fast sensing is that transmission time is not wasted on sensing. This advantage, however, comes at the cost of some accuracy [Benko06].

Fine sensing, on the other hand, is done out-of-band during defined "quiet periods" in which no network traffic is generated. The BS schedules "quiet periods" ahead of time so that all user stations can synchronize their sensing with one another. This method of sensing provides a higher degree of accuracy, but reduces the overall throughput of the network. As a result fine sensing is typically only used in cases when ambiguities in fast sensing arise [Benko06].

If, as a result of sensing, a BS realizes that it is operating on the same channel as an incumbent user it must broadcast a channel hop message to all users in the service area and switch to an unoccupied channel within in a 2 second time period. It should be noted that since television operators do not typically switch broadcasting channels the vast majority of interference will be with less significant devices such as wireless microphones [Benko06].

In rare cases, a situation may arise where a user terminal is powered on and cannot sense the presence of a

BS because an incumbent, that the BS cannot see, is transmitting on the same channel as the BS. This issue is referred to as the "Hidden Incumbent Problem" (see Figure 7), and can be remedied by having the BS periodically broadcast transmission frames on both its current designated channel and one or more additional unoccupied channels. When the blocked user picks up the broadcasted signal they can then alert the BS that they are interfering with an incumbent user and that a channel hop is needed [Benko06].

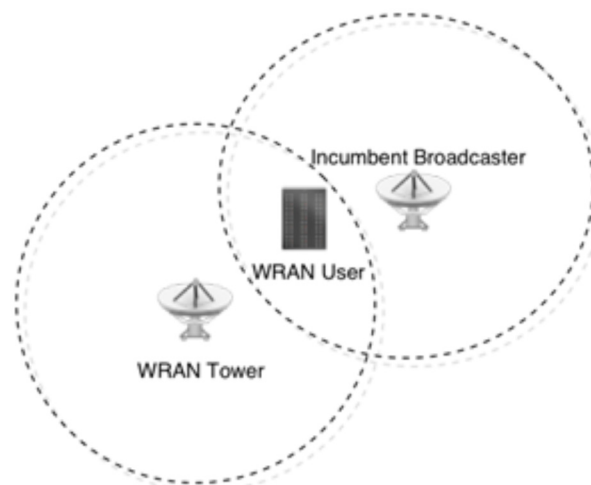


Figure 7: The Hidden Incumbent Problem

### 4.2.3 Self Co-Existence

By virtue of operating over unlicensed bands in a frequency band where incumbents exist, the issue of co-existence between competing 802.22 systems operators is somewhat more significant than it would be otherwise. In areas with a significant number of incumbent users (i.e. television channels), open channels will already be a sparse commodity even when only one 802.22 network is operating. Therefore when multiple operators are located in the same physical region, a fair channel allocation and reservation method needs to be utilized in order to prevent one operator from stealing all of the available bandwidth.

To facilitate communication between operators a BS-to-BS communication channel is specified in the 802.22 standard. By use of this mechanism, competing BS's can negotiate with one another to fairly partition the available channels and work to come to a solution that best meets the needs of both operators. Although the exact methodology for conflict resolution has yet to be defined, one current proposal involves the use of replenishable "tokens" and a bidding system by which the operator most willing to "pay" for an available channel is the one that is allowed to transmit on it. Only time will tell, however, if such a system is actually implemented in the standard [Benko06].

### 4.2.4 QoS Support

At this point in time, the standard committee has been mainly focusing on effectively solving the incumbent detection and self co-existence problems that plague 802.22. As a result, smaller issues such as QoS support have been left by the wayside for the time being. QoS support similar to that provided by 802.16e is expected to be provided, however, with full support for UGS, rtPS, nrtPS and BE flow classifications. Furthermore, DiffServ and RSVP support is expected in order to provide end-to-end QoS support [Chouinard04].

### 4.2.5 Security Features

Much like QoS support, the security features of the 802.22 standard are largely undefined at this point. The functional requirements document, however, states that data security is of the utmost importance. To that end,

support for features such as authentication, authorization, message integrity and data encryption are expected to be included in the final draft of the standard [[Chouinard04](#)].

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## Summary

Recently, the IEEE has begun to look beyond short-distance WLAN standards such as 802.11b/g towards further reaching metropolitan and regional-area wireless networking solutions. The 802.16 and 802.20 standards, described in sections 2 and 3 of this paper, seek to provide stationary (802.16a/d), semi-mobile (802.16e) and highly mobile (802.20) wireless network access in cells approximately 1 to 5 km in radius. 802.22, described in section 4, seeks to define a WRAN standard serving rural and remote users within 50 to 100 km of a BS. A summary of the major features provided by all three standards can be seen in Table 3.

	Target Market	Frequency Usage	Maximum Data Rate	Spectral Efficiency	Special Concerns	Maximum Range of a Single Base Station
802.16	Enterprise-class Fixed Wireless Access.	10 to 66 GHz Licensed Bands. Line of Sight Operation.	75 Mbps Aggregate.	0.5 to 4.5 bps/Hz.	Requires LOS to Work Properly.	50 km maximum; 4 km or less expected.
802.16a/d	Consumer-class Fixed Wireless Access.	2 to 11 GHz Licensed and Unlicensed Bands. Non Line of Sight Operation.	75 Mbps Aggregate.	0.5 to 4.5 bps/Hz.	None.	50 km maximum; 4 km or less expected.
802.16e	Consumer-Class Semi-Mobile Wireless Access.	2 to 11 GHz Licensed and Unlicensed Bands. Non Line of Sight Operation.	75 Mbps aggregate; 500 kbps for Mobile Users.	0.5 to 4.5 bps/Hz. Lowers as mobility increases.	Handoff and Power Management.	4 km or less.

802.20	Consumer-Class Highly-Mobile Wireless Access	Less than 3.5 GHz Licensed Bands. Non Line of Sight Operation.	1 Mbps downstream and 300 Kbps upstream per user. Aggregate BW not yet finalized.	Greater than 1.0 bps/Hz is Expected.	Handoff and Power Management.	4 km or less.
802.22	Consumer-Class Fixed Wireless Access for Rural or Remote Users.	47 to 910 MHz (Depending on Country) Shared Bands. Non Line of Sight Operation.	5 to 70 Mbps aggregate; 1 Mbps or higher per user.	0.5 to 5.0 bps/Hz.	Incumbent Detection and Avoidance. Self-Coexistence.	100 km maximum; 50 km or less expected.

Table 3: Summary of Major Features of the IEEE WMAN and WRAN Standards [[Goth04](#), [Legg04](#), [Nichols04](#), [Klerer03](#), [Upton05](#), [Chouinard04](#)].

As can be seen in the above table, the standards are largely based on the same technologies and all offer support for features such as adaptive modulation/coding and various enhanced transmission systems. These similarities can largely be attributed to the fact that 802.20 and 802.22 were developed after the 802.16a/d standards. As a result, their developers have been able to learn from the mistakes made in defining that standard, while at the same time integrating the most successful portions into their own implementations.

In terms of marketability, 802.16 is the only of the three standards for which both service-provider and end-user devices are available for purchase. Furthermore, with the recent approval of the semi-mobile 802.16e specification and the backing of the WiMAX Forum, the standard seems destined to garner nearly universal support throughout the industry. This success, however, does not come without a certain amount of controversy, as various developers within the 802.20 working group have criticized those in the 802.16e camp for developing what essentially could be construed as a self-competing standard [[Kiernan05](#)]. The argument can be made, however, that the 802.20 developers have had just as much time to work as the 802.16e group yet they have not managed to deliver anything remotely resembling a full-featured standard.

Meanwhile, the 802.22 standard has been developing at a fairly brisk pace. Within 2 years of being founded, the working group has produced a nearly complete specification that addresses the unique incumbent detection problems associated with operating within the Television band. As a result, the standard seems poised to provide a solid alternative to current satellite-based approaches for broadband network access in remote or rural regions.

In short, 802.16, 802.20 and 802.22 are all striving to provide wireless access to users in areas that pre-existing technologies such as 802.11 simply cannot. If all three standards eventually succeed in the marketplace, users will be able to connect to the Internet from locations never before possible. This, in turn, will lead to a more mobile society as a whole and allow consumers living "off-the-grid" to have access to the same types of services as those living in urban or suburban areas.

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## List of Acronyms

2.5G	Two and One-Half Generation
3G	Third Generation
4G	Fourth Generation
64QAM	64 State Quadrature Amplitude Modulation
AAS	Adaptive Antenna System
ADSL	Asynchronous Digital Subscriber Line
AES	Advanced Encryption Standard
ARQ	Automatic Repeat ReQuest
BE	Best Effort
BPSK	Binary Phase Shift Keying
BS	Base Station
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
DES	Data Encryption Standard
DL	Downlink
DL-MAP	Downlink Map
DS	Differentiated Services (DiffServ)
DSL	Digital Subscriber Line
FTP	File Transfer Protocol
GHz	Gigahertz
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat ReQuest
IEEE	Institute of Electrical and Electronics Engineers
KBps	Kilobytes Per Second
Kbps	Kilobits per Second
km	Kilometer
LOS	Line of Sight
MAC	Media Access Control
Mbps	Megabytes per Second
MBWA	Mobile Broadband Wireless Access
Mbps	Megabits per Second
MIMO	Multiple Input, Multiple Output
NLOS	Non Line of Sight



nrtPS	Non-Real Time Polling Service
PHY	Physical
QoS	Quality of Service
RSVP	Resource ReSerVation Protocol
rtPS	Real Time Polling Service
SBTC	Shortened Block Turbo Code
STBC	Space Time Block Code
SC	Single Carrier
LDPC	Low Density Parity Check
SDMA	Space Division Multiple Access
SM	Spatial Multiplexing
TDD	Time-Division Duplexing
FDD	Frequency-Division Duplexing
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
S-OFDMA	Scalable Orthogonal Frequency Division Multiple Access
TPC	Turbo Product Code
UGS	Unsolicited Grant Service
UHF	Ultra High Frequency
UL	Uplink
ULCS	Uplink Channel Sounding
UL-MAP	Uplink Map
VHF	Very High Frequency
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WRAN	Wireless Regional Area Network

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