Cellular Networks and WiMAX

CS 687
University of Kentucky
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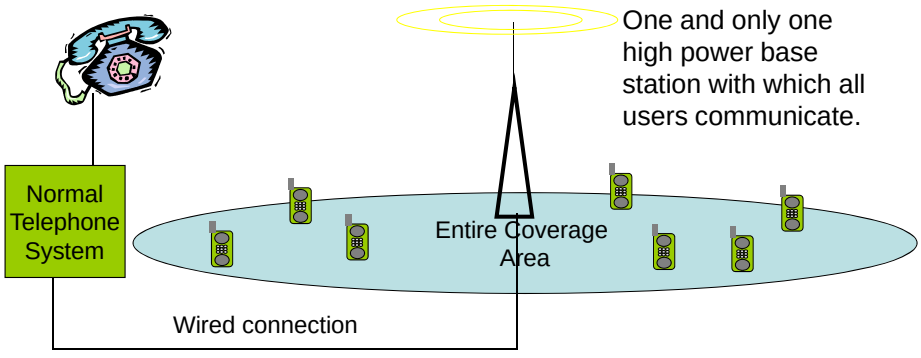
Cellular Networks

System Architecture

- A base station provides coverage (communication capabilities) to users on mobile phones within its coverage area.
- Users outside the coverage area receive/transmit signals with too low amplitude for reliable communications.
- Users within the coverage area transmit and receive signals from the base station.
- The base station itself is connected to the wired telephone network.

First Mobile Telephone System



Problem with Original Design

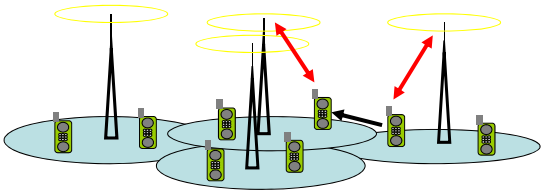
- Original mobile telephone system could only support a handful of users at a time…over an entire city!
- With only one high power base station, users phones also needed to be able to transmit at high powers (to reliably transmit signals to the distant base station).
- Car phones were therefore much more feasible than handheld phones, e.g., police car phones.

Improved Design

- Over the next few decades, researchers at AT&T Bell Labs developed the core ideas for today's cellular systems.
- Although these core ideas existed since the 60's, it was not until the 80's that electronic equipment became available to realize a cellular system.
- In the mid 80's the first generation of cellular systems was developed and deployed.

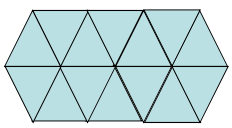
The Core Idea: Cellular Concept

- The core idea that led to today's system was the cellular concept.
- **The cellular concept**: multiple lower-power base stations that service mobile users within their coverage area and **handoff** users to neighboring base stations as users move. Together base stations **tessellate** the system coverage area.

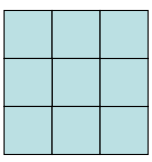


Tessellation (Cont'd)

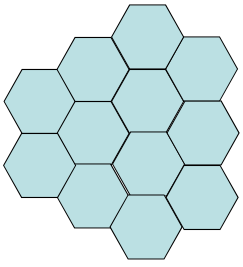
- Three regular polygons that always tessellate:
  - Equilateral triangle
  - Square
  - Regular Hexagon



Triangles



Squares



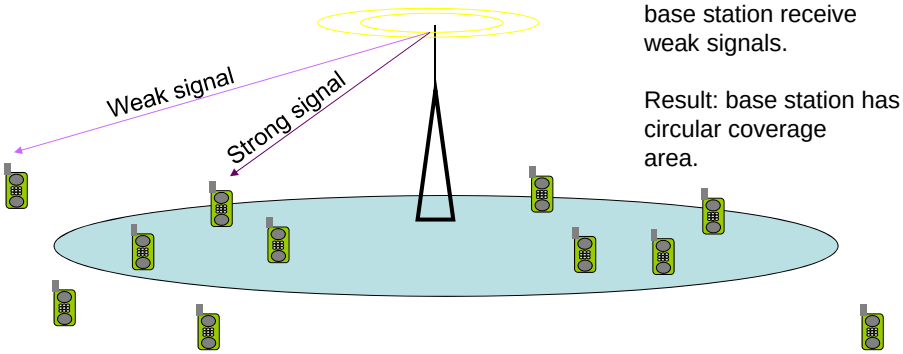
Hexagons

Circular Coverage Areas

- Original cellular system was developed assuming base station antennas are omnidirectional, i.e., they transmit in all directions equally.

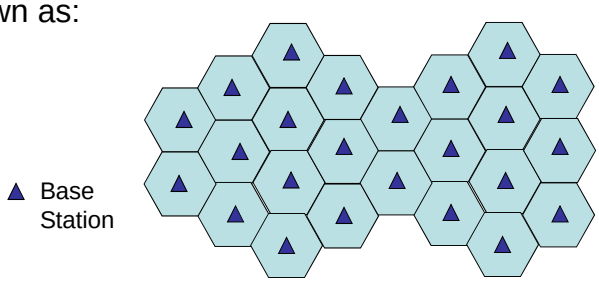
Users located outside some distance to the base station receive weak signals.

Result: base station has circular coverage area.



Thus the Name Cellular

- With hexagonal coverage area, a cellular network is drawn as:



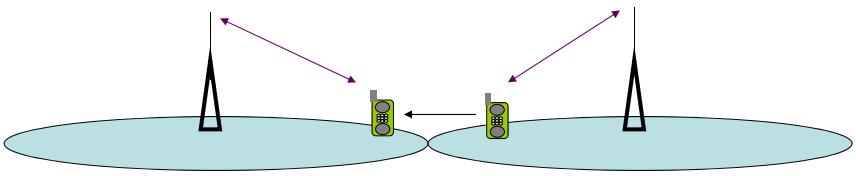
- Since the network resembles cells from a honeycomb, the name cellular was used to describe the resulting mobile telephone network.

Handoffs

- A crucial component of the cellular concept is the notion of handoffs.
- Mobile phone users are by definition mobile, i.e., they move around while using the phone.
- Thus, the network should be able to give them continuous access as they move.
- This is not a problem when users move within the same cell.
- When they move from one cell to another, a **handoff** is needed.

A Handoff (Cont'd)

- Assume that the user moves from B_1 to B_2
- At some point, the user's signal is weak enough at B_1 and strong enough at B_2 for a handoff to occur.
- Specifically, messages are exchanged between the user, B_1, and B_2 so that communication to/from the user is transferred from B_1 to B_2.



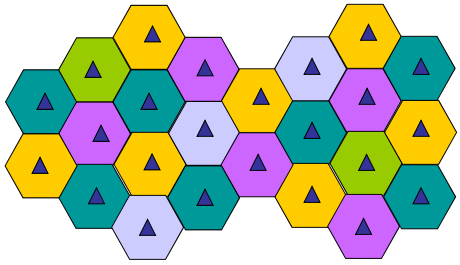
Frequency Reuse

- Extensive frequency reuse allows for many users to be supported at the same time.
- Total spectrum allocated to the service provider is broken up into smaller bands.
- A cell is assigned one of these bands. This means all communications (transmissions to and from users) in this cell occur over these frequencies only.

Frequency Reuse (Cont'd)

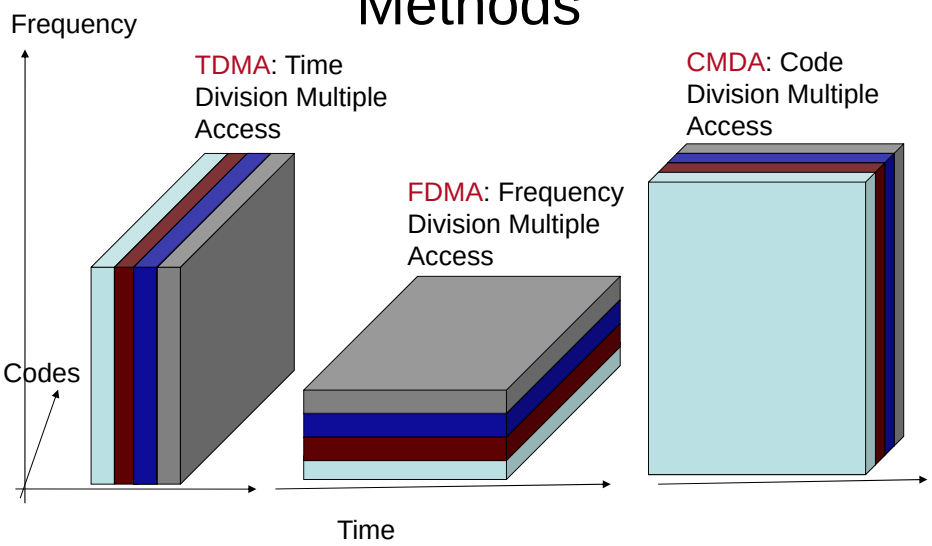
- Neighboring cells are assigned a different frequency band.
- This ensures that nearby transmissions do not interfere with each other.
- The same frequency band is reused in another cell that is far away. This large distance limits the interference caused by this co-frequency cell.
- More on frequency reuse a bit later.

Example of Frequency Reuse



Cells with the same colors using the same frequencies

Basics: Multiple Access Methods

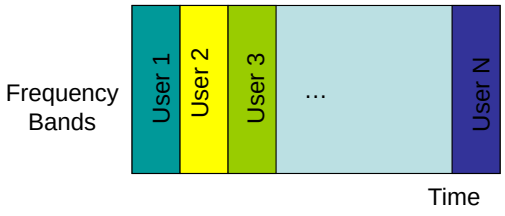


FDMA

- A subband is also a range of continuous frequencies, e.g., 824 MHz to 824.1 MHz. The width of this subband is 0.1 MHz = 100 KHz.
- When a users is assigned a subband, it transmits to the base station using a sine wave with the **center frequency** in that band, e.g., 824.05 MHz.

TDMA

- In pure TDMA, base station does not split up its allotted frequency band into smaller frequency subbands.
- Rather it communicates with the users one-at-a-time, i.e., “round robin” access.

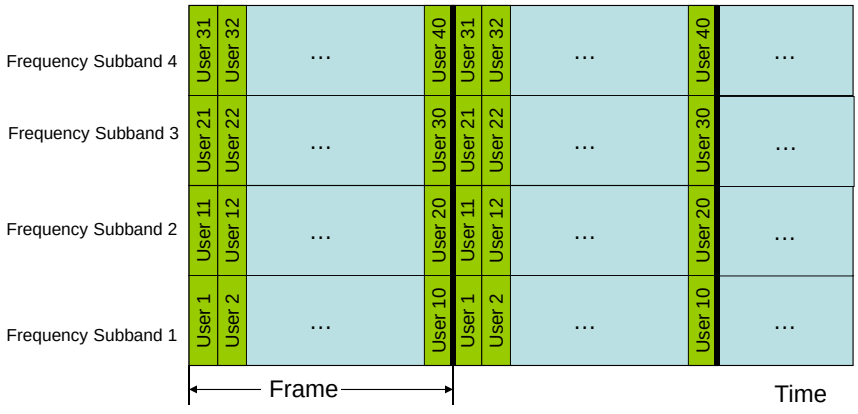


Hybrid FDMA/TDMA

- The TDMA used by real cellular systems (like AT&T's) is actually a combination of FDMA/TDMA.
- Base station breaks up its total frequency band into smaller subbands.
- Base station also divides time into slots and frames.
- Each user is now assigned a frequency and a time slot in the frame.

Hybrid FDMA/TDMA (Cont'd)

Assume a base station divides its frequency band into 4 subbands and time into 10 slots per frame.



CDMA

- Here all users communicate to the receiver at the same time and using the same set of frequencies.
- This means they may interfere with each other.
- The system is designed to control this interference.
- A desired user's signal is deciphered using a unique code assigned to the user.

- There are two types of CDMA methods.

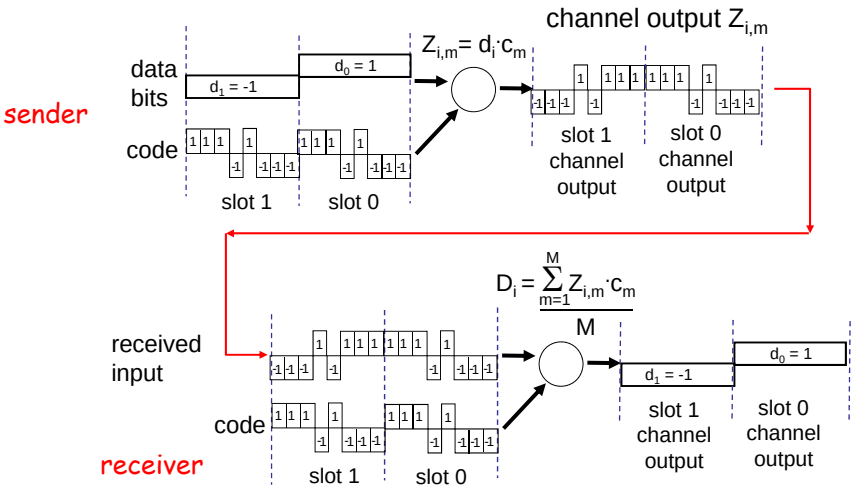
CDMA Method 1: Frequency Hopping

- First CDMA technique is called frequency hopping.
- In this method each user is assigned a frequency hopping pattern, i.e., a fixed sequence of frequency values.
- Time is divided into slots.
- In the first time slot, a given user transmit to the base station using the first frequency in its frequency hopping sequence.
- In the next time interval, it transmits using the second frequency value in its frequency hop sequence, and so on.
- This way, the transmit frequency keeps changing in time.

Second Type of CDMA: Direct Sequence

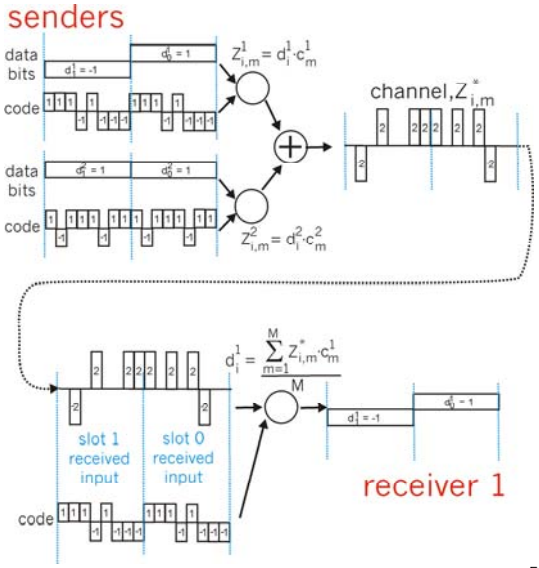
- Basically, each in-cell user transmits its message to the base station using the same frequency, at the same time. Here signals from different users interfere with each other.
- But the user distinguishes its message by using a special, unique code. This code serves as a special language that only the transmitter and receiver understand. Others cannot decipher this language.

CDMA Encode/Decode



From Kurose and Ross,
Computer Networking: A Top-Down Approach.

CDMA: two-sender interference



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Computer Networking: A Top-Down Approach.

Channels

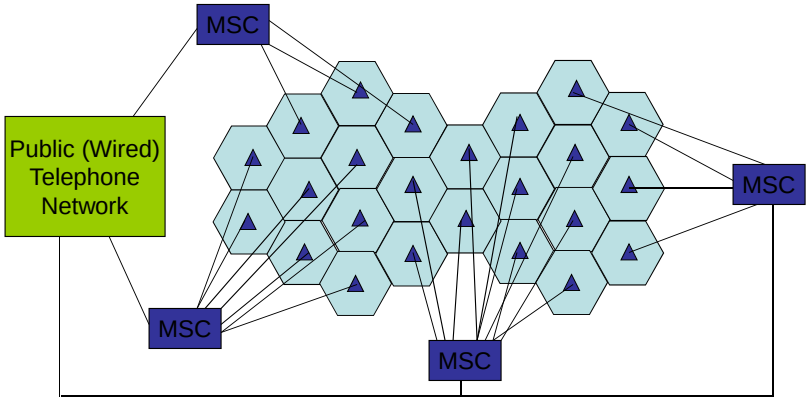
- Channel is a general term which refers to a frequency in an FDMA system, a timeslot/frequency combination in TDMA, or a code in CDMA.
- This way, a base station has a fixed number of channels and can support only that many simultaneous users.

Cellular Network Technology Evolution

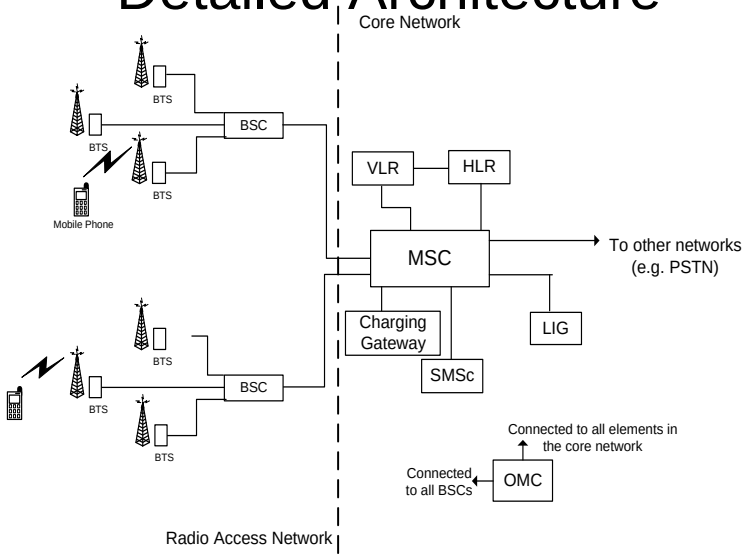
- The first generation (1G) uses analog signal.
  - AMPS
- The second generation (2G) uses digital technology and provided enhanced services (e.g., messaging, caller-id, etc.).
  - Two U.S. standards: Interim Standard 136 (IS-136) based on TDMA, and IS-95 based on CDMA.
  - European standard: Global System Mobile Communications (GSM)
- 2.5G offers enhanced services over second generation systems (emailing, web-browsing, etc.).
  - GPRS, EDGE
- 3G offers higher data rates than 2.5G. This allows users to send/receive pictures, video clips, etc. (up to 3.1Mbps)
  - Wideband CDMA (WCDMA, UMTS) and CDMA 2000 EVDO/EVDV. These two standards have been adopted world-wide.
- 4G (practically 3-5Mbps, target over 100Mbps)
  - Long term Evolution (LTE), LTE-advanced
  - Worldwide Interoperability for Microwave Access (WiMAX), WiMax 2

Complete Cellular Network

A group of local base stations are connected (by wires) to a mobile switching center (MSC). MSC is connected to the rest of the world (normal telephone system).



Detailed Architecture



Mobile Switching Centers

- Mobile switching centers control and coordinate the cellular network.

- They serve as intermediary between base stations that may be handing off users between each other.
- Base stations communicate with each other via the MSC.
- MSC keep track of cell phone user subscription.
- MSC connects to the wired phone network (rest of the world).

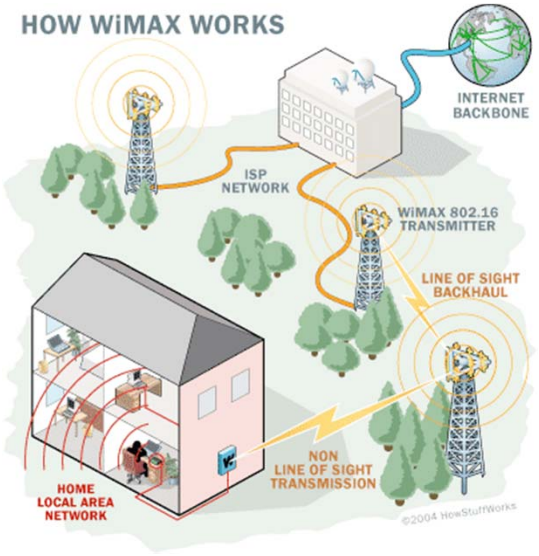
Roaming

- When a mobile is on, it sends a registration message to the local MSC, which includes unique identification for the mobile.
- The identification allows the MSC to identify the HLR to which the mobile belongs.
- The MSC sends a registration message to the HLR to notify that the mobile is being served.
- The HLR sends a cancellation message to the MSC that was previously serving the mobile.
- The HLR sends a confirmation to the MSC that is serving the mobile.

WiMAX

Why WiMax?

- 2G and 3G cellular infrastructure is optimized to carry circuit switched voice traffic.
- Mobile WiMAX is technology that claims to meet the demand for personal broadband services now.
- Mobile WiMax could support peak downlink data rates up to 63 Mbps per sector and peak uplink data rates up to 28 Mbps per sector in a 10 MHz channel.



Basics

- A WiMAX tower station can connect directly to the Internet using a high-bandwidth, wired connection (for example, a T3 line).
- It can also connect to another WiMAX tower using a line-of-sight, microwave link. This connection to a second tower (often referred to as a **backhaul**), along with the ability of a single tower to cover up to 3,000 square miles, is what allows WiMAX to provide coverage to remote rural areas.
- WiMAX actually can provide two forms of wireless service.

2 Types of Service

- **Non-line-of-sight service**: WiFi-like. Small antenna on computer connects to the tower. In this mode, Uses a lower frequency range -- 2 GHz to 11 GHz (similar to WiFi). Limited to a 4-to-6 mile radius (similar in range to a cell-phone zone).

- L**ine-of-sight service**: Fixed dish antenna points straight at the WiMAX tower from a rooftop or pole. Line-of-sight connection is stronger and more stable, so able to send a lot of data with fewer errors. Line-of-sight transmissions use higher frequencies, with ranges reaching a possible 66 GHz. The radius is 30 miles.

Uses for WiMAX

- The bandwidth and range of WiMAX make it suitable for the following potential applications:
  - Connecting Wi-Fi hotspots to the Internet.
  - Providing a wireless alternative to cable and DSL for "last mile" broadband access.
  - Providing data and telecommunications services.
  - Providing a source of Internet connectivity as part of a business continuity plan. That is, if a business has both a fixed and a wireless Internet connection, especially from unrelated providers, they are unlikely to be affected by the same service outage.
  - Providing portable connectivity.

Some Basics

- Based on all-IP core network, that offers low latency, advanced security, QoS (Quality of Service), and worldwide roaming capabilities.
- Service providers also benefit from low costs due to open standards (i.e., IEEE 802.16), vendor interoperability, and favorable Intellectual Property Rights.
- All parties participating in WiMax standards process join a licensing program with goal of creating a portfolio of essential 802.16 technology that can be offered to companies at a single license price.
- This licensing program would offer patents "under fair, reasonable, and nondiscriminatory terms."

WiMax vs Cellular

- WiMAX will coexist and interwork with existing and emerging technologies, both wired and wireless.
- Even though it can support Voice over IP (VoIP), WiMAX will not replace or compete with 2G or 3G for voice.
- WiMAX was however meant to compete with cellular (and other broadband technologies) for high-speed data communications.
- 3G networks cover many urban and suburban areas, but not offer sufficient capacity for data applications.

WiMAX vs Broadband Internet Access

- Some believe WiMAX has the potential to do to broadband Internet access what cell phones have done to phone access.
- In the same way that many people have given up their "land lines" in favor of cell phones, WiMAX could replace cable and DSL services, providing universal Internet access just about anywhere you go.
- WiMAX will also be as painless as WiFi -- turning your computer on will automatically connect you to the closest available WiMAX antenna.

Comparing Wi-Fi & Wi-MAX

- WiMAX and Wi-Fi are complementary and are expected to be incorporated in dual-mode chipsets in mobile devices. WiMAX provides wider coverage; Wi-Fi is better suited for high-throughput, indoor applications
- WiMAX is a long range system, covering many kilometers, that uses licensed /unlicensed spectrum to deliver a point-to-point connection to the Internet.
- Different 802.16 standards provide different types of access, from portable (similar to a cordless phone) to fixed (an alternative to wired access, where end user's wireless termination point is fixed in location.)
- Wi-Fi uses unlicensed spectrum and is more popular in end user devices.

More Comparisons to Wi-Fi

- WiMAX and Wi-Fi have quite different quality of service (QoS) mechanisms.
- Wi-Fi runs on CSMA/CA protocol, which is connectionless and contention based, whereas WiMAX can also run a connection-oriented MAC.
- Both 802.11 and 802.16 define Peer-to-Peer (P2P) and ad hoc networks, where an end user communicates to users or servers on another LAN using its access point or base station.

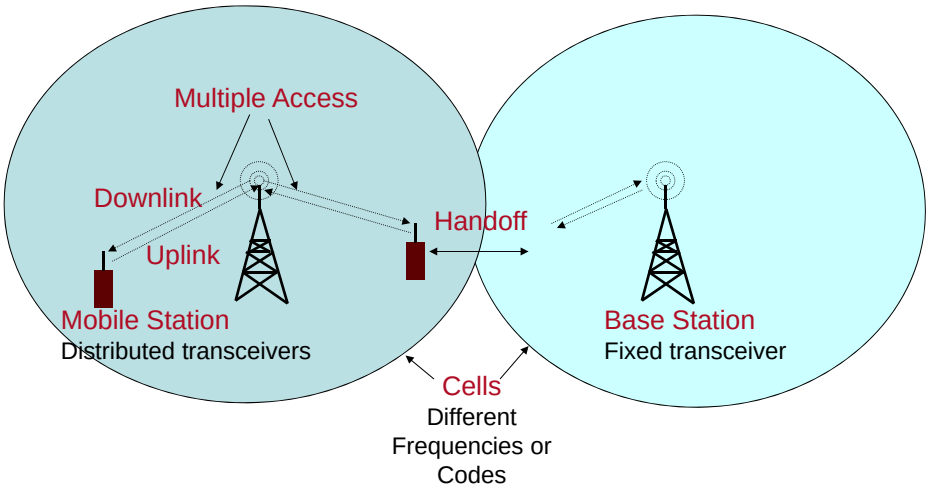
When WiMax?

- Products compliant with first fixed WiMAX certification profiles were released in Jan. 2006.
- Mobile WiMAX is based on IEEE 802.16e-2005 and will initially operate in 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.4-3.8 GHz bands. Support for additional bands will be added on basis of market demand and new spectrum allocations. (Channel sizes range from 3 to 10 MHz.) Became available at end of 2007.
- WiMAX market is still relatively small — the equipment and device market in the fourth quarter of 2008 was $275 million, and the number of WiMAX subscribers is only at 3.9 million — but it's set to grow to 85 million subscribers by the end of 2013.
  - Clearwire
  - Sprint
- 802.16 Reference Model

More Basics

- Uses Orthogonal Frequency Division Multiple Access (OFDMA), a multiplexing technique well suited to multipath environments that gives network operators higher throughput and capacity.
- WiMAX performance is further enhanced by the use of Time Division Duplex (TDD), but it can also support Frequency Division Duplex (FDD).
- For IP-based services use of a single channel for the uplink and the downlink (i.e., TDD) makes it substantially less complex and more cost-effective to implement advanced features (e.g., MIMO and beamforming).

TDD vs FDD



TDD vs FDD

- Uplink & Downlink separated in
  - Time: Time Division Duplex (TDD)
    - where the uplink and downlink transmissions use the same radio frequency with synchronized time intervals.
  - Frequency: Frequency Division Duplex (FDD)
    - where the uplink and downlink transmissions use two separated radio frequencies.

OFDM

- Orthogonal Frequency Division Multiplexing (OFDM) is a *multiplexing* technique that subdivides bandwidth into multiple frequency sub-carriers.
- In an OFDM system, input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier.
- Increased symbol duration improves robustness of OFDM to echoes in the wireless channel (multipaths).

OFDMA

- Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access/multiplexing scheme that provides multiplexing operation of data streams from multiple users onto the downlink sub-channels and uplink multiple access by means of uplink sub-channels.

Subcarriers

- “Logical” subcarriers because not all subcarriers are used for data transmissions.
- There are three types of sub-carriers
  - Data sub-carriers for data transmission (sub-carriers over which multiple users are supported)
  - Pilot sub-carriers for estimation and synchronization purposes
  - Null sub-carriers for no transmission

Mobility Management

- Battery life and handoff are two critical issues for mobile applications.
- Mobile WiMax supports Sleep Mode and Idle Mode to enable power-efficient mobile station operation.
- Mobile WiMax also supports seamless handoff to enable the mobile station to switch from one base station to another at vehicular speeds without interrupting the connection.

Power Management

- Sleep Mode: MS conducts pre-negotiated periods of absence from the serving base station air interface.
- These periods are characterized by unavailability of MS (as observed from serving BS) to DL or UL traffic.
- Minimizes MS power usage and minimize usage of serving BS air interface resources.
- Also provides flexibility for MS to scan other BSs to collect information to assist handoff during sleep mode.

Power Management (Cont'd)

- Idle mode provides mechanism for MS to become periodically available for DL broadcast traffic messaging without registration at a specific BS as MS traverses an air link environment populated by multiple BSs.
- Idle Mode benefits MS by removing requirement for handoff and other normal operations.
- Benefits network and BS by eliminating air interface and network handoff traffic from essentially inactive MSs while still providing a simple and timely method (paging) for alerting MS about pending DL traffic.

Smart Grid Uses for WiMAX

- For smart metering, directly from customers to utilities.
- For backhaul portion of smart metering, i.e., low-rate network can relay smart metering information back to hubs, which then use WiMAX to communicate with substations. The substations relay the data using fiber optics.
- Can be used around major grid assets, like substations, to collect a lot of data from phasor units (monitor the grid reliability and collect information like voltage, current and frequency in real time).
- Could also be used to deliver services like mapping information and video tools for mobile workers, or provide video services for facility monitoring.

WiMAX & SG….thus far

- Some major current initiatives related to WiMAX and the Smart Grid:
  - GE says will work with utility company Consumers Energy to deliver WiMAX-based grid sensors and energy meters to more than 6 million customers in Michigan.
  - National Grid (2nd largest utility) will be testing out WiMAX gear provided by Alvarion, which can connect smart meters and distribution automation devices to the utilities' back office.
- San Diego Gas & Electric (SDG&E) has (?) stimulus funds to build a smart grid wireless network that would include about 30 percent of its network built with WiMAX.
- Southern California Edison (SCE) has also said it is looking at WiMAX for part of its smart grid network.
- Beyond utilities, General Electric, Intel and startup Grid Net have been the loudest voices for using WiMAX to connect smart meters.