

15-496 : A Hand-on Introduction to Wireless Networks

Lecture 9: Cellular and WIMAX

Peter Steenkiste
Departments of Computer Science and
Electrical and Computer Engineering
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<http://www.cs.cmu.edu/~prs/wireless08/>

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Outline

- 802 protocol overview
- Wireless LANs – 802.11
- Personal Area Networks – 802.15
- Wireless Access – 802.16
- Cellular technologies

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Overview

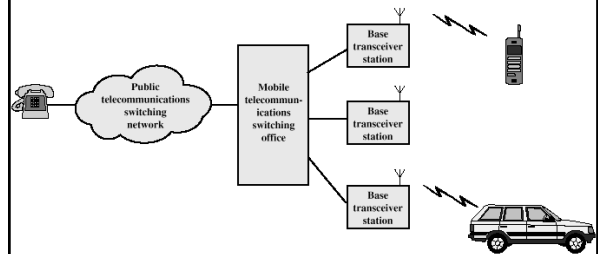
- Cellular overview
- First, second, third generation
- Local loop overview
- WiMax

- Need to add: UMTS as example of 3rd generation

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Cellular System Overview



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Cellular Systems Terms

- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
 - › Control channels – used to exchange information having to do with setting up and maintaining calls
 - › Traffic channels – carry voice or data connection between users

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Cellular Network Organization

- Use multiple low-power transmitters
 - › 100 W or less
- Areas divided into cells
 - › Each served by its own antenna
 - › Served by base station consisting of transmitter, receiver, and control unit
 - › Band of frequencies allocated
 - › Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

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Frequency Reuse

- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Ideally hexagonal cells to allow nice coverage
 - » But cannot be maintained perfectly in practice
 - » Limitation on tower placement, shadows, etc.
- Objective is to reuse frequency in nearby cells
 - » 10 to 50 frequencies assigned to each cell
 - » Transmission power controlled to limit power at that frequency escaping to adjacent cells
 - » The issue is to determine how many cells must intervene between two cells using the same frequency

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Approaches to Cope with Increasing Capacity

- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
 - » No new towers - directional antennas
- Microcells – antennas move to buildings, hills, and lamp posts

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Mobile Radio Propagation Effects

- Signal strength
 - » Must be strong enough between base station and mobile unit to maintain signal quality at the receiver
 - » Must not be so strong as to create too much co-channel interference with channels in another cell using the same frequency band
- Fading
 - » Signal propagation effects may disrupt the signal and cause errors

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Power Control

- Desirable to include dynamic power control in a cellular system
 - » Received power must be sufficiently above the background noise for effective communication
 - » Desirable to minimize power in the transmitted signal from the mobile
 - Reduce cochannel interference, alleviate health concerns, save battery power
 - » In SS systems using CDMA, it's desirable to equalize the received power level from all mobile units at the BS

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Types of Power Control

- Open-loop power control
 - » Depends solely on mobile unit
 - » No feedback from BS
 - » Not as accurate as closed-loop, but can react quicker to fluctuations in signal strength
- Closed-loop power control
 - » Adjusts signal strength in reverse channel based on metric of performance
 - » BS makes power adjustment decision and communicates to mobile on control channel

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Cellular Performance Metrics

- Cell blocking probability – probability of a new call being blocked
- Call dropping probability – probability that a call is terminated due to a handoff
- Call completion probability – probability that an admitted call is not dropped before it terminates
- Probability of unsuccessful handoff – probability that a handoff is executed while the reception conditions are inadequate

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Handoff Discussion

- **Complex procedure – several error modes**
 - » Lack of capacity, fading, ...
- **Many metrics to capture properties**
 - » Handoff propability, rate, etc.
 - » Handoff blocking probability, interrupt duration, handoff delay, ..
- **Different strategies used to manage handoff**
 - » Relative signal strength primary metric
 - » Can add threshold, hysteresis, predictive techniques, etc.

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Optimizing Performance

- Ideally, available channels would equal number of subscribers active at one time
- In practice, not feasible to have capacity handle all possible load
- Minimize probability that handoffs or new calls are blocked
 - » Blocked calls can be dropped or delayed
- What capacity is needed to achieve a certain upper bound on probability of blocking?
- Based on detailed historical statistics
 - » Rate of attempted calls, duration of the calls, ...

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First-Generation Analog

- **Advanced Mobile Phone Service (AMPS)**
 - » In North America, two 25-MHz bands allocated to AMPS
 - One for transmission from base to mobile unit
 - One for transmission from mobile unit to base
 - » Each band split in two to encourage competition
 - » Frequency reuse exploited across cells
- **Used analog transmission based on FM**
 - » Both for control and voice channels

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AMPS Operation

- Subscriber initiates call by keying in phone number and presses send key
- MTSO verifies number and authorizes user
- MTSO issues message to user's cell phone indicating send and receive traffic channels
- MTSO sends ringing signal to called party
- Party answers; MTSO establishes circuit and initiates billing information
- Either party hangs up; MTSO releases circuit, frees channels, completes billing

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Differences Between First and Second Generation Systems

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users
- Examples: Global System for Mobile Comm, CDMA

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Mobile Wireless TDMA Design Considerations

- Number of logical channels (number of time slots in TDMA frame): 8
- Maximum cell radius (R): ~35 km
- Frequency: region around 900 MHz
- Maximum vehicle speed (V_m): 250 km/hr
- Maximum coding delay: approx. 20 ms
- Maximum delay spread (Δ_m): 10 μ s
- Bandwidth: Not to exceed 200 kHz (25 kHz per channel)

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GSM Components

- Mobile equipment (ME) – physical terminal, such as a telephone or PCS
 - » ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)
 - » GSM subscriber units are generic until SIM is inserted
- BSS consists of base station controller and one or more base transceiver stations (BTS)
 - » Reserves radio frequencies, manages handoff of mobile unit from one cell to another within BSS
- Network subsystem provides link between cellular network and public switched telecom networks
 - » Controls handoffs between cells in different BSSs
 - » Authenticates users and validates accounts
 - » Enables worldwide roaming of mobile users

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Advantages of CDMA Cellular

- Frequency diversity – frequency-dependent transmission impairments have less effect on signal
- Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation
- Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- Graceful degradation – system only gradually degrades as more users access the system

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Drawbacks of CDMA Cellular

- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- Near-far problem – signals closer to the receiver are received with less attenuation than signals farther away
- Soft handoff – requires that the mobile acquires the new cell before it relinquishes the old; this is more complex than hard handoff used in FDMA and TDMA schemes

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ITU's View of Third-Generation Capabilities

- Voice quality comparable to the public switched telephone network
- 144 kbps data rate available to users in high-speed motor vehicles over large areas
- 384 kbps available to pedestrians standing or moving slowly over small areas
- Support for 2.048 Mbps for office use
- Symmetrical / asymmetrical data transmission rates
- Support for both packet switched and circuit switched data services

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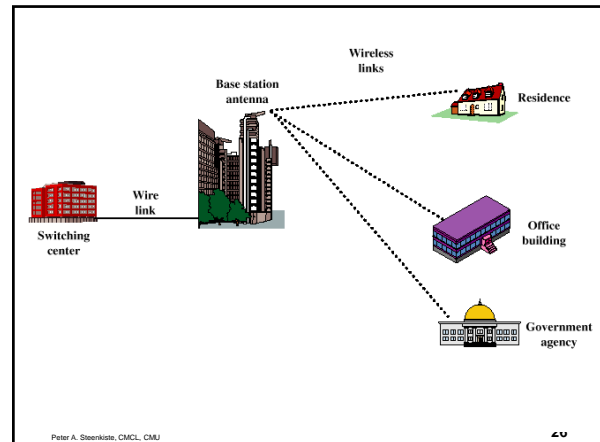
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Wireless Local Loop

- **Wired technologies** responding to need for reliable, high-speed access by residential, business, and government subscribers
 - » ISDN, xDSL, cable modems
- **Increasing interest** shown in competing wireless technologies for subscriber access
- **Wireless local loop (WLL)**
 - » Narrowband – offers a replacement for existing telephony services
 - » Broadband – provides high-speed two-way voice and data service

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Advantages of WLL over Wired Approach

- **Cost** – wireless systems are less expensive due to reduced cost of cable installation
- **Installation time** – WLL systems can be installed in a small fraction of the time required for a new wired system
- **Incremental installation** – radio units installed for subscribers who want service at a given time
 - » With wired system, cable is laid out in anticipation of serving all subscribers in an area
- **Competition** - compete with cable + DSL

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Propagation Considerations

- **Most high-speed WLL schemes** use millimeter wave frequencies (10 GHz to about 300 GHz)
 - » Wide unused frequency bands available above 25 GHz
 - » Wide channel bandwidths provide high data rates
 - » Small size transceivers and adaptive antenna arrays
- **Millimeter wave systems** have some undesirable propagation characteristics
 - » High loss in millimeter wave range
 - » Above 10 GHz, attenuation effects due to rainfall and atmospheric or gaseous absorption are large
 - » Multipath losses can be quite high
 - » Foliage can lead to high loss, variable multipath (wind)

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What is WiMax?

- **Worldwide Interoperability for Microwave Access**
- **Last mile wireless broadband access**
 - » Alternative to cable and DSL
 - » Deliver data, voice, video
 - » Support hundreds to thousands of homes/business
- **Defined by IEEE as 802.16**
- **Typical target environment:**
 - » Targets fixed, portable, and mobile stations
 - » Environments with and without line of sight
 - » Cell radius of 3-10 kilometers
 - » Capacities of up to 40 Mbps per channel
 - » Mobile network deployments of up to 15 Mbps, 3 km radius

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Builds on and Extends WiFi Technology

- **Advantages of WiFi are:**
 - » Easy to deploy, unlicensed spectrum, low cost
 - » Supports (limited) mobility
- **But WiMax needs to address the following WiFi limitations:**
 - » Susceptible to interference
 - » 802.11 targets short-range indoor operation (mostly)
 - » Security is a concern
 - » Limited level of mobility
- **WiMax is intended to complement WiFi**
- **WiMax Forum: promotes WiMax and looks after interoperability**

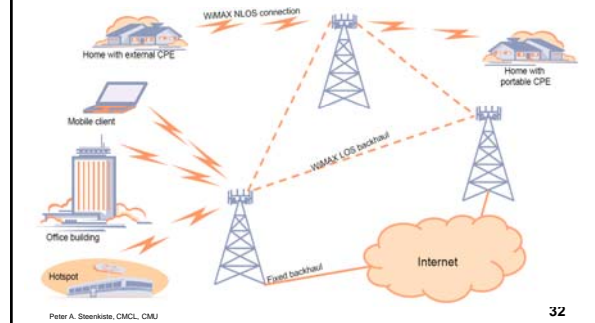
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IEEE 802.16 Standard

	802.16	802.16a/HiperMAN	802.16e
Completed	December 2001	January 2003 (802.16a)	December 2005
Spectrum	10 - 66 GHz	< 11 GHz	< 6 GHz
Channel Conditions	Line of Sight Only	Non Line of Sight	Non Line of Sight
Bit Rate	32 - 134 Mbps in 28MHz channel bandwidth	Up to 75 Mbps in 20MHz channel bandwidth	Up to 15 Mbps in 5MHz channel bandwidth
Modulation	QPSK, 16QAM and 64QAM	OFDM 256 sub-carriers QPSK, 16QAM, 64QAM	Same as 802.16a
Mobility	Fixed	Fixed, Portable	Nomadic Mobility
Channel Bandwidths	20, 25 and 28 MHz	Scalable 1.5 to 20 MHz	Same as 802.16a with UL sub-channels
Typical Cell Radius	2-5 km	7 to 10 km Max range 50 km	2-5 km

Envisioned WiMax Deployment



Types of Service

- **Non-LOS, Wi-Fi style service**
 - › Small antenna on a computer connects to the tower
 - › Uses lower frequency range (2 to 11 GHz).
- **LOS based on a fixed antenna pointed at the WiMax tower from a rooftop or pole**
 - › LOS connection should be stronger and more stable
 - › Higher bandwidth, fewer errors
 - › Larger range
 - › Uses higher frequencies, possibly as high as 66 GHz
- **WiMax Forum anticipates rollout in 3 phases:**
 - › Phase 1: Fixed Location, Private Line Services, Hot Spot Backhaul
 - › Phase 2: Broadband Wireless Access/Wireless DSL
 - › Phase 3: Mobile/Nomadic Users.

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WiMax Evolution

	Fixed access	Limited mobility	Full mobility
Dominating standard	IEEE 802.16-2004	IEEE 802.16e	
Services	Alternative to T1, DSL, cable Backhaul for cellular and Wi-Fi	Plus: VoIP, QoS-based applications; enterprise networking	Plus: mobile access with handoffs (data), some roaming and interworking
CPE form factor	External CPE	Desktop CPE	PCMCIA card
CPE price tag	\$500-\$300		\$100
Residential markets	Underserved areas	Initial deployments in competitive markets	Underserved and competitive markets, mobile users
Business markets	Underserved areas	Underserved and competitive areas	Underserved and competitive markets, mobile users
	2005	2006	2007

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WiMax Spectrum

- **WiMax Forum is focusing on 3 spectrum bands for global deployment:**
- **Unlicensed 5 GHz:**
 - › Includes bands between 5.25 and 5.85 GHz. In the upper 5 GHz band (5.725 - 5.850 GHz) many countries allow higher power output (4 Watts) that makes it attractive for WiMax applications
- **Licensed 3.5 GHz:**
 - › Bands between 3.4 and 3.6 GHz have been allocated for BWA in majority of countries
- **Licensed 2.5 GHz:**
 - › The bands between 2.5 and 2.6 GHz have been allocated in the US, Mexico, Brazil and in some SEA countries
 - › MDS: Multipoint Distribution Service (US)
 - › ITFS: Instructional Television Fixed Service (US)

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Benefits of Licensed and License-Exempt Solutions

Licensed Solution	License-Exempt Solution
Better QoS	Fast Rollout
Better NLOS reception at lower frequencies	Lower Costs
Higher barriers for entrance	More worldwide options

- Both use OFDM as the PHY layer
- **Creating bi-directional channels for uplink and downlink:**
 - › Licensed solutions use FDD
 - › License exempt solutions use TDD

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TDD Versus FDD

- **Time Division Duplex:**
 - › Single channel is used for uplink and downlink
 - › Usually used in unlicensed spectrum
 - › Flexible but cannot transmit and receive at same time
 - › Good for bursty, asymmetrical data applications, with varying traffic patterns
- **Frequency Division Duplex:**
 - › Separate channels for uplink and downlink
 - › Typically used in licensed spectrum
 - › Works well for predictable and symmetric traffic loads (e.g. voice)
 - › Equipment cost can be lower but spectrum use can be less efficient

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PHY Layer based on IEEE 802.16-2004

- **Based on OFDM over 256 carriers**
 - › Robust and multi-path resistant in both LOS and non-LOS contexts
 - › Can supports channels with diverse bandwidths
- **Employs adaptive Modulation and variable error correction encoding**
 - › Support subscribers in different locations
- **Includes supports for TDD and FDD**
 - › Can be adapted to different frequency bands in regions with different regulations

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MAC Layer

- **Based on scheduling of slots on both downlink and uplink**
 - › Connection oriented
 - › Efficient use of link
- **Lends itself to QoS support**
 - › Low latency, video, prioritized data
- **ARQ support**
 - › Helps hide wireless-induced errors
- **Adaptive modulation, power control**

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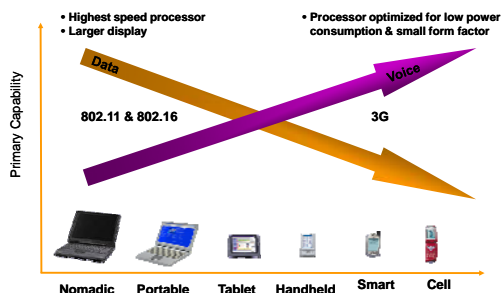
WiMax Mobility Issues

- **Device cost and availability may limit demand**
 - › How much data bandwidth do mobile users want?
- **Competing technologies have a time-to-market advantage**
 - › Many mobile operators have invested heavily in 3G systems
- **Multiple technologies will co-exist as they meet different needs**
- **Mobility may become a powerful differentiating factor when competing with DSL or Cable**
- **WiMax not meant to replace other wireless technologies**
 - › It will not replace Wi-Fi in the LAN
 - › Cellular technologies may still be needed for voice, data in WAN

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Wireless Device Continuum



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