

CPET 565/499
Mobile Computing Systems

Lecture 2

**Mobile Networking Communication
Infrastructures and Technologies**

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A Specialty Course for Purdue University's M.S. in Technology
Graduate Program

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**Mobile Wireless Networking Infrastructure &
Technologies**

- WAN : Wide Area Network
- MAN: Metro Area Network
- LAN: Local Area Network
- PAN: Personal Area Network
- Cellular Networks

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Mobile Networking & Communication Infrastructures

- Wireless Mobile Networking: An Introduction
 - Infrastructure Network Topology
 - Ad Hoc Network Topology
- Mobile Communication Infrastructures
 - 1G
 - 2G
 - 2.5G
 - 3G, 4G
 - Bluetooth, IrDA, IrFM, OMA (Open Mobile Alliance, <http://www.openmobilealliance.org/>) Device Management

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Wireless Networking Technologies

- Satellite (WAN)
- Microwave (MAN)
- WiMax - Broadband Wireless (MAN)
 - 802.16 standard
- Cellular network (WAN)
- Wireless LANs (WLAN) – Wi-Fi
 - 802.11 standards
- Bluetooth (Wireless PAN)
- IrDA (Infrared Data Association)
 - Wireless point-to-point PAN
- RFID
- Sensor Network
 - 802.15.4 Standard
 - ZigBee – a protocol for sensor network

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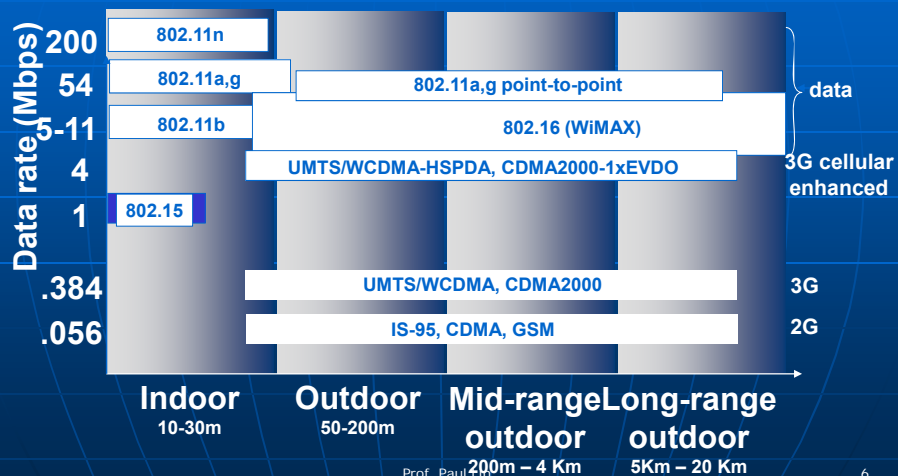
Wireless Networks

- IEEE 802.11 or WiFi
 - Wireless LANs – up to 100 meters
- IEEE 802.15
 - Bluetooth technology over short distance
- IEEE 802.16 or WiMax
 - WiMax – World Interoperability for Microwave Access
 - Provide wireless broadband service over longer distance
 - Aimed at support mobility at speeds at 70-80 miles per hour
- Wireless WANs
 - Cellular telephone networks
 - Satellite networks

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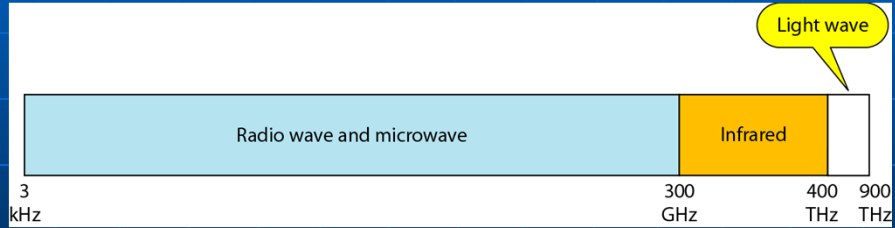
Characteristics of selected wireless link standards



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Electromagnetic spectrum for wireless communication

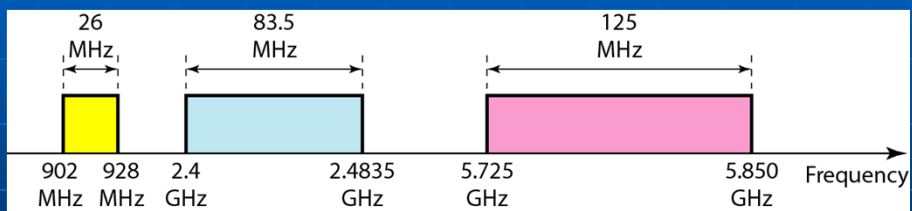


Source: Figure 7.17 of Data Communications and Networking by Forouzan, 4th

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Figure 14.14 Industrial, scientific, and medical (ISM) band



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Wireless: Problems

- Typically much slower than wired networks
 - “State of the art” wireless LAN: 54Mb/sec
 - Wired LAN: 10000Mb/sec+
- Higher transmission bit error rates (BER)
- Uncontrolled population
- Difficult to ensure Quality of Service (QoS)
- Asymmetric bandwidth
- Limited communication bandwidth aggravates the problem of limited battery life

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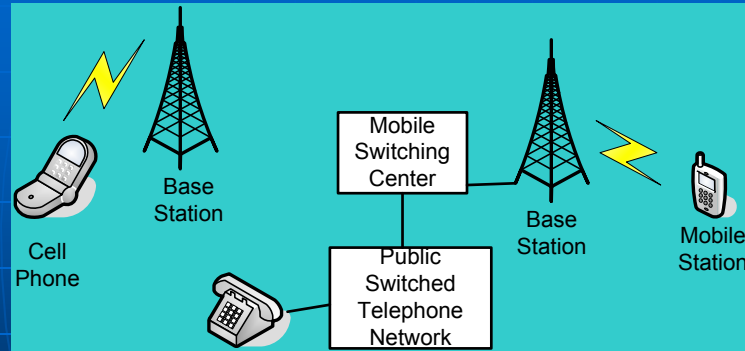
Cellular Phone Network

- Mobile Cellular Phone Communication Infrastructures
 - 1G
 - 2G
 - 2.5G
 - 3G
 - 4G

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Cellular Phone System



- List of Mobile Network Operators, http://en.wikipedia.org/wiki/List_of_mobile_network_operators

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Mobile Communication Infrastructures

- Mobile Communication Infrastructures
 - 1G Analog FM
 - 2G TDMA-FDMA/ CDMA (Code Division Multiple Access)
 - 2.5 G – extend 2G system by adding packet-switched connection
 - GPRS (General Packet Radio Service; for data packet service on GSM network)
 - EDGE (Enhanced Data GSM Evolution, up to 384 Kbps) - a transition to 3G by Cingular that used TDMA for 2G
 - Support WAP, search, directory services, etc
 - 3G
 - 4G

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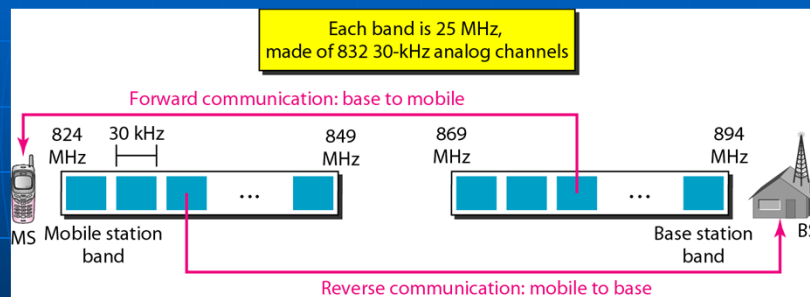
1st Generation Cellular Phone System

- **Advanced Mobile Phone Service (AMPS)**
 - Invented by Bells Labs and first installed in the U.S. in 1982
 - Analog FDMA (Frequency Division Multiple Access)
 - ISM 800-MHz band
 - Base Station → Mobile Station: forward communication channels (824-849 MHz: 25 MHz band)
 - Base Station ← Mobile Station: reverse communication channels (869-894 MHz: 25 MHz band)
 - Voice channel – Frequency modulation (30 kHz)
 - Control Channels - FSK (Frequency Shift Keying) – 10 kbps/30 kHz signal
 - No of Channels
 - 832 channels: 25 MHz / 30 kHz, can be shared by two providers
 - Each provider: 416 channels in each cell , 21 channels for control, 395 channels for voice
- **Frequency Reuse Factor**
 - Each cell uses some set of frequencies not used by any of its neighbors
 - Reuse factor 7

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Cellular bands for AMPS (Advanced Mobile Phone System)

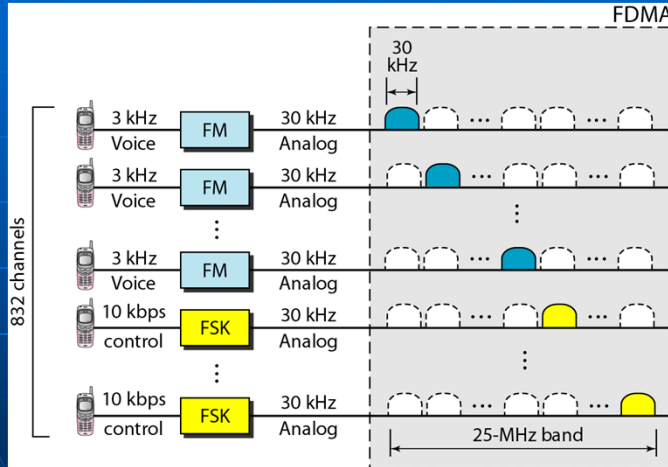


Source: From Figure 16.3 of Data Communications and Networking by Forouzan, 4th

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AMPS reverse communication band



From Figure 16.4 of Data Communications and Networking by Forouzan, 4th

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Frequency Reuse

- **Base Stations: Transmitter, Receiver, and Control Unit**
 - Adjacent cells are assigned different frequency bands to avoid interference
 - Cell sufficiently distant, D , from each other can use the same frequency band
 - $K = 10$ to 50 frequencies, assigned to each cell
- **Hexagonal pattern cell clustering**
 - Center-to-Center Distance $d = \sqrt{3} R$
 - Reuse Factor $N = I^2 + J^2 + (I \times J)$;
 - $I, J = 0, 1, 2, 3, \dots$
 - Possible $N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, \dots$
- $D/R = \sqrt{3} N \Rightarrow D/d = \sqrt{N}$



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Frequency Reuse Factor 4



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Frequency Reuse Factor 7



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2nd Generation Cellular Telephone System

- D-AMPS (Digital Advanced Mobile Phone System)
 - IS-136
 - TDMA-FDMA
- GSM (Global System for Mobile Communication)
 - TDMA-FDMA
- IS-95 CDMA (Code Division Multiple Access)
 - CDMA-FDMA

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Digital Advanced Mobile Phone System (D-AMPS)

- D-AMPS (Digital AMPS)
 - Backward compatible with AMPS: FDMA
 - First defined by IS-54 (Interim standard 54) and later revised by IS-136
 - TDMA (Time Division Multiple Access)/IS-136
 - Added to each sub-band
 - Triple the no. of channels
 - ISM 800 MHz band
 - 824-849 MHz range: Base station → Cellular phone (forward channels)
 - 869-894 MHz range: Cellular phone → Base station (reverse channels)

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D-AMPS (continue)

- Voice Signal Digitization
 - Digitizing: PCM (Pulse Code Modulation) and compression
 - 3 kHz → PCM Digitized → 7.95 kbps digital voice channel
- TDMA
 - 1 slot – 7.95 kbps
 - 3 slots: 48.6 kbps digital data: 3 x 7.95 kbps
 - Combined using TDMA
 - TDMA Frame [1 2 3 1 2 3]

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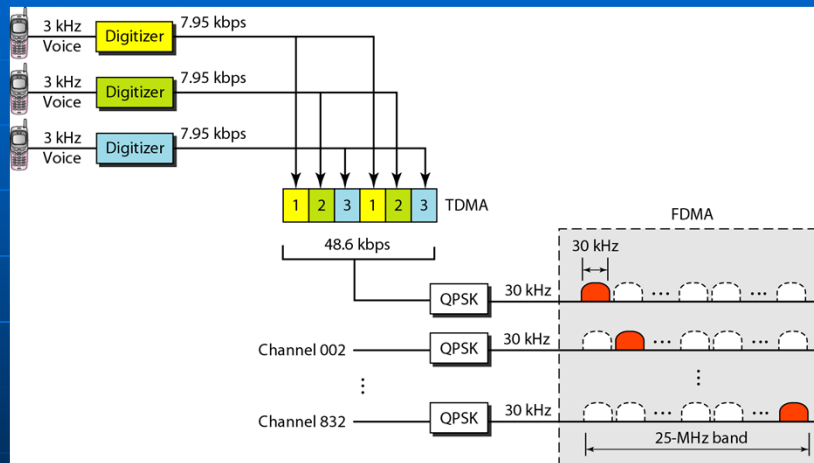
D-AMPS (continue)

- Digitized Voice Signal Transmission
 - 25 frames per second
 - 1944 bits per frame
 - Each frame last 40 ms (1/25) and is divided into 6 slots shared by three digital channels: TDMA [1 2 3 1 2 3]
 - Each channel: 2 slots
 - 324 bits per slot: 159 bits digitized voice, 64-bits control, 101-bits for error correction
- QPSK Modulation (Quadrature Phase-Shift Keying)
 - 48.6 kbps → QPSK Modulation → 30 kHz analog signal
- FDMA
 - 25 MHz band, 30 kHz analog signal
- Reuse Factor 7

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D-AMPS



Source: From Figure 16.6 of Data Communications and Networking by Forouzan, 4th

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GSM

- GSM (Global System for Mobile Communication)
 - Digital mobile telephony system launched in Finland in 1991
 - Use time division multiplexing (TDMA), Digitize and compress data
 - 900 MHz or 1800 MHz frequency band
 - SIM cards (Subscriber Identity Module)
 - Capture 82.4% of all global mobile connection
 - Widely used in Europe and Asia

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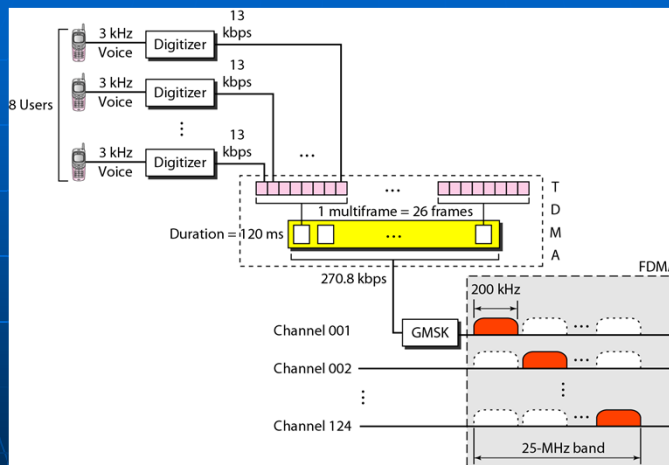
GSM (continue)

- Bands
 - 2 bands, each band 25 MHz
 - 124 Channels of 200 kHz separated by guard bands
- Transmission
 - Voice channel → Digitize + Compress → 13-kbps digital signal
 - 1 slot = 156.25 bit
 - 1 Frame (TDMA) = 8 slots; frame duration 120 ms
 - A Multi-frame = 26 frames (TDMA) = 270.8 kbps
 - 26 frames = 24 traffic frames + 2 control frames
 - 270.8 kbps → GMSK → 200 kHz signal (FDMA)
- Reuse Factor 3

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GSM



Source: Figure 16.8 of Data Communications and Networking by Forouzan, 4th

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3rd Generation Technologies

- A Combination of Technologies
 - Audio and Video
 - VoIP
 - Still & Moving Images
 - Digital Data
 - UMTS (Unified Mobile Telephone Service)
 - Enhanced multimedia: movie, images, music
 - Internet Surfing
 - Video telephony, Video conferencing
 - Always connected infrastructure

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3rd Generation Technologies

- IMT-2000 (Internet Mobile Communication 2000)
 - Voice quality (public telephone network)
 - Data rate
 - 144 kbps for access in a moving vehicle
 - 384 kbps for access as the user walks
 - 2 Mbps for stationary user (office or home)
 - Support packet-switched and circuit-switched data services
 - 2 GHz band
 - 2 MHz Bandwidth
 - Interface to Internet

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3rd Generation Technologies

- WCDMA (wideband CDMA)
 - Used by most GSM cellular providers
- CDMA2000
 - Code Division Multiple Access
 - Pioneered by Qualcomm
 - Used by most CDMA providers
 - Used by Verizon Wireless and Sprint

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Cell Telecom Technologies

- **GMS** (Global System for Mobile Communications): 2G digital cellular networks used by mobile phones, <http://en.wikipedia.org/wiki/GSM>
 - GPRS (General Packet Radio Services), 2G and 3G GSM, <http://en.wikipedia.org/wiki/GPRS>
 - EDGE (Enhanced Data Rates for GSM Evolution or EGPRS), single-carrier based on GSM, Pre-3G radio technology, <http://en.wikipedia.org/wiki/EDGE>
 - UMTS (3rd generation, 3G, Universal Mobile, Telecommunications System) – requires new base stations and new frequency allocation, <http://en.wikipedia.org/wiki/UMTS>
 - 4G LTE Advanced
- HSDPA (High Speed Downlink Packet Access, TDMA – Time Division Multiple Access)
- EV-DO (Evolution-Data Optimized data standard)
- iDEN (Integrated Digital Enhanced Network)

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Cell Telecom Technologies

- 4G, <http://en.wikipedia.org/wiki/4G>
- LTE (Long Term Evolution) Specification:
[http://en.wikipedia.org/wiki/LTE_\(telecommunication\)](http://en.wikipedia.org/wiki/LTE_(telecommunication))
 - Download link max 300 Mbits/sec, uplink peak rate 75 Mbits/sec
 - Transfer latency of less than 5 ms in the radio access network
 - 4G LTE (Long Term Evolution), based on GSM/EDGE and UMTS/HSPA network technologies
- Mobile WiMAX,
 - Worldwide Interoperability for Microwave Access
http://en.wikipedia.org/wiki/Mobile_WiMAX_Release_2

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Mobile Network Operators

- 4G LTE Networks
- AT&T,
<http://www.att.com/network/?view=technology&WT.srch=1&wtPaidSearchTerm=4g>
- Verizon Wireless,
<http://network4g.verizonwireless.com/>
- Sprint, 4G LET & WiMax,
<http://coverage.sprint.com/IMPACT.jsp>
- T-Mobile, <http://t-mobile-coverage.t-mobile.com/>

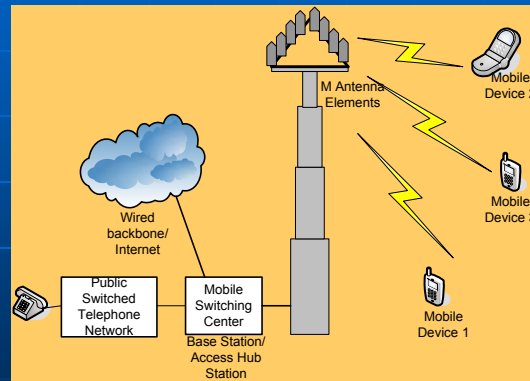
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Wireless Mobile Networking

■ Cellular Infrastructure Network Topology

- Fixed infrastructure with Wide Area Network coverage
- Mobile ↔ Mobile devices
- Mobile ↔ Fixed Computer Node
- Mobile device ↔ Servers



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Wireless Mobile Networking Architecture (GSM)

■ MS - Mobile Station

- ME - Mobile Equipment
- SIM (Subscriber Identification Module)

■ BSS (Base Station Subsystem)

- BTS – Base Transceiver Subsystem
- BSC – Base Station Controller

■ NSS (Network & Switching Subsystem)

- MSC – Mobile Switching Center
 - VLR – Visitor Location Register
 - HLR – Home Location Register
 - EIR – Equipment Identity Register
 - AuC - Authentication Center
- OMC – Operation Management center
- PSTN Interface (Public Switched Telephone Network)

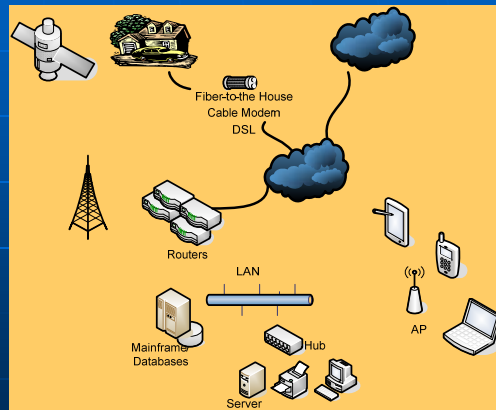
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Wireless Mobile Networking

■ Infrastructure Network Topology (WAN Access)

- Fiber-to-the-House, Cable Modem, DSL, Dial-up
- Wireless Access Points/Routers
- Wired Routers
- LAN, WLAN, WiMAX



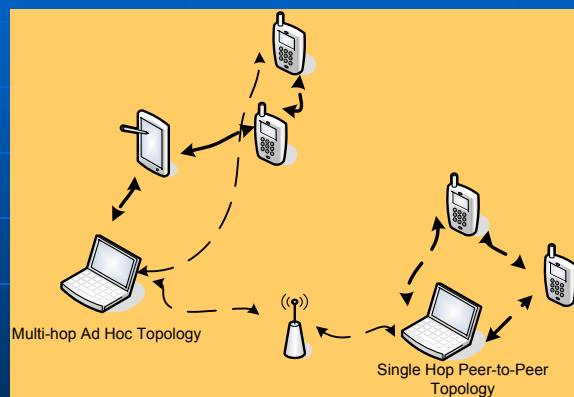
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Wireless Mobile Networking

■ Ad Hoc Network Topology

- Single-Hop Peer-to-Peer
- Multi-hop Ad Hoc Network



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Wireless Mobile Networking (cont.)

- Mobile Ad Hoc Networks (MANET) Routing Protocols
 - RFC2501, RFC3561, RFC3626
 - RFC3684
- MANET Charter,
<http://www.ietf.org/html.charters/manet-charter.html>,
<http://www3.ietf.org/proceedings/05mar/manet.html>
- MANET Internet Drafts,
<http://bgp.potaroo.net/ietf/html/ids-wg-manet.html>,
<http://ietfreport.isoc.org/ids-wg-manet.html>
- National Institute of Standards, MANET Projects,
<http://w3.antd.nist.gov/wctg/manet/manet.html>
- OPNET – MANET Discrete Event Simulation,
<http://www.opnet.com/products/library/MANET.html>

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Signal Modulation Techniques

- Mobile Communication Infrastructures
 - 1G Analog FM (Carrier modulation), FDMA (Frequency Division Multiple Access)
 - 2G TDMA (Time Division Multiple Access) + FDMA
- Digital Wireless Transmission Techniques
 - Impulse transmission
 - Infrared Pulse Transmission
 - UWB (Ultra Wideband), impulse radio
 - TDMA Cellular
 - CDMA (Code Division Multiple Access) - Spread Spectrum

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Signal Modulation Techniques (cont.)

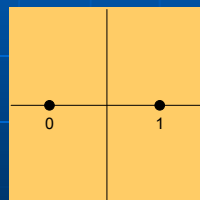
- Analog Modulation
 - Frequency Modulation (FM)
- Digital Frequency Modulation
 - Digital (0, 1) FM – Frequency Shift Keying (FSK)
 - GMSK (Gaussian Minimum Shift Keying)
 - FSK modulation with minimal tone distance of $1/2T$; T – the duration of transmitted data symbols
 - Data In \rightarrow Gaussian Filter \rightarrow FM modulator
 - Adopted by GSM

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Signal Modulation Techniques (cont.)

- Digital Phase Modulation (PSK)
 - B-PSK (Binary Phase Modulation)
 - [0, 1] – $(\cos 2\pi f_c t + 0^\circ)$, $(\cos 2\pi f_c t + 180^\circ)$



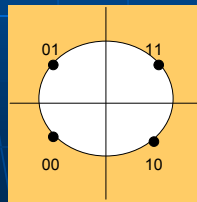
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Signal Modulation Techniques (cont.)

■ Digital Phase Modulation (PSK)

- QPSK (Quadrature PSK, 4 Phases)
- 11 – $(\cos 2\pi f_c t + 45^\circ)$
- 01 – $(\cos 2\pi f_c t + 135^\circ)$
- 00 – $(\cos 2\pi f_c t + 225^\circ)$ or $(\cos 2\pi f_c t - 135^\circ)$
- 10 – $(\cos 2\pi f_c t + 315^\circ)$ or $(\cos 2\pi f_c t - 45^\circ)$

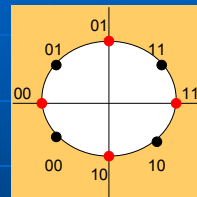


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Signal Modulation Techniques (cont.)

- $\pi/4$ -QPSK – adopted by the North American TDMA digital cellular standard, IS-136
- Two identical constellation – rotated by 45° or $\pi/4$ radians



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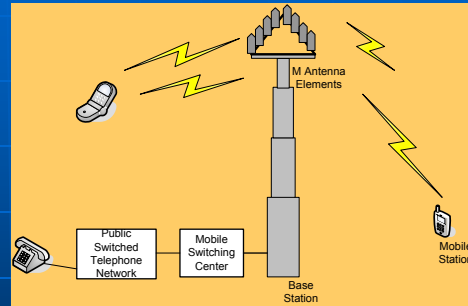
SIMO and MIMO Channels

- SIMO (Single Input Multiple Output) Radio Channel

- Complex receiver with adaptive smart antenna with M antenna elements

- MIMO (Multiple Input Multiple Output) Radio Channel

- N mobile antenna elements
- M base station antenna elements



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802.11 Details

- Medium-range wireless local area network technology
- 2.45GHz Industrial, Scientific, Medical (ISM) Band
- Old: 1Mb/sec , now: 2 - 54Mb/sec transmission speeds
- Older 1Mb/sec spec used Frequency Hopping Spread Spectrum (FHSS)
 - Units change frequency rapidly according to an agreed channel hopping sequence
 - Helps to reduce interference
- Higher data rates use Direct Sequence Spread Spectrum (DSSS) Radio
 - Units broadcast a broad, redundant signal that is resistant to interference
- US: 11 distinct channels (partially overlapping)
- Three channels (1, 6, 11) do not overlap at all

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802.11: Future

- Revisions to standards for security
- 802.1X / 802.11i (later)
- 802.11a: 54Mb/sec, 5GHz
- 802.11g: ~20Mb/sec, compatible w/ 802.11b
- 802.11a has more non-overlapping channels than 802.11b
 - 802.11b 3 non-overlapping channels
 - 802.11a channels do not overlap

Major Wireless Carriers

- AT&T, <http://www.att.com/#fbid=Z00S5jDcd1z>
 - Wireless, Digital TV, Internet, Home Phone
 - Small Business (less than 100 employees), Enterprise Businesses Services (> 100), <http://www.att.com/gen/landing-pages?pid=9214>
 - Government Agency, Wholesale
- Verizon, http://www22.verizon.com/home/verizonglobalhome/ghp_landing.aspx
- Sprint, <http://www.sprint.com/>
- T-Mobile, www.t-mobile.com