Wireless# Guide to Wireless Communications

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
- List the range of WMAN technologies, including FSO, LMDS, MMDS, and 802.16 (WiMAX)
- Explain how WMANs function
- Outline the security features of WMANs

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

Last Mile Wired Connections

- Last mile connection
  - Link between a customer and ISP
  - Most last mile connections use copper wiring
- 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 carrier
  - Must be able to justify the cost of installing wired connections to remote areas

Last Mile Wired Connections (continued)

Figure 9-1 Last mile connection

Last Mile Wired Connections (continued)

Table 9-1 Connection options

Connection type	Speed	Typical use	Approximate cost per month	Approximate time to transmit contents of one full 680 MB CD-ROM (hours:minutes)
Dial-up modem	56 Kbps	Home	Free and up	26:53
ISDN (1 or 2 ch.)	64 or 128 Kbps	Home or office	$100 plus usage fees	24:10/12:50
Cable modem	5 Mbps	Home	$45 and up	0:18
DSL	5 Mbps	Home	$30 and up	0:18
T1	1.544 Mbps	Office	$400 and up	0:58
T3	44.736 Mbps	Office, ISP	$2,500 and up	0:02
OC-3 (optical fiber)	155 Mbps	ISP	$20,000 to $45,000	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	½ second

Last Mile Wireless Connections

- 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
- Fixed wireless
  - Wireless as the last mile connection for buildings
- Backhaul connection
  - Company's internal infrastructure connection

Baseband vs. Broadband

- Broadband transmission
  - Sends multiple signals at different frequencies
- Baseband transmission
  - Treats the entire transmission medium as if it were only one channel
  - Only one signal can be set at a time

Baseband vs. Broadband (continued)

Figure 9-2 Baseband vs. broadband transmissions

Land-Based Fixed Broadband Wireless

- Most are proprietary solutions or RF-based equipment
  - Require licensed frequency bands
- Solutions
  - Free Space Optics
  - Local multipoint distribution service
  - Multichannel multipoint distribution service

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

Free Space Optics (continued)

Figure 9-3 FSO transceiver (transmitter/receiver)

Free Space Optics (continued)

- 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

Free Space Optics (continued)

- Disadvantages of FSO (continued)
  - 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

Free Space Optics (continued)

Figure 9-4 Spatial diversity

Free Space Optics (continued)

- FSO applications
  - Last mile connection
  - LAN connections
  - Fiber-optic backup
  - Backhaul

Local Multipoint Distribution Service (LMDS)

- Local multipoint distribution service (LMDS)
  - Fixed broadband 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)

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-5 LMDS transmissions

Local Multipoint Distribution Service (LMDS) (continued)

- Frequency
  - Based on high frequency, low-powered signals over short distances
  - LMDS used the following ranges of frequencies
    - 27.5 MHz and 28.35 MHz
    - 29.1 MHz and 29.25 MHz
    - 30 GHz, 31.075 GHz, and 31.225 GHz
- Architecture
  - Cells (like a cellular telephone system)
  - LMDS is a fixed wireless technology for buildings

Local Multipoint Distribution Service (LMDS) (continued)

- Architecture (continued)
  - Factors that determine the cell size
    - Line-of-sight
    - Antenna height
    - Overlapping cells
    - Rainfall

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-6 Tall building obstructs signal

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-7 Divide into smaller cells

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-8 Antenna height

Local Multipoint Distribution Service (LMDS) (continued)

- Architecture (continued)
  - 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

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-9 LMDS infrastructure

Local Multipoint Distribution Service (LMDS) (continued)

Figure 9-10 LMDS receiving equipment

Local Multipoint Distribution Service (LMDS) (continued)

- Architecture (continued)
  - 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

Local Multipoint Distribution Service (LMDS) (continued)

- Disadvantages of LMDS
  - LMDS requires a direct line of sight between buildings
  - LMDS signals are susceptible to interference from rain and fog

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

Multichannel Multipoint Distribution Service (MMDS) (continued)

- Layout
  - 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)

Multichannel Multipoint Distribution Service (MMDS) (continued)

- Layout (continued)
  - 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
    - Modem can connect to a single computer or an LAN

Multichannel Multipoint Distribution Service (MMDS) (continued)

Figure 9-11 Pizza box antenna

Multichannel Multipoint Distribution Service (MMDS) (continued)

Figure 9-12 MMDS infrastructure

Multichannel Multipoint Distribution Service (MMDS) (continued)

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

IEEE 802.16 (WiMAX)

- Standard for wireless broadband metropolitan area networks
- 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)
- WiMAX Forum
  - Promotes the implementation of 802.16 by testing and certifying equipment
- WiMAX stands for worldwide interoperability for microwave access

WiMAX Applications

- Applications
  - Suitable for backhaul applications for business
  - Last mile delivery applications
  - Supports simultaneous voice, video, and data transmission
  - 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

WiMAX Applications (continued)

- Applications (continued)
  - WiMAX CPE devices will support TV (video), telephone (voice), and data on the same network
- WiMAX MAC layer makes it easy for carriers to deploy the network
- Range of a WiMAX network is measured in miles
- Cellular phone operators can easily incorporate WiMAX networks

Standards Family Overview

- 802.16-2001 and 802.16-2004 standards
  - Define the interface specification for fixed, point-to-multipoint broadband WMANs
- 802.16a
  - Supports systems in the 2 GHz to 11 GHz band
- 802.16c
  - Provided clarifications related to performance evaluation and testing
- 802.16e
  - Defines specifications for a *mobile* version of WiMAX

WiMAX Protocol Stack

- PHY layer supports multiple frequency bands and several modulation techniques
- 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, and VLAN

WiMAX Protocol Stack (continued)

Figure 9-13 802.16 protocol stack

WiMAX Protocol Stack (continued)

- PHY layer
  - Five 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
    - Subframes are further divided into a series of time slots
    - Burst is a data transmission to or from a single device
    - Use time division duplexing (TDD)

WiMAX Protocol Stack (continued)

Figure 9-14 WiMAX TDD frame

WiMAX Protocol Stack (continued)

- PHY layer (continued)
  - WiMAX allows two different frequency channels
    - Frequency division duplexing (FDD)
  - WiMAX can support half-duplex and full-duplex equipment
  - Variations of the PHY layer specified in the standard
    - WirelessMAN-SC (single carrier)
    - WirelessMAN-SCa (single-carrier access)
  - 802.16 standard also provides support for non-line-of-sight applications

WiMAX Protocol Stack (continued)

Figure 9-15 Non-line-of-sight

WiMAX Protocol Stack (continued)

- PHY layer (continued)
  - Additional PHY layer transmission mechanisms to support NLOS applications
    - WirelessMAN-OFDM
      - Uses TDMA
    - WirelessMAN-OFDMA
      - Divides the available channel into a large number of orthogonal subcarriers
  - Third transmission mechanism
    - Wireless high-speed unlicensed metro area network (WirelessHUMAN)

WiMAX Protocol Stack (continued)

Table 9-2 WiMAX specifications summary

Designation	Frequencies	Application	Duplexing
WirelessMAN-SC	10-66 GHz licensed bands	Fixed only	TDD, FDD
WirelessMAN-SCa	Below 11 GHz licensed bands	Fixed or mobile (802.16e)	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	Below 11 GHz	Fixed or mesh	TDD only

WiMAX Protocol Stack (continued)

- Modulation and error correction
  - 802.16 uses forward error correction
  - 802.16 also uses automatic repeat requests (ARQ)
  - 802.16 dynamically changes modulations
  - Latency
    - Amount of time delay that it takes a packet to travel from source to destination device
  - 802.16 defines several transmission profiles
    - Sets of predefined connection parameters
  - System profiles are combination of the basic profile and one of the transmission profiles

WiMAX Protocol Stack (continued)

Table 9-3 802.16 modulations and mandatory FEC coding

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

WiMAX Protocol Stack (continued)

Figure 9-16 How WiMAX applies different modulations

WiMAX Protocol Stack (continued)

- 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

WiMAX Protocol Stack (continued)

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

WiMAX Protocol Stack (continued)

Table 9-4 Maximum WiMAX data rates (Mbps)

	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

WiMAX Protocol Stack (continued)

- MAC layer
  - Most wireless MAN implementations function in 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

WiMAX Protocol Stack (continued)

- MAC layer (continued)
  - 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

WiMAX Protocol Stack (continued)

Figure 9-17 802.16 (WiMAX) MAC frame

WiMAX Coexistence

- As the number of transmitters grows, so does interference
- WiMAX is not limited to the 2.4 GHz or the 5 GHz bands
- U-NII band offers 12 channels and about 300 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

WMAN Security

- Security in WMANs is a major concern
- FSO systems are generally considered secure
  - 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

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
- Components in the privacy sublayer
  - An encapsulation protocol for encrypting packet data
  - A privacy key management protocol that provides secure key distribution

WiMAX Security (continued)

- 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
  - RSA with 1024-bit key
  - AES with 128-bit key

Summary

- WMANs are a group of technologies
  - Provide wireless connectivity throughout an area such as a city without cable infrastructure
- 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)

Summary (continued)

- 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
  - Bring 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

Summary (continued)

- Variations of the WiMAX PHY layers for point-to-point connections:
  - WirelessMAN-SC
  - WirelessMAN-OFDM
- OFDM and OFDMA in 802.16 are scalable
- WiMAX transmission profile
  - Specifies the frequency channel, bandwidth, and transmission mechanism
- MAC layer is the key to the intelligence and security behind WiMAX