Guide to Wireless Communications, Third Edition

Chapter 9
Wireless Metropolitan Area Networks

Objectives

- Explain why wireless metropolitan area networks (WMANs) are needed
- Describe the components and modes of operation of a WMAN
- Describe several WMAN technologies, including FSO, LMDS, MMDS, and 802.16 (WiMAX)
- Explain how WMANs function
- Outline the security features of WMANs

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What is a WMAN?

- Wireless metropolitan area networks (WMANs)
  - Provide wireless connectivity across a substantial geographical area such as a large city
- WMANs primary goals
  - Extend wired networks beyond a single location
    - Without the expense of high-speed cable-based connections
  - Extend user mobility throughout a metropolitan area
    - Provide high-speed connections to areas not serviced by any other method of connectivity

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Last Mile Wired Connections

- Last mile connection
  - Link between a end-user and ISP
  - Most last mile connections are based on some type of copper cabling
    - More recently, they are based on optical fiber cables
- Home users in large metropolitan areas have the options of DSL at up to 16 Mbps and cable-TV connections at up to 105 Mbps
  - Usually not available in small, remote communities

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Last Mile Wired Connections

- Copper-based digital communications lines
  - Require the signal to be regenerated every 6,000 feet
- Last mile delivery of telephone and data lines has long been a problem for the carriers (providers of the network)
  - Must be able to justify the cost of installing wired connections to remote areas
- Since the early 1980s, fiber-optic technology has largely replaced all other technologies for connections between metropolitan centers
  - Has a higher capacity for carrying voice and data

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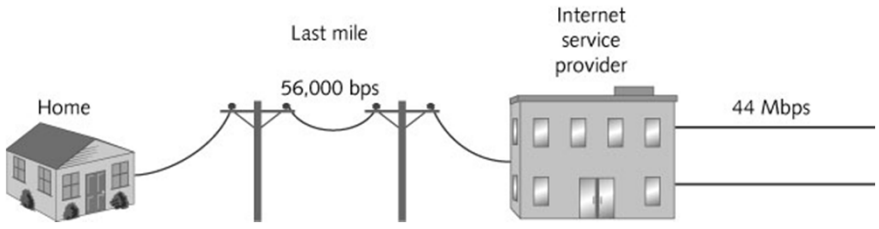

Figure 9-1 Last mile connection

Connection Type	Speed (or Range)	Typical Use	Approximate Cost Per Month	Approximate Time to Download Full Content of a 680 MB CD-ROM (Hours:Minutes)
Dial-up modem	56 Kbps	Home	Free and up	26:53
ISDN (1 or 2 channels)	64 or 128 Kbps	Home or business	Residential: $50 setup + $29.95 Business: $49.95	24:10 or 12:50
Cable modem	1.5–105 Mbps	Home	$30–$199	0:58 to less than 0:01
ADSL	6–16 Mbps	Home	$15–$140	0:15–0:06
T1	1.544 Mbps	Office	$400 and up	0:58
T3	44.736 Mbps	Office, ISP	$2,500–$5,000	0:02
OC-3 (optical fiber)	155 Mbps	ISP	$10,000–$30,000	32 seconds
OC-12 (optical fiber)	622.08 Mbps	ISP	Varies greatly	8 seconds
OC-192 (optical fiber)	9.6 Gbps	Large ISP	Varies greatly	Less than 1 second

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Table 9-1 Wired connection options

Last Mile Wireless Connections

- Most technologies used in WMANs are based on microwave signals
- Microwaves are higher frequency RF waves
  - In the 3 to 30 GHz range of the electromagnetic spectrum known as **super high frequency (SHF)** band
- Microwave towers are installed roughly 35 miles (56 kilometers) apart from each other
  - A link operating at 4 GHz carries about 1,800 voice calls simultaneously
  - T1 link can only carry 24 simultaneous voice calls

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Last Mile Wireless Connections

- Fixed wireless networks have been used for years
  - For both voice and data communications
- **Backhaul connection** – Company's internal infrastructure connection
  - Cellular telephone towers along highways are often interconnected using a microwave backhaul link

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Baseband vs. Broadband

- Broadband transmission
  - Sends multiple signals at different frequencies
  - Example: Cable TV
- Baseband transmission
  - Treats the entire transmission medium as if it were only one channel
  - Transmits only one data signal at a time over a single frequency
  - Example: Ethernet

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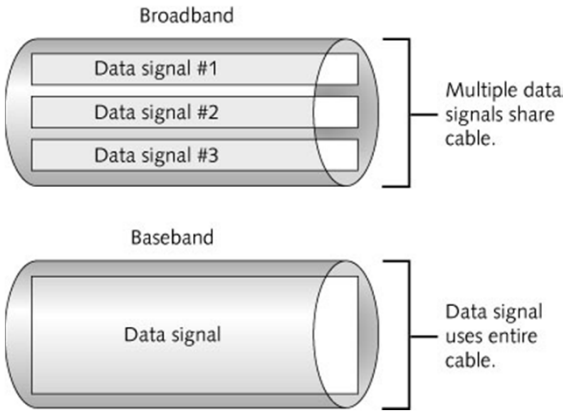

Figure 9-2 Baseband vs. broadband transmissions

Land-Based Fixed Broadband Wireless

- Most solutions for last mile connections are proprietary solutions or RF-based equipment
  - Require licensed frequency bands
- Building-to-building connectivity solutions
  - Free Space Optics
  - Local multipoint distribution service
  - Multichannel multipoint distribution service
  - IEEE 802.16 (WiMAX)

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Free Space Optics

- Free space optics (FSO)
  - Optical, wireless, point-to-point, line-of-sight broadband technology
  - Excellent alternative to high-speed fiber-optic cable
  - Can transmit up to 1.25 Gbps at a distance of 4 miles (6.4 kilometers) in full-duplex mode
  - Uses infrared (IR) transmission instead of RF
    - Transmissions are sent by low-powered invisible infrared beams through the open air
  - FSO is a line-of-sight technology

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Free Space Optics

- Advantages of FSO
  - Cost
  - Speed of installation
  - Transmission rate
  - Security
- Disadvantages of FSO
  - Atmospheric conditions impact FSO transmissions
  - Scintillation
    - Temporal and spatial variations in light intensity caused by atmospheric turbulence

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Free Space Optics

- Disadvantages of FSO (cont'd)
  - FSO overcomes scintillation by sending the data in parallel streams (spatial diversity) from several separate laser transmitters
  - Dealing with fog
    - Increase the transmit power of the signal
  - Signal interference
  - Tall buildings or towers can sway due to wind or seismic activity
    - Affecting the aim of the beam

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Figure 9-4 Spatial diversity

Free Space Optics

- FSO applications
  - Last mile connection – can be used in high-speed links connecting end-users with ISPs or other networks
  - LAN connections – used for interconnecting LAN segments separated by streets or other obstacles
  - Fiber-optic backup – deployed in redundant links to back up fiber-optic cables
  - Backhaul – can be used to carry cellular phone traffic from antenna towers back to high-speed communications lines

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Local Multipoint Distribution Service (LMDS)

- Local multipoint distribution service (LMDS)
  - Fixed broadband microwave, line-of-sight technology that can provide a wide variety of wireless services
    - High-speed Internet access
    - Real-time multimedia file transfer
    - Remote access to local area networks
    - Interactive video, video-on-demand, video conferencing
    - Telephone service
  - Can transmit from 51 to 155 Mbps downstream and 1.54 Mbps upstream
    - Over a distance of up to about 5 miles (8 kilometers)

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Local Multipoint Distribution Service (LMDS)

- Examining each of the words that make up its name:
  - Local (L) – area of coverage (2 – 5 miles)
  - Multipoint (M) – signals are transmitted to the remote stations in a point-to-multipoint fashion from a base station omnidirectional antenna
  - Distribution (D) – refers to the distribution of the various types of information that can be transmitted
  - Service (S) – indicates there are a variety of services available

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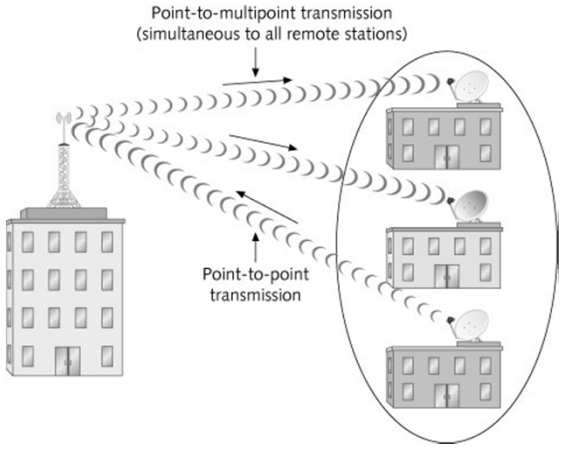

Figure 9-5 LMDS transmissions

Local Multipoint Distribution Service (LMDS)

- Frequency Bands
  - LMDS used the following ranges of frequencies
    - Block A: consisting of frequencies in the 27.5-28.35 GHz, 29.1-29.25 GHz, and the 31.075-31.225 GHz range
    - Block B: frequencies in the 31-31.075 GHz and the 31.225-31.3 GHz range
- LMDS Network Architecture
  - Composed of cells similar to a cellular telephone system
  - LMDS is a fixed wireless technology for buildings

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Local Multipoint Distribution Service (LMDS)

- LMDS Network Architecture (cont'd)
  - Factors that determine the cell size
    - Line-of-sight
    - Antenna height
    - Overlapping cells
    - Rainfall

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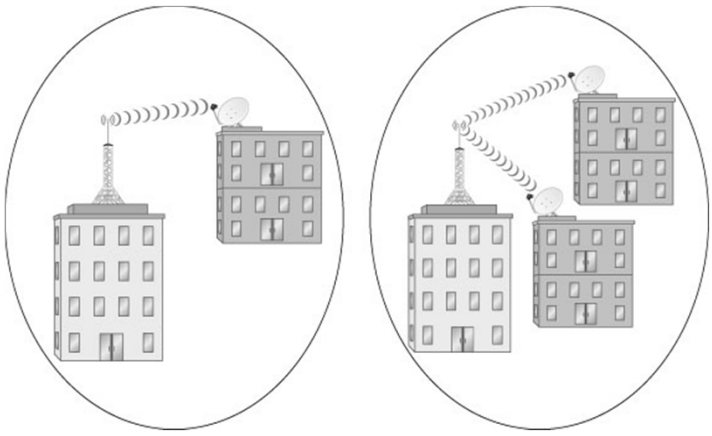

Figure 9-6 LMDS system with multiple cells

Local Multipoint Distribution Service (LMDS)

- Architecture (cont'd)
  - LMDS signals are broadcast from radio hubs that are deployed throughout the carrier's market
    - Area in which the LMDS provider has a license to use a certain frequency
  - Hub connects to the service provider's central office
    - Can connect to other networks, such as the Internet
  - Equipment at the receiving site
    - 12- to 15-inch diameter directional antenna
    - Digital radio modem
    - Network interface unit – connects to a LAN as well as to other services

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Local Multipoint Distribution Service (LMDS)

- Architecture (cont'd)
  - LMDS systems can use either:
    - Time division multiple access (TDMA)
    - Frequency division multiple access (FDMA)
  - Modulation techniques
    - Quadrature phase shift keying (QPSK)
    - Quadrature amplitude modulation (QAM)
- Advantages of LMDS
  - Cost, service area, and data capacity

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Multichannel Multipoint Distribution Service (MMDS)

- Multichannel multipoint distribution service (MMDS)
  - Fixed broadband wireless technology similar to LMDS
  - Can transmit video, voice, or data signals at 1.5 to 2 Mbps downstream and 320 Kbps upstream
    - At distances of up to 35 miles (56 kilometers)
  - MMDS is sometimes called wireless cable
    - Can broadcast 300 channels
  - Internet access using MMDS is an alternative to cable modems and DSL service
    - Particularly in rural areas where cabling is scarce

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Multichannel Multipoint Distribution Service (MMDS)

- MMDS Network Architecture
  - MMDS hub is typically located on a high point
    - Uses a point-to-multipoint architecture that multiplexes communications to multiple users
  - Tower has a backhaul connection to carrier's network
    - Carrier network connects with the Internet
  - MMDS signals can travel longer distances
    - Provide service to an entire area with only a few radio transmitters
  - MMDS cell size can have a radius of up to 35 miles (56 kilometers)

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Multichannel Multipoint Distribution Service (MMDS)

- MMDS Network Architecture (cont'd)
  - **Pizza box antenna**
    - 13 by 13 inches antenna used at receiving site
    - Aimed at the hub to receive the MMDS signal
  - Cable runs from the antenna to an MMDS wireless modem
    - Converts the transmitted analog signal to digital
    - Modem can connect to a single computer or an LAN

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Figure 9-7 Pizza box antenna

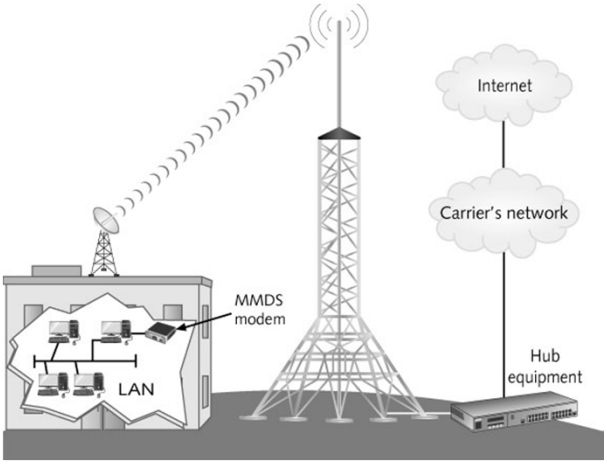

Figure 9-8 MMDs system infrastructure

Multichannel Multipoint Distribution Service (MMDS)

- Advantages of MMDS
  - Signal strength
  - Large cell size
  - Cost
- Disadvantages of MMDS
  - Physical limitations
  - Frequency sharing
  - Security
  - Availability of the technology

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IEEE 802.16 (WiMAX)

- Open-standard for wireless broadband metropolitan area networks
  - WiMAX stands for worldwide interoperability for microwave access
  - Can work in either line-of-sight or non-line-of-sight mode (depending on frequency used)
- 802.16 supports enhancements and extensions to the MAC protocols
  - **Base station (BS)** can communicate with another BS
    - And also directly with **subscriber stations (SS)**
      - Can be a laptop or any device that attaches to a LAN

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IEEE 802.16 (WiMAX)

- FSO, LMDS, and MMDS are not based on an open standard
  - All equipment must be purchased from a single manufacturer
- WiMAX Forum
  - Promotes the implementation of 802.16 by testing and certifying equipment for compatibility and interoperability
- IEEE 802.16 standard offers multiple RF interfaces (PHY layers)
  - All based on a common MAC protocol

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WiMAX Applications

- Applications
  - Suitable for backhaul applications for business
  - Last mile delivery applications
    - That replace T1, DSL, and cable modems
  - Supports simultaneous voice, video, and data transmission with QoS
    - Suitable for voice-over-IP (VoIP) connections
  - Enables vendors to create **customer premises equipment (CPE)**
  - Can also be deployed as a point-to-point network
    - Provide broadband access to rural and remote areas

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WiMAX Applications

- Some WiMAX CPE devices will support TV (video), telephone (voice), and data on the same network
  - Cost for equipment and service has dropped significantly
- WiMAX MAC layer makes it easy for carriers to deploy the network
- Range of a WiMAX network is measured in miles
- With low costs and interface availability for laptops:
  - WiMAX offers serious competition to 802.11 networks and hotspots

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Standards Family Overview

- 802.16-2001 and 802.16-2004 standards
  - Define the interface specification for fixed, point-to-multipoint broadband WMANs
  - 802.16-2001: support in the 10-66 GHz range
  - 802.16-2004: support in the 2 GHz to 11 GHz band
- 802.16e
  - Defines specifications for a mobile version of WiMAX
  - Can enable data rates of up to 2 Mbps
- Most recent amendment: 802.16m (Release 2)
  - Raises data rate to 100 Mbps

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WiMAX Protocol Stack

- PHY layer supports multiple frequency bands and several modulation techniques
  - PHY layer is able to adapt on the fly
- WiMAX MAC layer is *connection oriented*
  - Includes service-specific convergence sublayers that interface to the upper OSI layers
- WiMAX offers multiple simultaneous services through the same link
  - Asynchronous transfer mode (ATM), IPv4, IPv6, Ethernet, VLAN, and others

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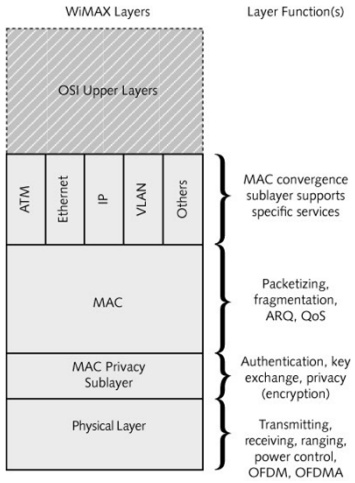

Figure 9-10 802.16 protocol stack

WiMAX Protocol Stack

- PHY layer
  - Several variations of the PHY layer in 802.16
  - First two are based on the modulation of a single carrier signal
    - Transmission is half-duplex
    - Each frame is subdivided into one uplink subframe and one downlink subframe
  - **Burst** – a data transmission to or from a single device
  - **Time Division Duplexing (TDD)** – mechanism that divides a single transmission into two parts: an uplink part and downlink part

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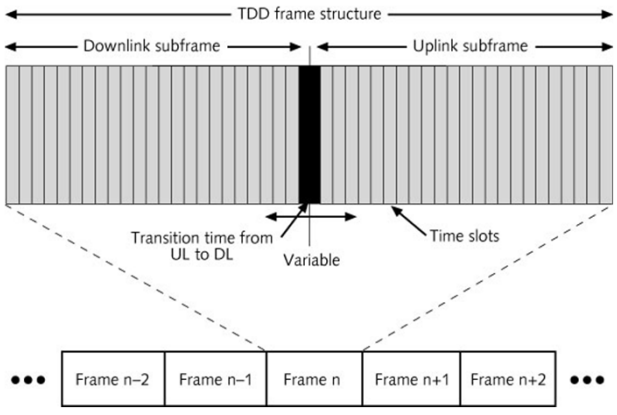

Figure 9-11 WiMAX TDD frame

WiMAX Protocol Stack

- PHY layer (cont'd)
  - **Frequency division duplexing (FDD)** – mechanism that uses one frequency for uplink and another for downlink
    - A WiMAX FDD network can support half-duplex and full-duplex equipment
  - 802.19-2009 supports one transmit mode:
    - **WirelessMAN-SC (single carrier)** – used for fixed point-to-point connections using either TDD or FDD
  - 802.16 standard also provides support **for non-line-of-sight (NLOS)** applications

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WiMAX Protocol Stack

- PHY layer (cont'd)
  - Additional PHY layer transmission mechanisms to support NLOS applications
    - WirelessMAN-OFDM
      - Can be used for fixed, mobile, or mesh applications
    - WirelessMAN-OFDMA
      - Uses **Orthogonal Frequency-Division Multiple Access (OFDMA)**: divides the available channel into 1536 orthogonal data subcarriers
    - **Wireless High-Speed Unlicensed Metro Area Network (WirelessHUMAN)**
      - Based on OFDM and is designed for use in the unlicensed 5 GHz U-NII band

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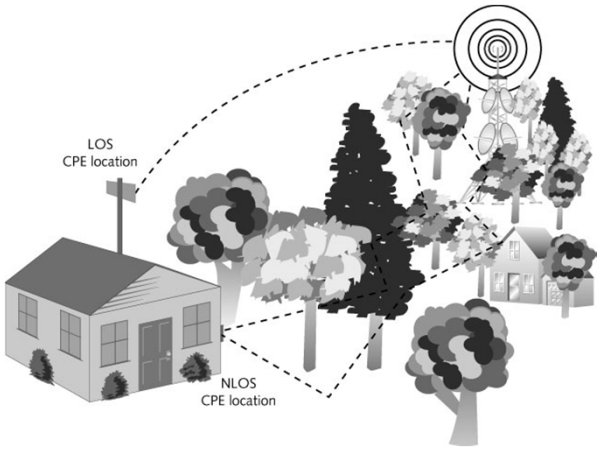

Figure 9-12 Line-of-sight and non-line-of-sight examples

Designation	Frequencies	Application	Duplexing
WirelessMAN-SC	10–66 GHz licensed bands	Fixed only	TDD, FDD
WirelessMAN-OFDM	Below 11 GHz licensed bands	Fixed, mobile, or mesh	TDD, FDD
WirelessMAN-OFDMA	Below 11 GHz licensed bands	Fixed or mobile	TDD, FDD
WirelessHUMAN	5 GHz U-NII band	Fixed or mesh	TDD only

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Table 9-2 WiMAX specifications summary

WiMAX Protocol Stack

- Modulation and error correction
  - 802.16 uses forward error correction
    - A technique that inserts additional bits in the data stream to enable the receiver to detect multiple-bit errors and to correct single-bit errors in groups of bits
  - 802.16 also uses automatic repeat requests (ARQ)
    - Ensures reliability of transmissions
  - 802.16 was designed to achieve 99.999 percent reliability (referred to as “five nines” in the industry)

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WiMAX Protocol Stack

- Modulation and Error Correction
  - 802.16 dynamically changes modulations which makes it possible for WiMAX to reduce latency and improve QoS
    - Latency: amount of time delay that it takes a packet to travel from source to destination device

Modulation	FEC Coding Rates
BPSK	1/2, 3/4
QPSK	1/2, 2/3, 3/4, 5/6, 7/8
16-QAM	1/2, 3/4
64-QAM	2/3, 5/6
256-QAM (optional)	3/4, 7/8

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Table 9-3 802.16 modulations and mandatory FEC coding

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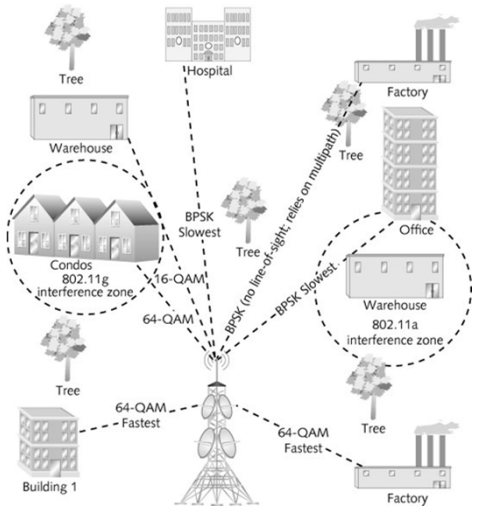

Figure 9-13 How WiMAX can apply different modulations

WiMAX Protocol Stack

- WiMAX Profiles
  - **Profiles** – sets of predefined parameters that can include:
    - Frequency channel, bandwidth of the channel, and transmission modes (OFDM, OFDMA, etc)
  - Help to reduce or eliminate the need for **truck-rolls**
    - Support technician visits to the site (they can be changed remotely)
  - WiMAX **system profile** – combination of basic profile and one of the transmission profiles
  - **Burst profiles** – negotiated between BSs and SSs for the allocation of time slots

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WiMAX Protocol Stack

- Range and throughput
  - Maximum distances achievable in a WiMAX network
    - Depend on the frequency band used
  - Higher frequencies are used for
    - Metropolitan area line-of-sight, point-to-point, or multipoint application at very high data rates
  - Lower licensed frequencies will be used for
    - Private, line-of-sight network connections up to 10 miles (16 kilometers)
    - Long distance links of up to 35 miles

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WiMAX Protocol Stack

- Range and throughput (cont'd)
  - Frequencies below 11 GHz are also be used for
    - Non-line-of-sight networks with a maximum range of up to 5 miles (8 kilometers)

	Modulation/ FEC Coding	QPSK 1/2	QPSK 3/4	16 QAM 1/2	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
Channel Bandwidth	1.75 MHz	1.04	2.18	2.91	4.36	5.94	6.55
	3.5 MHz	2.08	4.37	5.82	8.73	11.88	13.09
	7.0 MHz	4.15	8.73	11.64	17.45	23.75	26.18
	10.0 MHz	8.31	12.47	16.63	24.94	33.25	37.40
	20.0 MHz	16.62	24.94	33.25	49.87	66.49	74.81

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Table 9-4 Sample of WiMAX data rates in Mbps vs. channel bandwidth and FEC

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WiMAX Protocol Stack

- MAC layer
  - WiMAX is typically implemented on a point-to-multipoint basis
    - With one BS and potentially hundreds of SSs
  - 802.16 MAC dynamically allocates bandwidth to individual SSs for the uplink
  - **Advanced antenna system (AAS)**
    - Transmits multiple simultaneous signals in different directions to stations that fall within the range
  - WiMAX can also take advantage of multiple in multiple out (MIMO) antenna systems
    - Reduces interference with other systems

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WiMAX Protocol Stack

- MAC layer (cont'd)
  - BS uses a 16-bit connection identifier (CID)
    - To address a burst to a particular SS
  - Stations can request additional dedicated bandwidth (for QoS)
  - Jitter
    - Maximum delay variation between two consecutive packets over a period of time
  - WiMAX MAC protocol maintains a consistent bandwidth by using a self-correcting mechanism
    - For granting more bandwidth to SSs
    - Creates less traffic on the network

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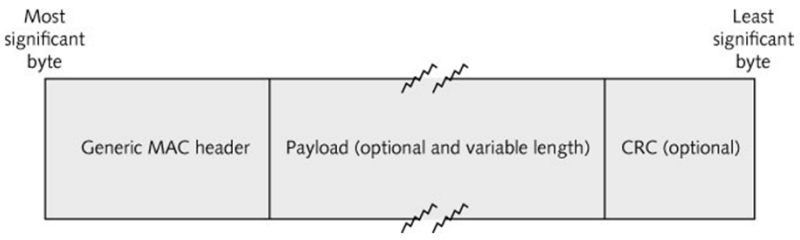

Figure 9-14 802.16 (WiMAX) MAC frame

WiMAX Coexistence

- As the number of transmitters grows, so does interference
- WiMAX is different from technologies such as 802.11
  - WiMAX is not limited to the 2.4 GHz or the 5 GHz bands
- U-NII band offers 12 channels and 555 MHz of bandwidth
  - WiMAX signals are limited to between 30 and 35 miles
  - Interference may not be a serious problem
- Adaptive modulations, variable data rates, signal power levels, and FEC help with interference

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WMAN Security

- Security in WMANs is a major concern
- FSO systems are generally considered secure
  - Attempting to *sniff* information from FSO systems is difficult
    - Attacker must access the equipment and block only a portion of an invisible beam
- LMDS and MMDS systems
  - RF signals can be captured by a receiver without blocking the radio signal

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WiMAX Security

- MAC layer includes a privacy sublayer
  - WiMAX standard was initially designed to include very powerful security measures
- Privacy sublayer provides a client/server authentication and key management protocol
  - Uses **digital certificates** which are messages digitally signed by a certification authority
- Components in the privacy sublayer
  - An encapsulation protocol for encrypting packet data
  - A privacy key management protocol that provides secure key distribution from BS and SSs

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WiMAX Security

- Traffic encryption key (TEK)
  - Security key used to encrypt the data
  - SS must renew the keys periodically with the BS
  - Default TEK lifetime is 12 hours
- Data encryption algorithms
  - 3-DES (Triple-DES)
  - RSA with 1024-bit key
  - AES with 128-bit key

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Summary

- WMANs are a group of technologies that provide wireless connectivity throughout an area
- Last mile wired connections are the link between the customer's premises and an ISP
- Transmission techniques
  - Broadband and baseband
- Land-based fixed broadband wireless techniques
  - Free space optics (FSO)
  - Local multipoint distribution service (LMDS)
  - Multichannel multipoint distribution service (MMDS)

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Summary

- IEEE 802.16 (WiMAX) standard introduced in 2000
  - Can transmit at speeds up to 70 Mbps in the 2 to 11 GHz bands
  - Can also achieve 120 Mbps at short distances in the 10 to 66 GHz bands
  - 802.16e brings full support of mobile devices to WiMAX technology
- The WiMAX MAC layer is connection oriented
- The BS can support both half-duplex and full-duplex devices simultaneously

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Summary

- Variations of the WiMAX PHY layers for LOS and NLOS implementations:
  - WirelessMAN-OFDM, WirelessMAN-OFDMA, and WirelessHUMAN
- OFDM and OFDMA in 802.16 are scalable
- WiMAX profiles specify the frequency channel, bandwidth, and transmission mechanism
- MAC layer is the key to the intelligence and security behind WiMAX
  - Uses verifiable digital certificates, advanced encryption mechanisms, and secure key exchange

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