Wireless Communications

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The Technology: Radio Spectrum

- **Radio Spectrum: from 30 KHz to 3 GHz**
  - **AM radio: 540KHz – 1800 KHz**
  - **FM radio: 88 MHz – 108 MHz**
  - **Cellular (e.g. AMPS): 824 – 849, 869 – 894 MHz**
  - **Cellular (e.g. GSM): 890 – 915, 935 – 960 MHz**
  - **PCS frequencies: 1800 – 2200 MHz**
- **Microwaves: from 3 GHz to 300 GHz**
- **Infrared Spectrum: from 300 GHz to 300 THz**

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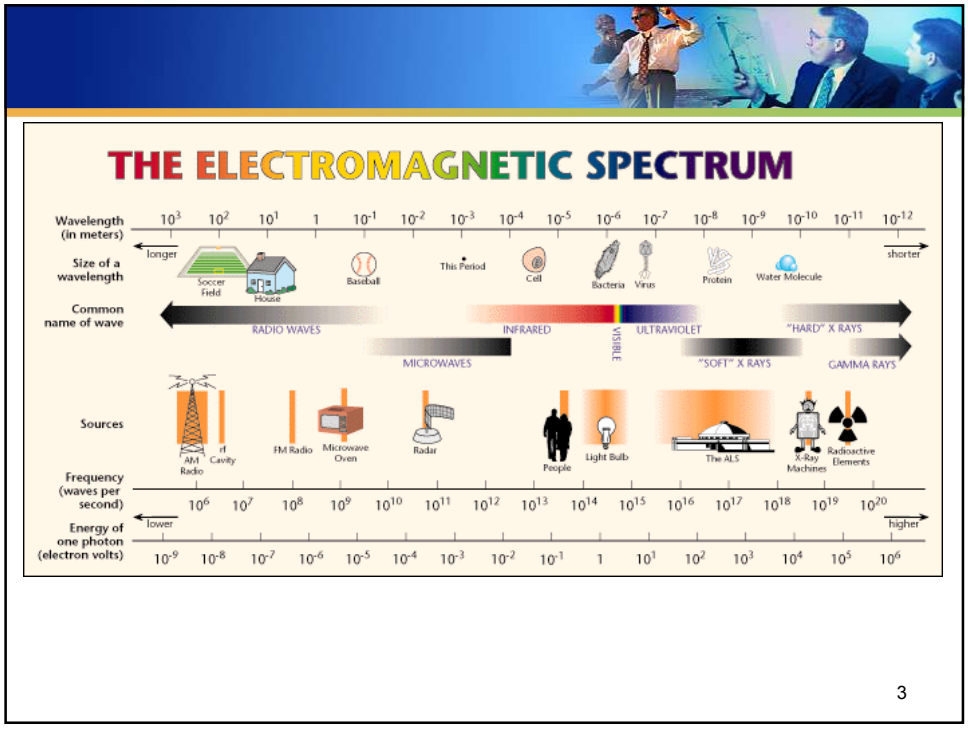

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Issue: Spectrum is a scarce resource!

Possible Solutions:

- **Frequency reuse (cells)**
- **Multiplexing**

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How wireless frequencies are allocated

- Garage door openers, alarm systems, etc. – 40MHz
- Cordless phones: 40-50MHz, 900MHz, 2.4GHz, 5.8GHz
- Baby monitors: 49MHz
- Radio controlled toys: 27-75MHz
- Wildlife tracking collars: 215-220MHz
- MIR space station: 145-437MHz
- Cell phones: 824-849MHz, 869-894MHz, 1850-1990MHz
- Public safety (fire, police, ambulance): 849-869MHz
- Air traffic control radar: 960MHz-1.215GHz
- Global Positioning System: 1.227-1.575MHz
- Satellite radio: 2.3GHz
- WiFi/802.11b/g and Bluetooth: 2.4GHz
- Zigbee/802.15.4: 868MHz, 915MHz, 2.4GHz
- Microwave ovens: 2.4Ghz
- TV: 54-216 (VHF 2-13), 470-806MHz (UHF 14-69)
- Ultra-wide-band: 3.1-10.6GHz
- ISM (industrial, scientific, medical): 900MHz, 1.8GHz, 2.4GHz, 5.8GHz

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Considerations in choosing a carrier frequency

- Carrier frequency
  - Signal that is modulated to carry data
  - Frequency is not equal to bandwidth
- Ability to carry data (modulation rate)
- Availability of devices to transmit and receive signals
- Interference from other devices in same band
  - ISM bands limit power output
- Interactions of radiation with environment
  - absorption by water, metal, building materials, foliage
- Reflection and multi-path properties
  - constructive/destructive interference patterns (e.g., nulls)

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Radio Protocols for Wireless Networks

- UHF (300-1000MHz)
  - Mote radio
- WiFi (2.4GHz)
  - Wireless LAN
- Bluetooth (2.4GHz)
  - Common in many consumer devices (PDAs, cell phones, etc.)
- Zigbee (850-930MHz)
  - Next generation radio for sensor networks and consumer devices

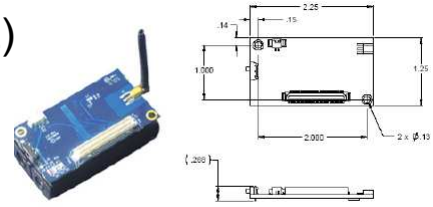

Figure 2-1. *Photo of the XM2110—IRIS with standard antenna*

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Wireless Network Evolution

- Point-to-point
  - Simple wire replacement (Virtual Wire, Bluetooth)
- Star pattern (single base-station)
  - Centralized routing and control point (WiFi, GSM)
- Multi-hop/Mesh (wireless sensor networks)
  - Multiple paths for data
  - Self-configuring

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Comparison of Major Protocols

Feature(s)	IEEE 802.11b	Bluetooth	ZigBee
Power Profile	Hours	Days	Years
Complexity	Very Complex	Complex	Simple
Nodes/Master	32	7	64000
Latency	Enumeration upto 3 seconds	Enumeration upto 10 seconds	Enumeration 30ms
Range	100 m	10m	70m-300m
Extendability	Roaming possible	No	YES
Data Rate	11Mbps	1Mbps	250Kbps
Security	Authentication Service Set ID (SSID)	64 bit, 128 bit	128 bit AES and Application Layer user defined

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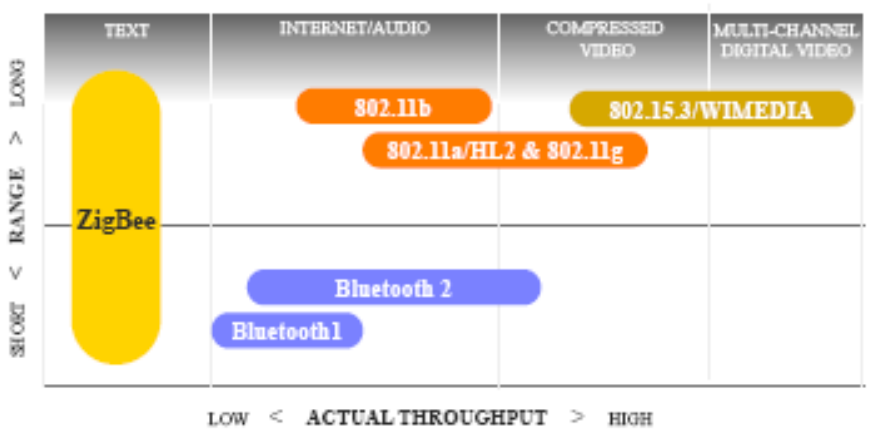
The Wireless Market



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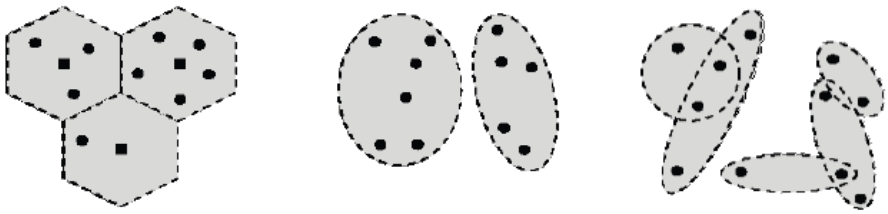
Wireless Network Configurations



Cellular system

Conventional
ad Hoc System

Scatternet

Radio Specification

- Classes of transmitters
  - Class 1: Outputs 100 mW for maximum range
    - Power control mandatory
    - Provides greatest distance
  - Class 2: Outputs 2.4 mW at maximum
    - Power control optional
  - Class 3: Nominal output is 1 mW
    - Lowest power

WIRELESS COMMUNICATIONS

- Wireless telephony
- Wireless LANs
- Location-based services

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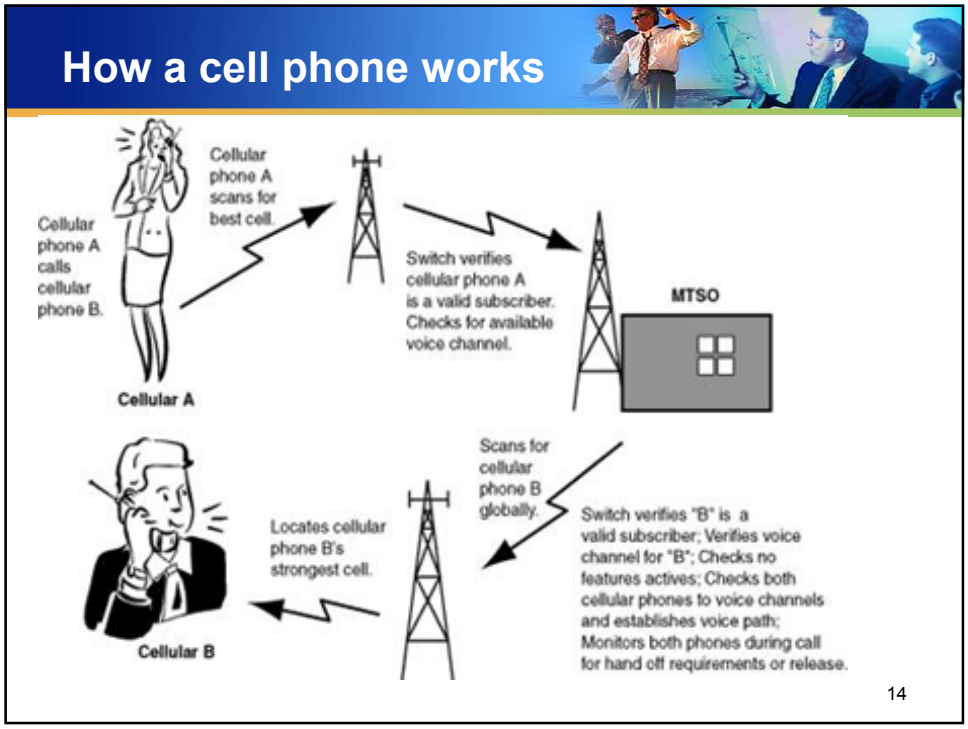
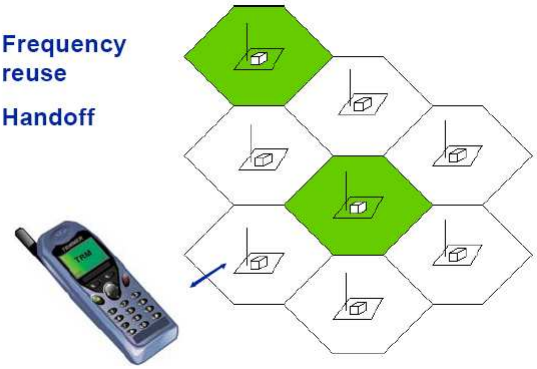


Cellular Phone Networks

- Frequency reuse
- Handoff



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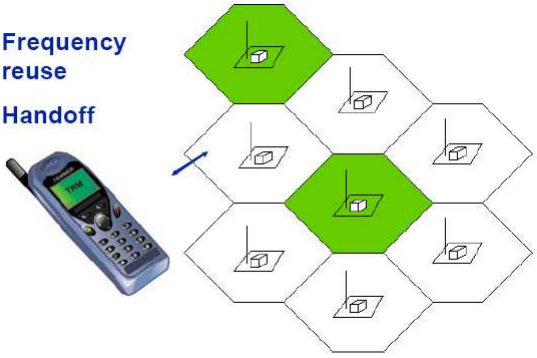

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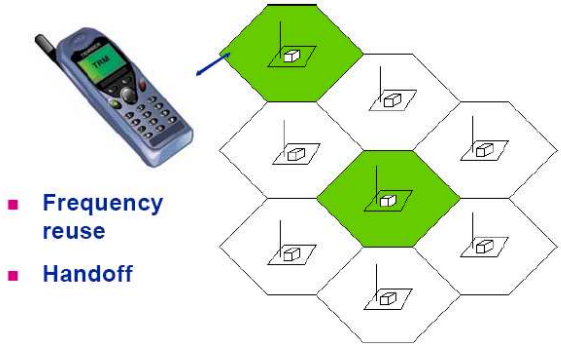
Cellular Phone Networks



- Frequency reuse
- Handoff

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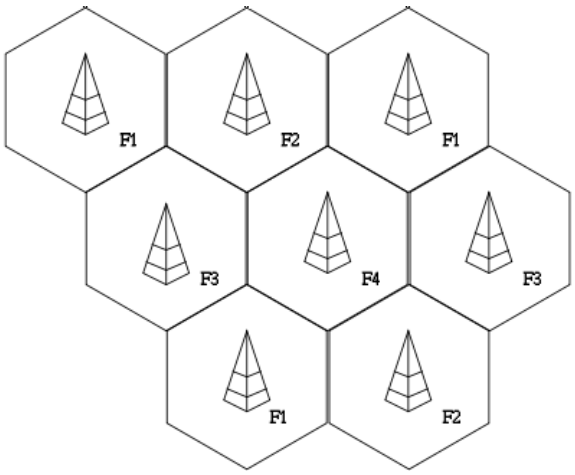
Example of frequency reuse factor or pattern 1/4



http://en.wikipedia.org/wiki/Cellular_network

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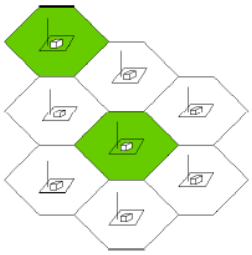
Problem: Reuse not good enough!

- Radio waves attenuate at a rate proportional to the square of distance ($1/r^2$)
- This means that faraway cells are irrelevant but we still can have interference from adjacent cells
- Therefore, a cell cannot reuse the same channels as its 6 immediate neighbors
- This means that each cell can only use $1/7^{th}$ of the spectrum allocation…
- Example: AMPS system
  - Each operator was given 416 2-way channels but could only use about 416/7 ~ 60 channels at any given cell



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Multiple Access Technologies

- ***FDMA: Frequency Division Multiple Access***
  - **Each call occupies a different frequency and has an exclusive use of that frequency during the call**
- ***TDMA: Time Division Multiple Access***
  - ***Several* calls can share the same frequency by alternating in time**
- ***CDMA: Code Division Multiple Access***
  - **Multiple calls mixed together; each call spread over the entire available spectrum; calls can be reconstructed by using call-specific keys.**

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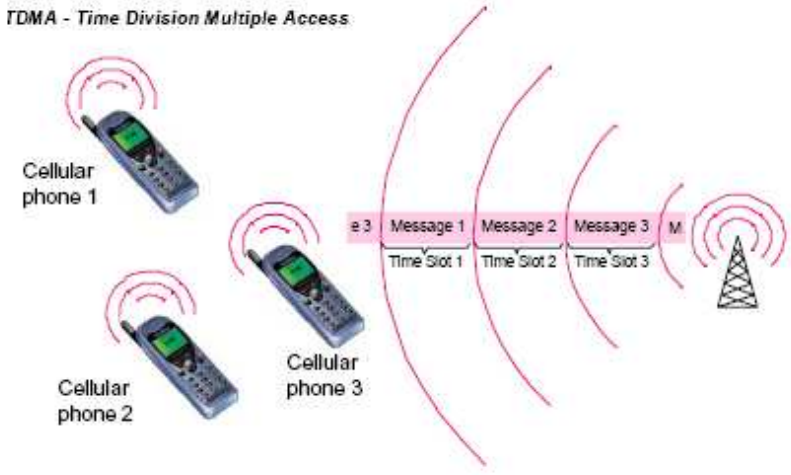
TDMA: Time Division Multiple Access



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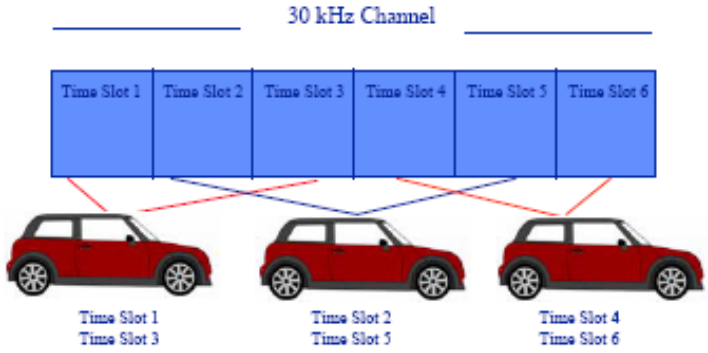
TDMA

- *Dual-Mode Capability*
- *3x the capacity of analog networks*
- *30 kHz Channel Spacing*
- *832 Channels*
- *8 kbps (Full Rate Mobiles)*
- *6 time slots per channel*
- *2 time slots per mobile*
- *uplink Tx*
- *downlink Rx*
- *3 calls per channel*



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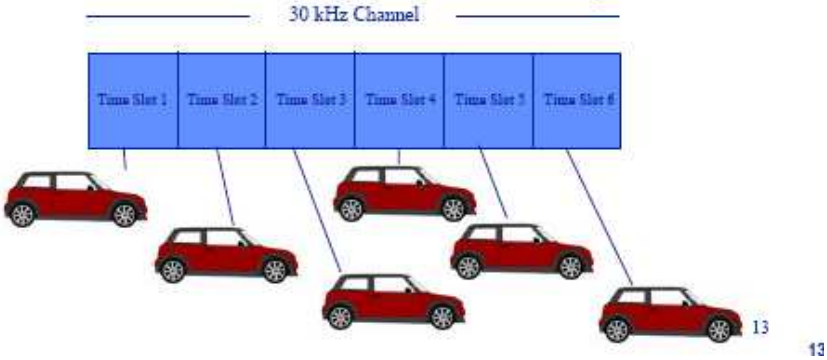
TDMA

- 4 Kbps (Half Rate Mobiles)
- 6 time slots per channel
- 1 time slots per mobile
  - handles both uplink Tx/ downlink Rx
- 6 calls per channel



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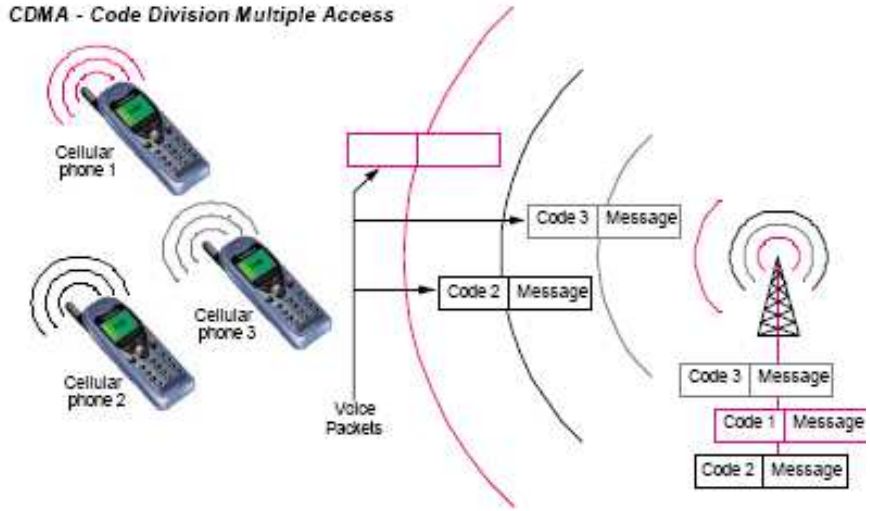
CDMA

CDMA - Code Division Multiple Access



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Varian CDMA

- W-CDMA
- TD-CDMA
- TD-SCDMA
- DS-CDMA
- FH-CDMA
- MC-CDMA

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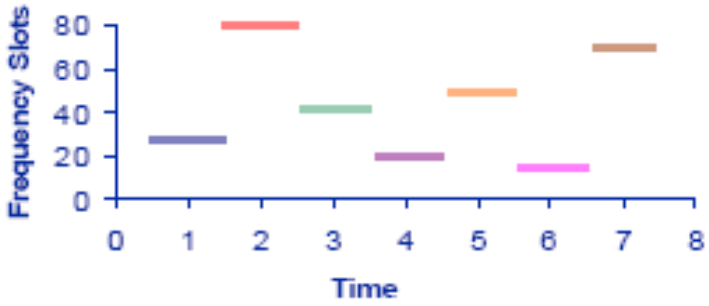
Frequency Hopping Spread Spectrum

- **Short duration hops between radio frequencies**
- **Sender and receiver know sequence**



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Random number generators

- Simplest approach is to use the following recurrence sequence:

  x_0 = given,

  $x_{n+1} = P_1 x_n + P_2 \pmod N \quad n = 0,1,2,...$

- For example:

  $P_1 = 16807$, $P_2 = 0$, and $N = 2^{31} - 1 = 2147483647$

- Basic property:
  - If P1, P2 known, then different choices of the initial seed x0 result in completely distinct sequences
  - Therefore, the seed x0 can act as the code, to be exchanged between sender and receiver

History of CDMA

- Co-invented by actress Hedy Lamarr during World War II as a technique against interference of submarine communications
- She was inspired by the musical notes encoded on the scrolls of a player piano

Advantages of CDMA

- Spread Spectrum Analysis
- 1.23 MHz channel vs. 30 kHz
- Each call is distinguished by a unique digital code different from others users transmitting at the same frequency band
- >= 10 times the capacity of analog networks
- Lower Power Terminals/Longer Battery Life

Generation of mobile phone technologies

- 1G
- 2G
- 2.5G
- 3G

History

- First Generation: Analog
  - AMPS (USA)
  - NMT (Europe)
- Second Generation: Digital
  - GSM (1st Europe, then world-wide)
  - Digital AMPS (IS-54)
- 2.5: PCS
  - DCS-1800 (world-wide except USA)
  - DCS-1900 (USA)
  - CDMA (IS-95, USA)
- Third Generation: Personal Communication Systems
  - UMTS

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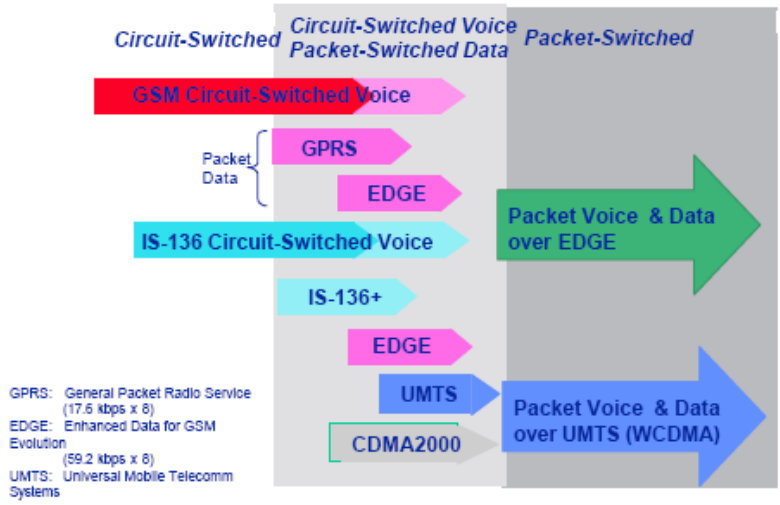
Migration of Digital Cellular Systems



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General Packet Radio Service (GPRS)

- Extension to GSM to support packet transmission
- Transmission rates: 57.6 and 115.2Kbps initial rates will be lower: 20-30 Kbps
- Good integration with the TCP/IP protocol

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Wireless Networking

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What Is Wireless Networking?

- The use of infra-red or radio frequency signals to share information and resources between devices
- A hot computer industry buzzword:
  - Lots of advertising by companies and media
  - Wireless Broadband, 3G wireless, WAP, iMode, Bluetooth
- Mobile Internet, Pervasive Computing, M-Commerce
  - Ubiquitous?
  - Global?
  - Revolutionary?

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Two Popular 2.4GHz Standards:

- IEEE 802.11
  - Fast (11B)
  - High Power
  - Long range
  - Single-purpose
  - Ethernet replacement
  - Easily Available
    - Apple Airport, iBook, G4
    - Cisco Aironet 350

- Bluetooth
  - Slow
  - Low Power
  - Short range
  - Flexible
  - Cable replacement
  - "Vapourware"
    - Anoto, Test cards, phone

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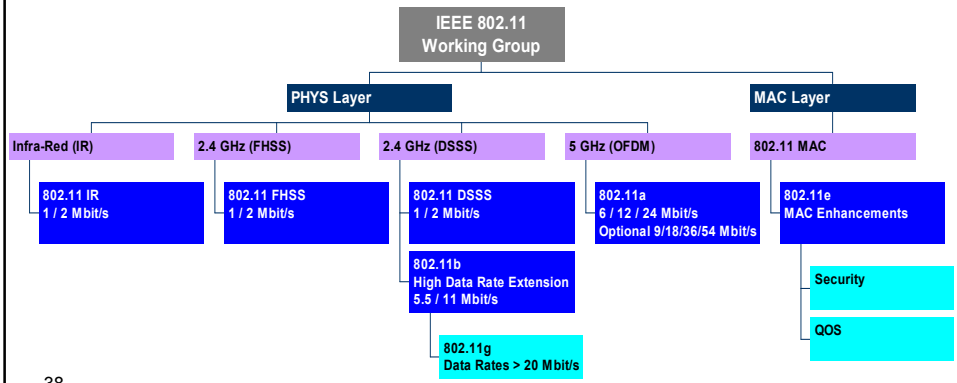
IEEE 802.11 Organization Tree:



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Wireless LANs and PANs

Major developments:

- **IEEE 802.11 standard for wireless LANs**
- **Home Radio Frequency Spec (HomeRF)**
- **Bluetooth**

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IEEE 802.11 Standard

- Operates in 2.4-2.4835GHz frequency band
  - unlicensed band for industrial/scientific/medical apps
- 2 standards:
  - original 802.11: transmission rates 1-2Mbps
  - 802.11b (High Rate): transmission rates up to 11Mbps (actual data transmission rate is about 7Mbps)
- Transmission distances:
  - top transmission rates achieved within 150 ft;
  - 1Mbps rates can be achieved within 1000 ft;
  - signals can be transmitted through walls

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Pros and Cons of 802.11:

- Pro:
  - High bandwidth (up to 11 Mbps)
  - Two modes of operation: infrastructure vs. ad hoc
- Con:
  - Incompatibility between old and new cards
  - Signal blocked by reinforced concrete or tinted glass
  - High channel BER can degrade performance (lots!)
  - No standard for hand-off between base stations
  - Some channel numbers overlap spectrum
  - High power consumption in laptops

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Wireless LAN Applications

- Earlier applications: mostly vertical
  - manufacturing facilities, warehouses, retail stores, car rentals
- More recent applications:
  - healthcare facilities (bedside access to patient info by doctors),
  - educational institutions (e.g., Stern - study group meetings, research links)
  - corporate offices (on-site consultants, database access for roving supervisors, customer info)

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Multi-Hop Ad Hoc Wireless Networking

- Routing protocols used to improve wireless connections
- Infrastructure-free, dynamic
- True Peer-to-Peer routing
- Fault tolerant

- Examples: DSDV, TORA, DSR, ...

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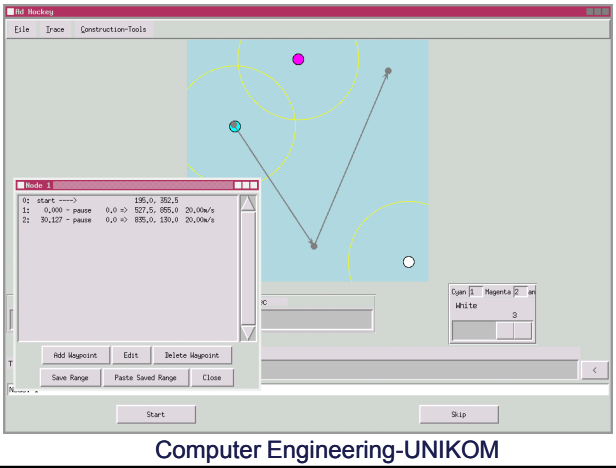
Ad-Hockey Screenshot (Simulation/Visualization Tool ns2)



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Bluetooth

- Think USB, not Ethernet
- Created by Ericsson
- A PAN – Personal Area Network
  - has a set of wireless protocols; enables devices to communicate within 10m distance. 1-2 Mbps connections
  - 1600 hops per second FHSS
  - Includes synchronous, asynchronous, voice connections
  - Piconet routing
- Transmission rates: 432.5Kbps (both ways for symmetric transmission)
- 721/57.6 Kbps (asymmetric transmission)
- Small, low-power, short-range, cheap, versatile radios
- Applications: cars, homes, wireless phones

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Security

- Wireless sniffers
- IEEE 802.11:
  - ESSID – Extended Services Set ID
  - WEP – Wired Equivalent Privacy
    - 40 bit RC4 (RSA) encryption
- Bluetooth Security
  - Rapid hop sequence
  - Short range
  - Encrypted transmissions

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Bluetooth

- Consortium: Ericsson, Intel, IBM, Nokia, Toshiba - many members
- Scenarios
  - connection of peripheral devices
    - loudspeaker, joystick, headset
  - support of ad-hoc networking
    - small devices, low-cost
  - bridging of networks
    - e.g., GSM via mobile phone - Bluetooth - laptop
- Simple, cheap (target < $5/device), replacement of cables and IrDA, low range, lower data rates
  - 2.4 GHz, FHSS, TDD, CDMA

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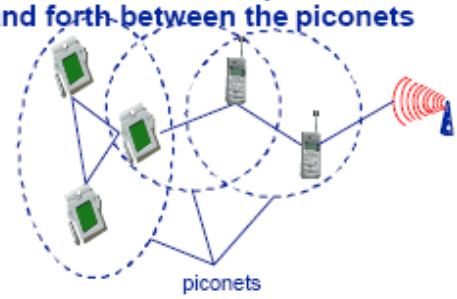
Piconets and Scatternets

- Each piconet has one master and up to 7 slaves
- Master determines hopping sequence, slaves have to synchronize
- Participation in a piconet = synchronization to hopping sequence
- Communication between piconets = devices jumping back and forth between the piconets



piconets

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Bluetooth Applications

- Wireless PDAs always connected to desktop via mobile phone
- Wireless headphones connected to notebook
- Office/Home device networks that automatically reconfigure by presence
- …

Bluetooth Success Factors

- **Low enough cost**
  - **Currently $25-50, will reach $5 at 2003-4**
- **Existence of wideband, circuit-switched mobile networks**
  - **Depends on 3G mobile developments**
- **Standardized software protocols**
  - **… still mostly on paper!**

Location-based Services: Definition

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Location-based Services: Definition

"Location-based services (LBS) are any activity conducted over a cellular network where the accurate determination of a user's position is fundamental to the enabling of that activity"

(Yankee Group)

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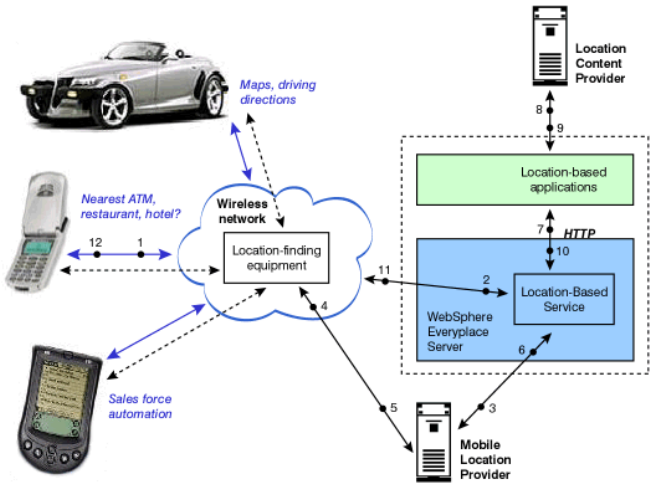
HTTP flow of location-based request



http://www.ibm.com/developerworks/ibm/library/i-lbs/

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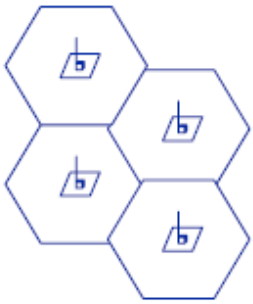
Cell-ID



- old technology
- cell size varies from 100m radius to 35km radius
- still: sufficient accuracy for many applications

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Time Difference of Arrival (TDOA)

- calculates difference in arrival time at pairs of cell sites
- requires two pairs, i.e. three different cell sites
- clocks at cell sites need to be synchronized

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TDOA Implementation

- Existing antennas can be used
- Additional device (clock, measurement unit) installed in each base station

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Angle of Arrival (AOA)

- only two base stations required
- complex antenna array in precise pattern
- cost and practical issues (zoning regulations)
- accuracy degrades over distance
- mainly used to supplement TDOA in areas where only two base stations are available

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Enhanced Observed Time Difference

- Cursor EOTD by CPS in UK beta trial with Vodafone
- Requires 3 Base station and Location Measurement Unit
- Promises under 50m precision with 3G
- Location circles by computing time delta between BTS and handset vs BTS and LMU.
- Intersection of 3 circles gives location

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Assisted GPS

- Snaptrack (Qualcomm)
- Increased sensitivity receiver allows for GPS tracking even when no line of sight
- Cell location sends request for snapshot from relevant GPS satellite
- Limitations within buildings
- Combines precision of GPS with information given by cell ID to achieve rapid location

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Location-Based Service Categories

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