Wireless Communications

- Wireless telephony
- Wireless LANs
- Location-based services

1

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

2

The electromagnetic spectrum

3

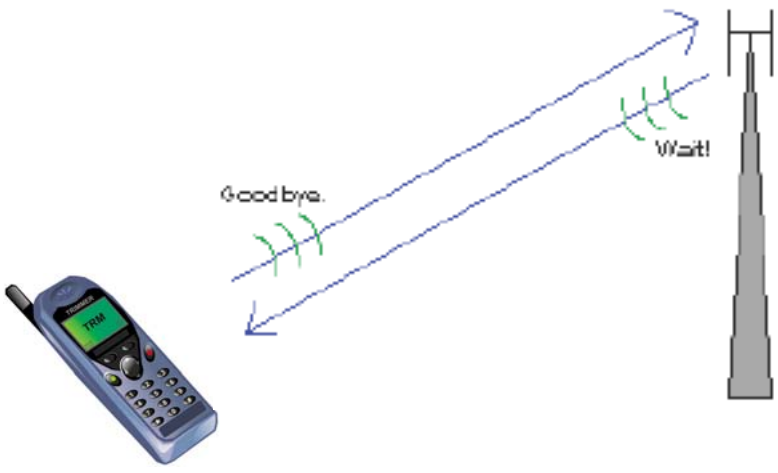
Issue: Spectrum is a scarce resource!

Possible Solutions:

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

4

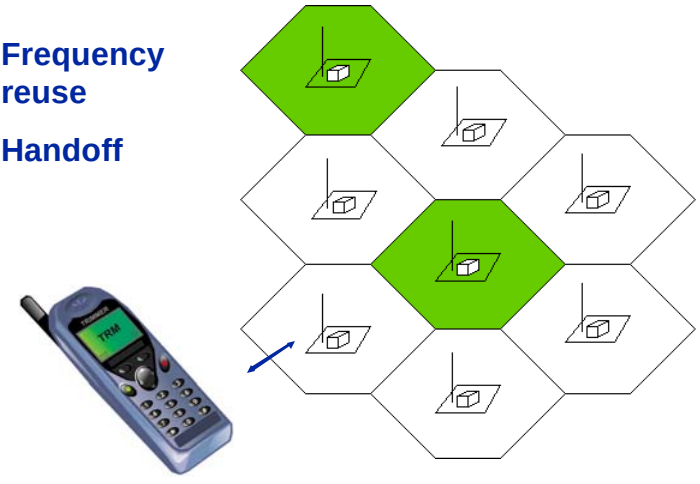
How a cell phone works



5

Cellular Phone Networks

- Frequency reuse
- Handoff



6

Cellular Phone Networks

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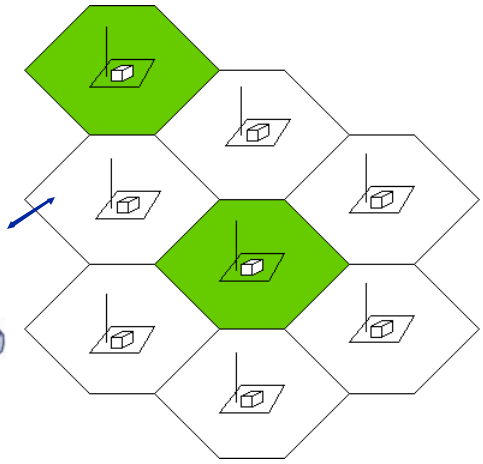
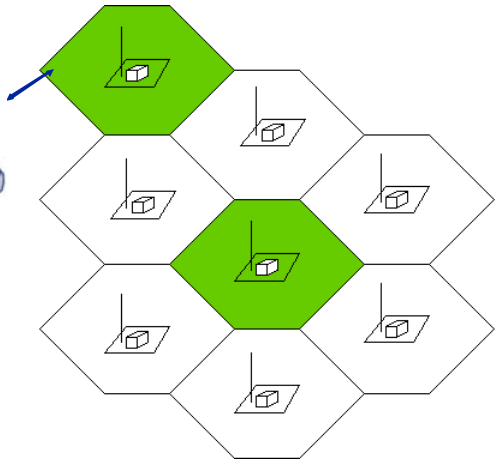


7

Cellular Phone Networks

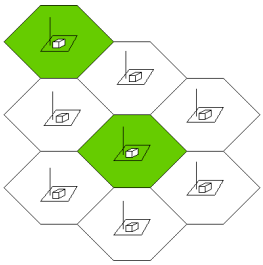


- Frequency reuse
- Handoff

8

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



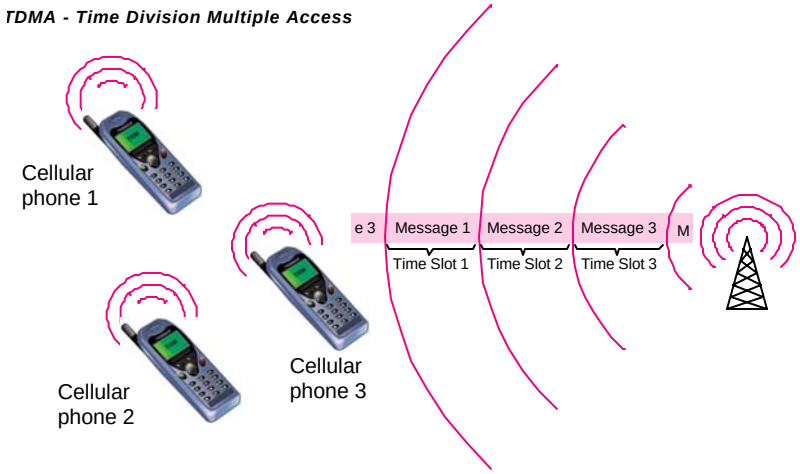
9

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.

10

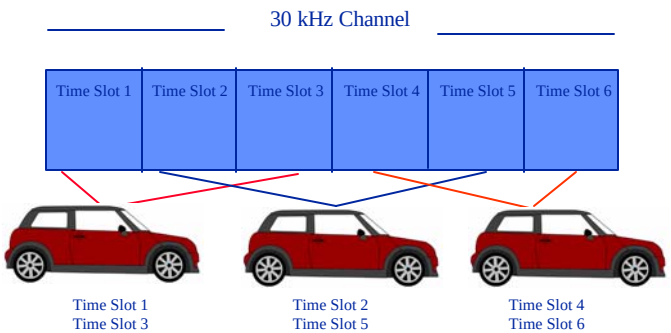
TDMA: Time Division Multiple Access



11

TDMA

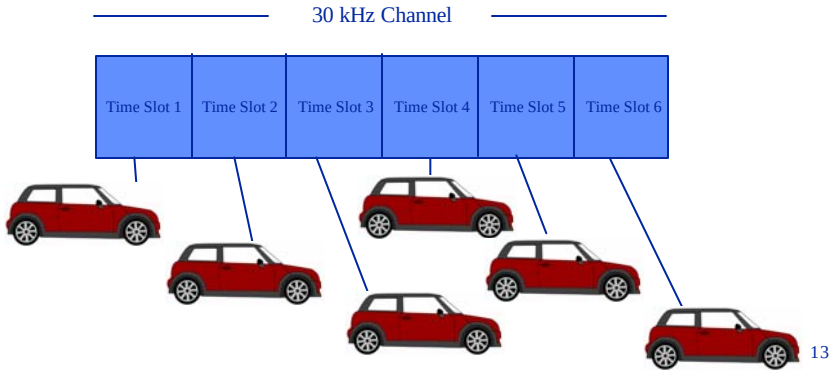
- *Dual-Mode Capability*
- *3x the capacity of analog networks*
- *30 kHz Channel Spacing*
- *832 Channels*
- *8 kbps (Full Rate Mobiles)*
- *6 time slots per channel*
- *2 time slots per mobile*
- *uplink Tx*
- *downlink Rx*
- *3 calls per channel*



12

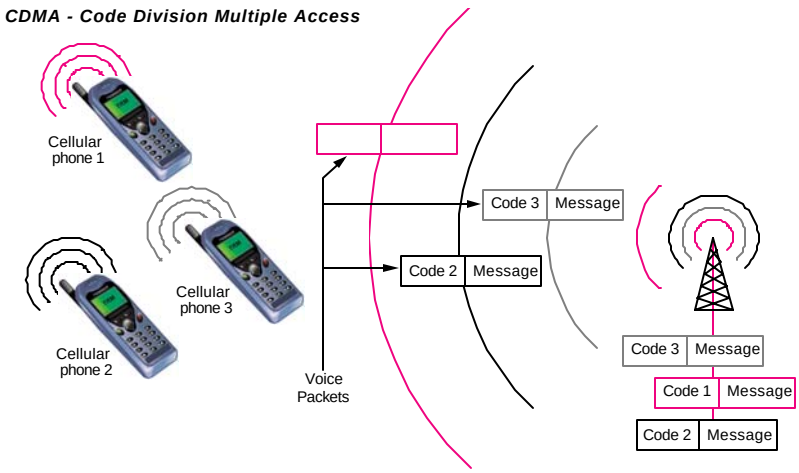
TDMA

- *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*



13

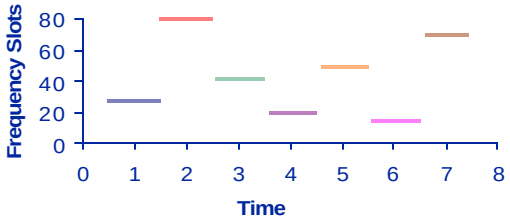
CDMA: Code Division Multiple Access



14

Frequency Hopping Spread Spectrum

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



17

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

18

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

19

Summary of multiplexing methods

20

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

21

21

Generations of mobile phone technologies

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

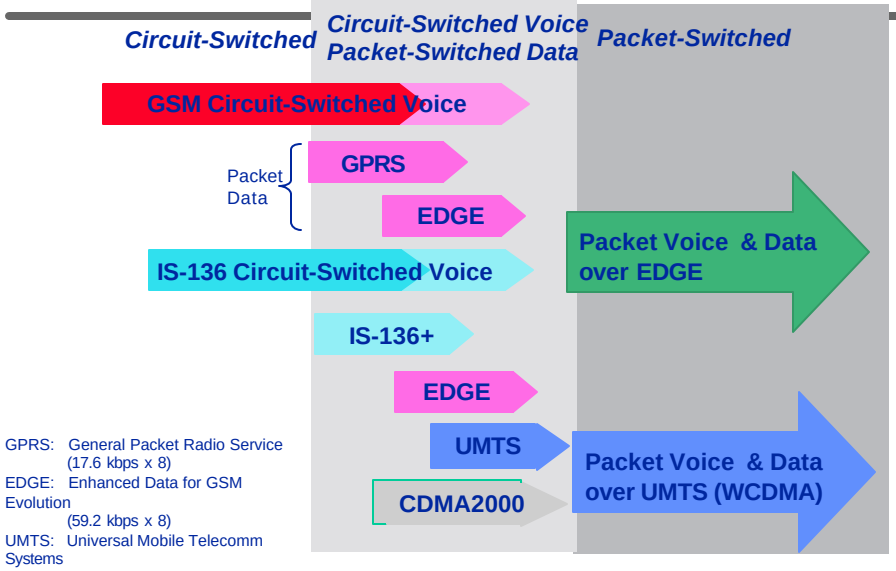
22

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

23

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

24

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

25

Summary

26

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)

27

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**

28

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

("WLANs: ROI/Cost-Benefit Study," WLANA, Oct 1998)

29

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)

30

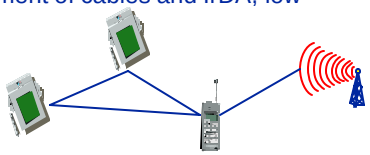
Bluetooth

- 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

31

Bluetooth

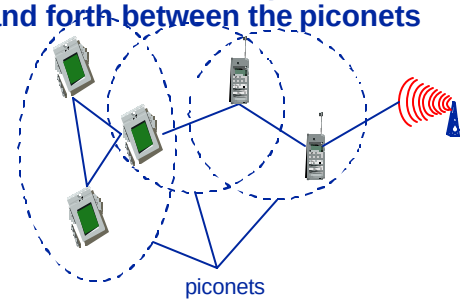
- Consortium: Ericsson, Intel, IBM, Nokia, Toshiba - many members
- Scenarios
  - connection of peripheral devices
    - loudspeaker, joystick, headset
  - support of ad-hoc networking
    - small devices, low-cost
  - bridging of networks
    - e.g., GSM via mobile phone - Bluetooth - laptop
- Simple,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



32

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



33

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
- …

34

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!

35

Summary

36

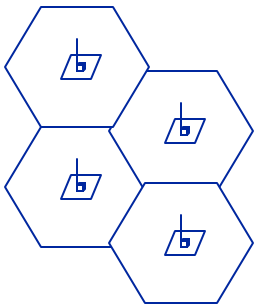
Location-based Services: Definition

"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)

37

Cell-ID



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

38

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

39

TDOA Implementation

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

40

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

41

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

42

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

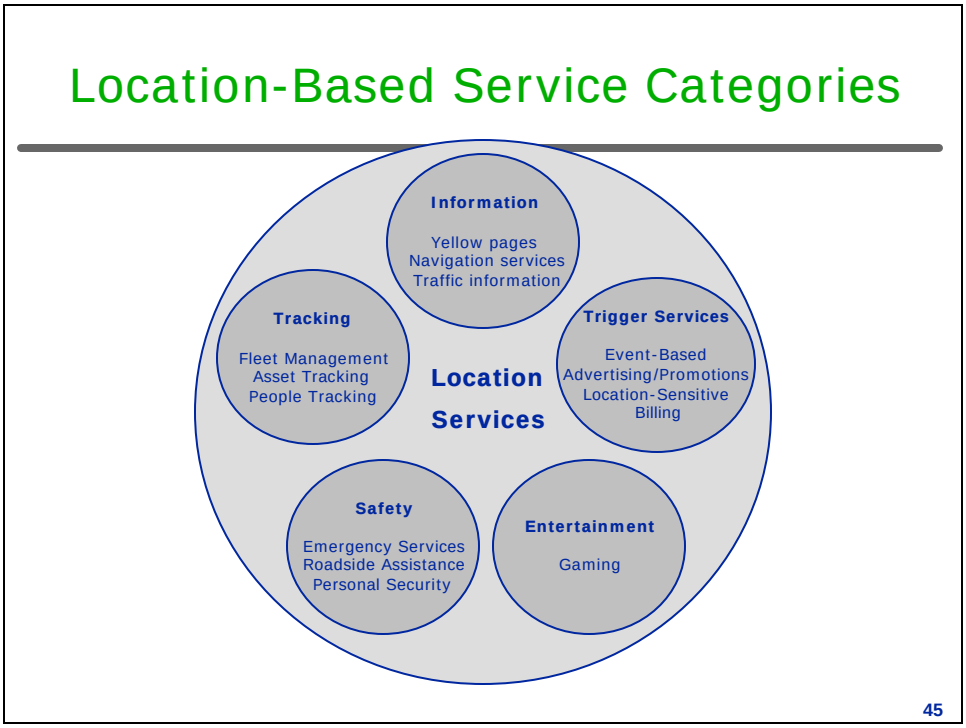
43

A Classic Example of Standards War

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

Difficult to predict the emerging standard
the real winner might be upstream in the value chain

44


Location-Based Service Categories
Information
Yellow pages
Navigation services
Traffic information
Tracking
Fleet Management
Asset Tracking
People Tracking
Location Services
Trigger Services
Event-Based
Advertising/Promotions
Location-Sensitive
Billing
Safety
Emergency Services
Roadside Assistance
Personal Security
Entertainment
Gaming
45