# CPET 565/499
# Mobile Computing Systems
## Lecture 2
## Mobile Networking Communication Infrastructures and Technologies

**Fall 2014**

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

**Paul I-Hai Lin, Professor**

**Dept. of Computer, Electrical and Information Technology**

**Purdue University Fort Wayne Campus**

---

# Mobile Wireless Networking Infrastructure & Technologies

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

1

## 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 LTE
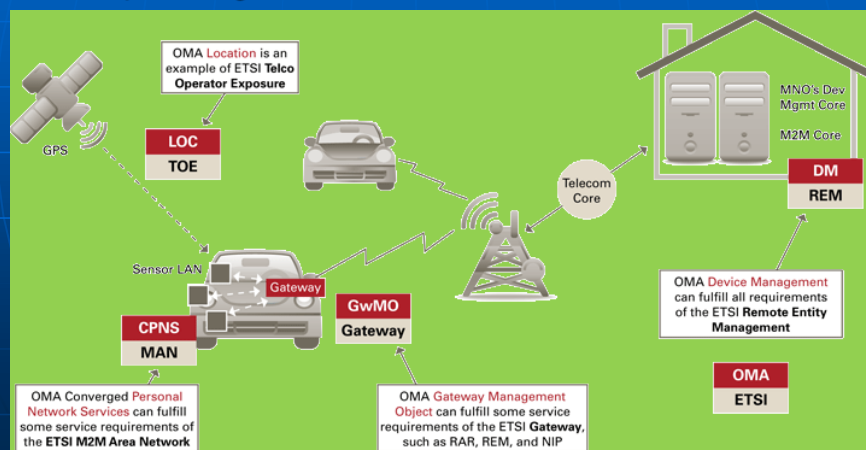  - Bluetooth, IrDA, IrFM, OMA (Open Mobile Alliance, http://www.openmobilealliance.org/) Device Management
    - Technology

Prof. Paul Lin

3

## OMA M2M (Machine-to-Machine) Enablers
http://openmobilealliance.org/about-oma/work-program/m2m-enablers/

- M2M White Paper, http://openmobilealliance.hs-sites.com/free-m2m-whitepaper-from-oma
- Example Usage

## Mobile Networking & Communication Infrastructures

- Alcatel-Lucent LightRadio Technology, http://www2.alcatel-lucent.com/techzine/lightradio-technology-overview/
- The Verizon Wireless 4G LTE Network: Transforming Next-Generation Technology, http://business.verizonwireless.com/content/dam/b2b/resources/LTE_Future MobileTech_WP.pdf
- AT&T 4G Network, https://www.wireless.att.com/businesscenter/built-for-business/network.jsp

## OMA M2M Enablers

http://openmobilealliance.org/about-oma/work-program/m2m-enablers/

- Arm's Presentation on LWM2M at Mobile World Congress
- M2M Device Management Spec, http://technical.openmobilealliance.org/Technical/technical-information/release-program/current-releases

## Wireless Networking Technologies

- Cellular network (WAN)
- Satellite (WAN)
- Microwave (MAN)
- WiMax - Broadband Wireless (MAN)
  - 802.16 standard
- 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
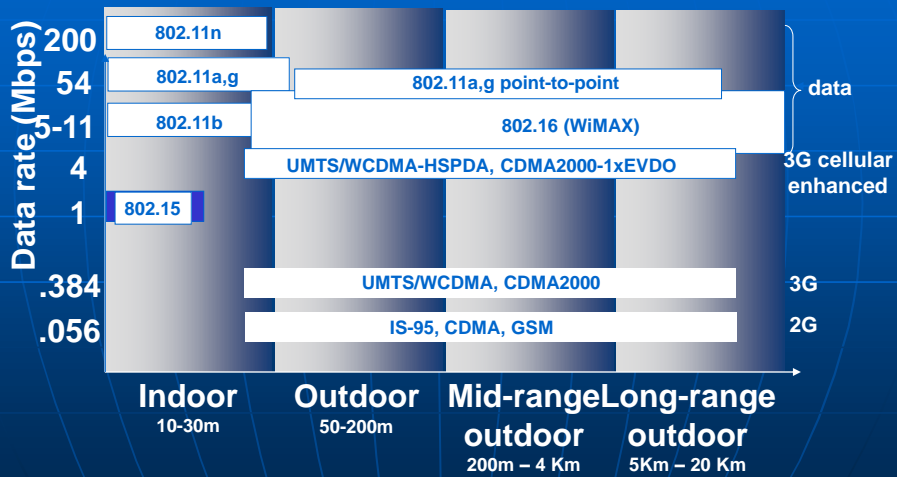  - ZigBee – a protocol for sensor network

## 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
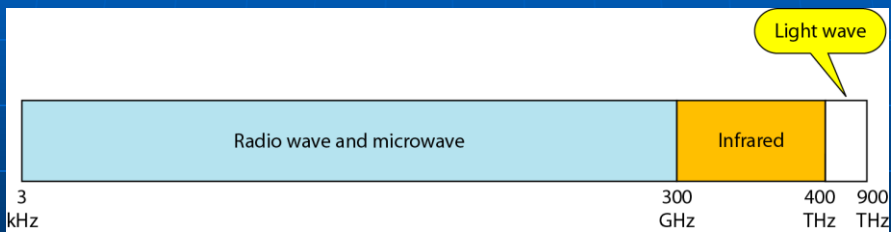  - Cellular telephone networks
  - Satellite networks

# Characteristics of selected wireless link standards

| Data rate (Mbps) | Indoor 10-30m | Outdoor 50-200m | Mid-range outdoor 200m – 4 Km | Long-range outdoor 5Km – 20 Km | |
|---|---|---|---|---|---|
| 200 | 802.11n | | | | data |
| 54 | 802.11a,g | 802.11a,g point-to-point | | | |
| 5-11 | 802.11b | 802.16 (WiMAX) | | | |
| 4 | | UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO | | | 3G cellular enhanced |
| 1 | 802.15 | | | | |
| .384 | | UMTS/WCDMA, CDMA2000 | | | 3G |
| .056 | | IS-95, CDMA, GSM | | | 2G |

# Electromagnetic spectrum for wireless communication

| Radio wave and microwave | | Infrared | Light wave |
|---|---|---|---|
| 3 kHz | 300 GHz | 400 THz | 900 THz |

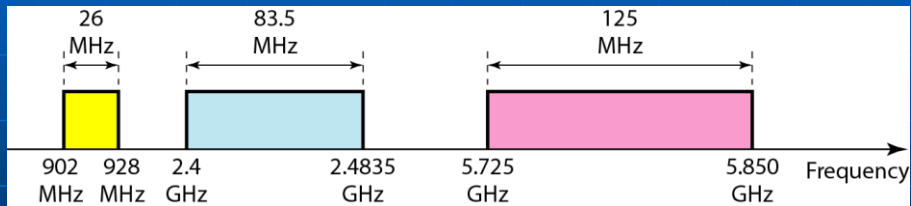**Source: Figure 7.17 of Data Communications and Networking by Forouzan, 4th**

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



Source: Figure 14.14 of Data Communications and Networking by Forouzan, 4th

## Wireless: Problems/Issues

- 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
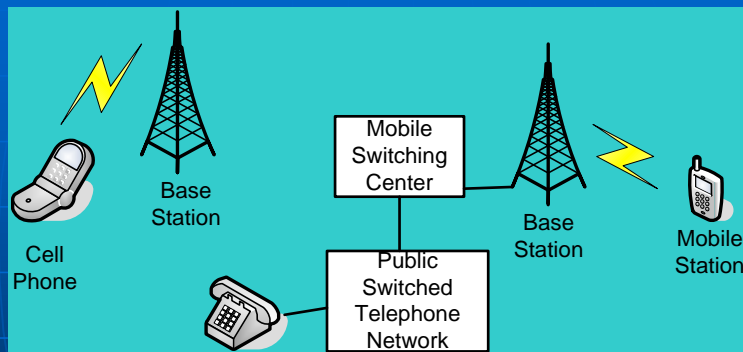- Limited communication bandwidth aggravates the problem of limited battery life

## Cellular Phone Network

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

## Cellular Phone System



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

## 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

## 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

# Cellular bands for AMPS
## (Advanced Mobile Phone System)



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

Prof. Paul Lin                                                                17

# AMPS Communication Band



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

Prof. Paul Lin                                                                18

9

## 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…**
    - **Possible N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, …**
- **D/R = $\sqrt{3}$ N  => D/d = $\sqrt{N}$**

---

## Frequency Reuse Factor 4

## Frequency Reuse Factor 7

## 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

## 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 Acceess)/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)

## 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 …]

# 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

# D-AMPS
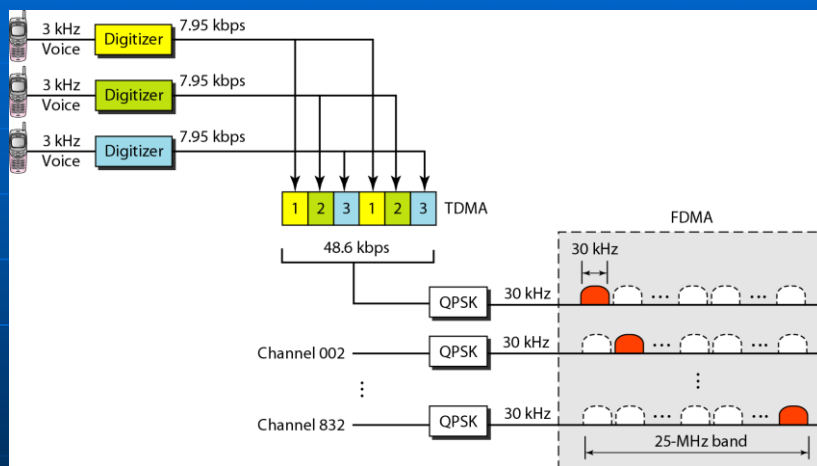


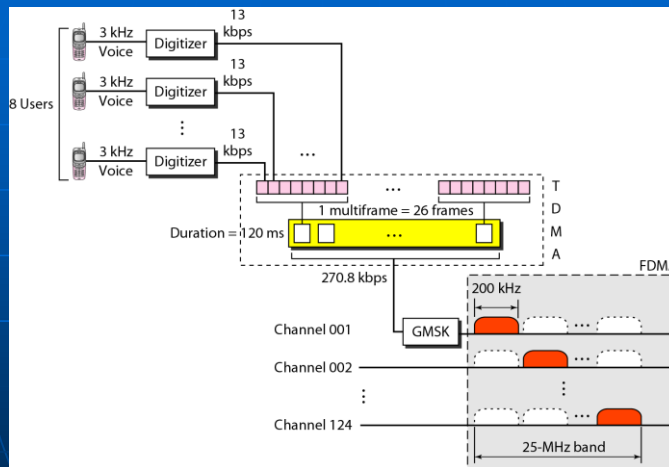**Source: From Figure 16.6 of Data Communications and Networking by Forouzan, 4th**

# 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

# 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

# GSM

Prof. Paul Lin

29

---

# 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

Prof. Paul Lin

30

15

# 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

# 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

## 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 (3 rd 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)

Prof. Paul Lin 33

## Cell Telecom Technologies

- 4G, http://en.wikipedia.org/wiki/4G
- LTE (Long Term Evolution) Specification: 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

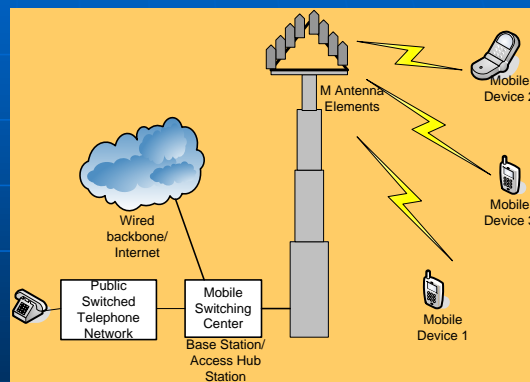Prof. Paul Lin 34

17

## 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/

## Wireless Mobile Networking

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

## 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)

---

## Wireless Mobile Networking

- Infrastructure Network Topology (WAN Access)
  - Fiber-to-the-House, Cable Modem, DSL, Dial-up
  - Wireless Access Points/Routers
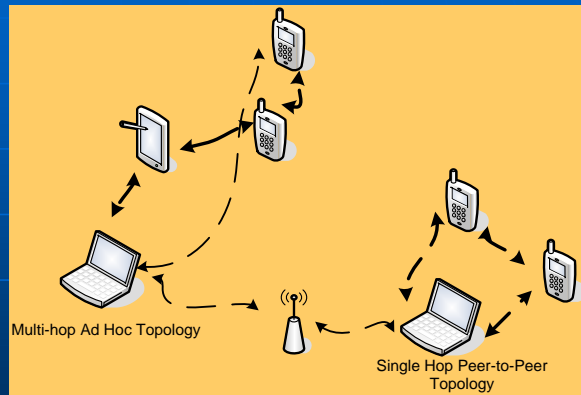  - Wired Routers
  - LAN, WLAN, WiMAX
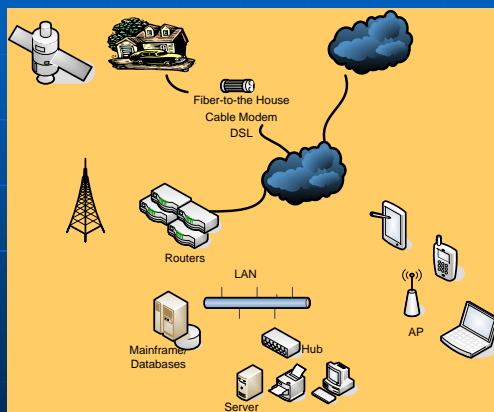
## Wireless Mobile Networking

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



Multi-hop Ad Hoc Topology

Single Hop Peer-to-Peer Topology

---

## 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
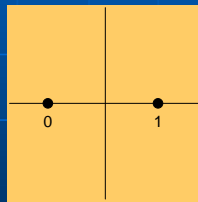
## Signal Modulation Techniques

- 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

## Signal Modulation Techniques (cont.)

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

## Signal Modulation Techniques (cont.)

- Digital Phase Modulation (PSK)
  - B-PSK (Binary Phase Modulation)
  - [0, 1] – (cos2π $f_c$ t + 0⁰), (cos2π $f_c$ t + 180⁰)

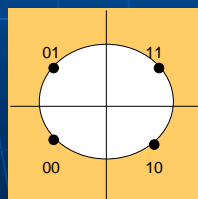## Signal Modulation Techniques (cont.)

- Digital Phase Modulation (PSK)
  - QPSK (Quadrature PSK, 4 Phases)
  - 11 – (cos2π $f_c$ t + 45⁰)
  - 01 - (cos2π $f_c$ t + 135⁰)
  - 00 – (cos2π $f_c$ t + 225⁰) or (cos2π $f_c$ t -135⁰)
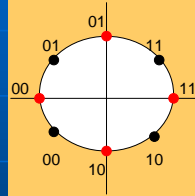  - 11 -  (cos2π $f_c$ t + 315⁰) or (cos2π $f_c$ t - 45⁰)

# Signal Modulation Techniques (cont.)

- π/4-QPSK – adopted by the North American TDMA digital cellular standard, IS-136
- Two identical constellation – rotated by 45⁰ or π/4 radians

# 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
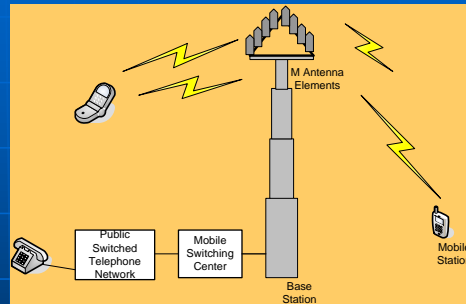
## 802.11 Details

- 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

## 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

## Other References

- 4G Statistics, http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=117
  - Infographics
  - Global Mobile Technology
  - America Mobile Technology
  - Technology Growth and Forecast
  - Global 3G & 4G Deployment Status
- LET Technology Suppliers, http://lteworld.org/technology
- 3GPP – The Mobile Broadband Standard, http://www.3gpp.org/about-3gpp