Wireless Communications

- Wireless telephony
- Wireless LANs
- Location-based services

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
The electromagnetic spectrum

Issue: Spectrum is a scarce resource!

Possible Solutions:
- Frequency reuse (cells)
- Multiplexing
How a cell phone works

Cellular Phone Networks
- Frequency reuse
- Handoff
Cellular Phone Networks

- Frequency reuse
- Handoff
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 \(\approx 60\) channels at any given cell

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.
TDMA: Time Division Multiple Access

- **TDMA - Time Division Multiple Access**

Cellular phone 1

Cellular phone 2

Cellular phone 3

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

**TDMA**

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TDMA

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

30 kHz Channel

CDMA: Code Division Multiple Access

CDMA - Code Division Multiple Access

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Frequency Hopping Spread Spectrum

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

Random number generators

- Simplest approach is to use the following recurrence sequence:
  \[ x_0 = \text{given}, \]
  \[ x_{n+1} = P_1 x_n + P_2 \mod N \quad n = 0, 1, 2, \ldots \]

  - For example:
    \[ P_1 = 16807, \quad P_2 = 0, \quad \text{and } N = 2^{31} - 1 = 2147483647 \]

- 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

Summary of multiplexing methods
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
- $\geq 10$ times the capacity of analog networks
- Lower Power Terminals/Longer Battery Life

Generations 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

Migration of Digital Cellular Systems

GPRS: General Packet Radio Service (17.6 kbps x 8)
EDGE: Enhanced Data for GSM Evolution (59.2 kbps x 8)
UMTS: Universal Mobile Telecomm Systems
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
- Cingular Wireless deploys GPRS network in San Francisco/San Jose in March 2001; uses Ericsson’s 520 handsets

Summary
Wireless LANs and PANs

Major developments:
- IEEE 802.11 standard for wireless LANs
- Home Radio Frequency Spec (HomeRF)
- Bluetooth

Wireless LAN industry will grow from $300M in 1998 to $1.6B in 2005 (Frost & Sullivan)

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
Advantages of 802.11b

- network access freedom for mobile workers
- cost-effective network setup for hard-to-wire locations (e.g., old buildings)
- reduced cost of ownership especially when frequent network changes required

Total economic benefits can add up to $16K per user


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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Bluetooth

- A PAN – has a set of wireless protocols; enables devices to communicate within 10m distance.
- Transmission rates: 432.5Kbps (both ways for symmetric transmission)
- 721/57.6 Kbps (asymmetric transmission)
- 1300 companies support Bluetooth (12/1999)
- Applications: cars, homes, wireless phones

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
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

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
- ...

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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!

Summary
**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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**Cell-ID**

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

TDOA Implementation

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

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
**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

**A Classic Example of Standards War**

<table>
<thead>
<tr>
<th></th>
<th>Cell Id</th>
<th>TDOA/AOA</th>
<th>E-OTD</th>
<th>A-GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>100m to 30 km</td>
<td>100 to 250m</td>
<td>50 to 125m</td>
<td>5 to 50m</td>
</tr>
<tr>
<td>Market stage</td>
<td>Proven</td>
<td>Beta</td>
<td>Beta</td>
<td>2002</td>
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<tr>
<td>Location fix</td>
<td>3 sec</td>
<td>10 sec</td>
<td>5 sec</td>
<td>3-5 sec</td>
</tr>
<tr>
<td>Network Modifications</td>
<td>None</td>
<td>Clock Measurement Units or Antennas</td>
<td>Location Measurement Units</td>
<td>None</td>
</tr>
<tr>
<td>Handset Modifications</td>
<td>None</td>
<td>None</td>
<td>Software installation</td>
<td>Hardware: GPS enabled units</td>
</tr>
<tr>
<td>E911 compliant</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Difficult to predict the emerging standard the real winner might be upstream in the value chain
Location-Based Service Categories

- **Information**
  - Yellow pages
  - Navigation services
  - Traffic information

- **Tracking**
  - Fleet Management
  - Asset Tracking
  - People Tracking

- **Safety**
  - Emergency Services
  - Roadside Assistance
  - Personal Security

- **Entertainment**
  - Gaming

- **Trigger Services**
  - Event-Based
  - Advertising/Promotions
  - Location-Sensitive
  - Billing

- **Event-Based**

- **Location-Sensitive**

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