Cellular Wireless Networks

Stallings: "Wireless Comm…", Chapter 10

- **Principles**
- 1G analog (AMPS, NMT)
- 2G TDMA (GSM900)
- 2G CDMA (IS-95)
- 3G CDMA (W-CDMA)
- 3G Evolution (HSPA, LTE)

(based on Erik: " 3G Evolution", *Academic Press Inc. UK)*

www.bth.se

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Cellular Networks

- Why use **cellular** networks? What mobile radio services where provided before cellular?
- Use multiple low-power transmitters (100 W or less)
- Areas divided into cells

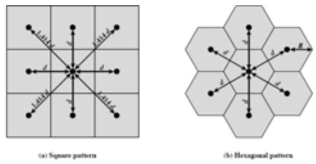


Figure 10.1 Cellular Geometries

Cellular Geometries

- Each served by its own antenna
- Served by base station consisting of transmitter, receiver, and control unit
- Band of frequencies allocated
- Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

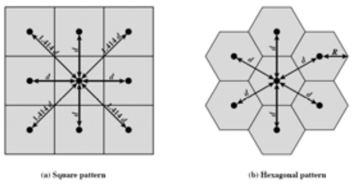


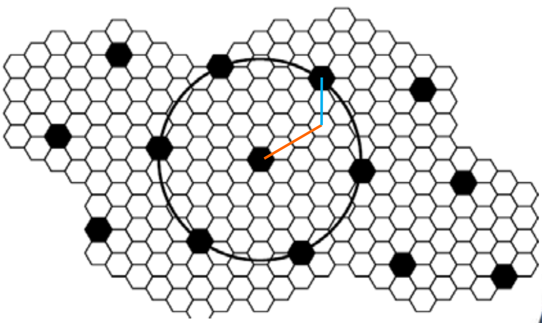
Figure 10.1 Cellular Geometries

Frequency Reuse

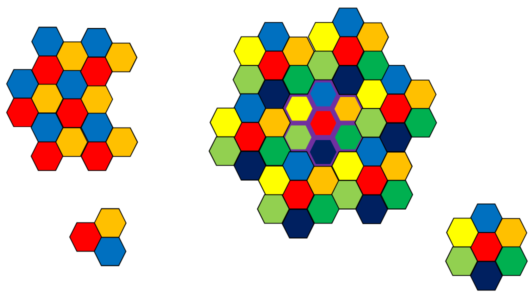
- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - Minimum distance between co-channel cells
  - Number of frequencies assigned to each cell
  - Transmission power control needed
  - Reuse factor (N at 1,3,4,7,9,12,13….)

$N=i^2 + j^2 + i \times j$ (i,j =0,1,2,3,4….)

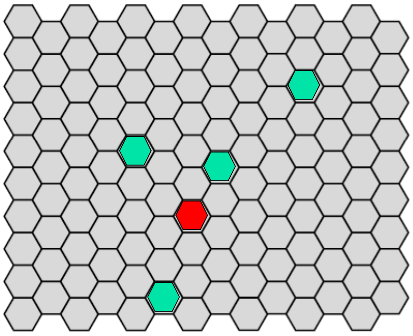
Example of Frequency Reuse



Cluster Size and Frequency Reuse Factor



Calculate Reuse Factors

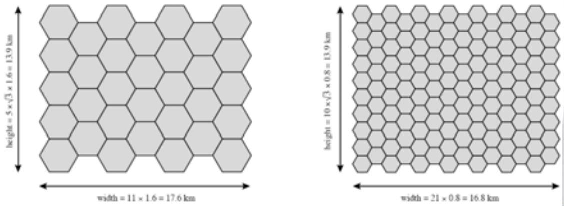


Ways to increase the capacity

- Add new channels (if such exists…)
- **Frequency borrowing** from adjacent cells (dynamically or permanent)
- **Cell splitting** – cells in areas of high usage can be split into smaller cells
- **Cell sectoring** – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- **Microcells** – radius less than 1 km. Used at crowded streets, inside buildings, along highways,…

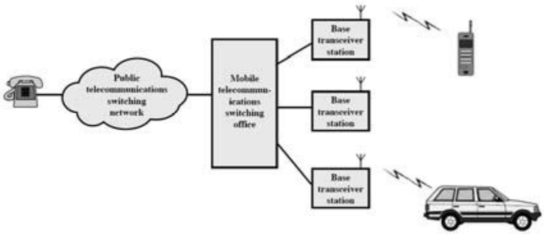
Frequency Reuse Example

- Assume a system can support 336 traffic channels with a reuse factor N at 7, compare the capacity of cell radius at 1.6 km with 32 cells and 0.8 km with 128 cells (refer to example 10.1 page 269)



(a) Cell radius = 1.6 km (b) Cell radius = 0.8 km

Cellular System Overview

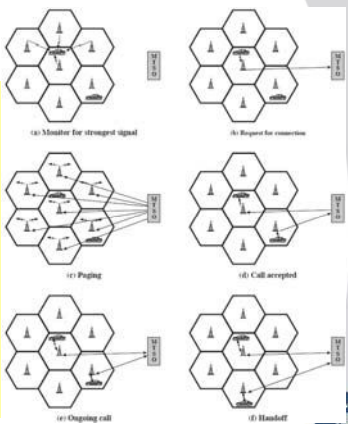


Cellular Systems Terms

- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile Telecommunications Switching Office MTSO (or Mobile Switching Center MSC) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - *Control channels* – used to exchange information having to do with setting up and maintaining calls
  - *Traffic channels* – carry voice or data connection between users

Typical call

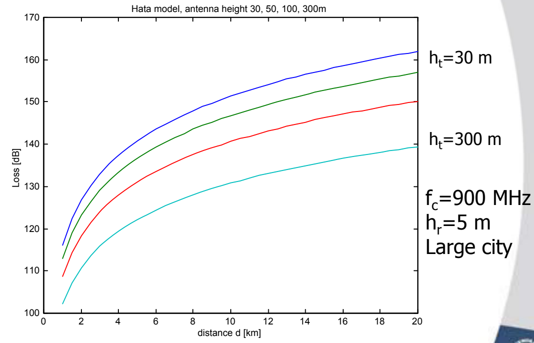
- Monitor for strongest signal
- Request for connection
- Paging
- Call accepted
- Ongoing call
- Handover (handoff) or termination
- Also: call blocking, call drop, call to fixed phone network



Mobile Radio Propagation Effects

- Take into consideration in design:
  - Signal strength
    - Must be strong enough (signal quality at the receiver)
    - Must not be too strong (co-channel interference)
  - Fading
  - Cell size
  - Carrier freq., antenna positions, …
- Widely used model developed by Okumura, refined by Hata
  - Differ between urban, suburban and open areas

Mobile radio propagation effects, an example



Pathloss for a medium-size city

PL(d)(dB) = 69.55 + 26.16log(f_c) - 13.82log(h_t)-A(h_r) +(44.9-6.55 log h_t)*log(d)

- where

f_c is the ferquency in MHz
h_t is base station antenna height in meters (30-200m)
h_r is mobile receiver antenna height in meters (1-10m)
d is T-R separation in km (1km<d<100km)

For medium-size city, the correction factor A(hr)=(1.1log fc -0.7)hr-(1.56log fc-0.8)dB

- Refer to page 274, example 10.2

  fc=900 MHz, hb=40m, hm=5m, d=10 km

  PL(d)=?

Estimate the number of BS

- Based on Okumura-Hata model in Page 273, if we have an area of 450,000 km^2 (medium-size urban city), the system works at 900 MHz, h_t at 40m and h_r at 5m, how many cellular base stations we need for maximal pathloss within a cell at 134 dB?

PL(d)(dB) = 69.55 + 26.16log(f_c) - 13.82log(h_t)-A(h_r) +(44.9-6.55 log h_t)*log(d)

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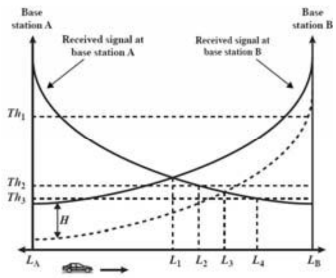
Handover

- Also called Handoff (mainly in US)
- Network initiated or mobile-assisted
- Performance metrics that may be used in decision:
  - Cell blocking probability
  - Call dropping probability
  - Call completion probability
  - Probability of unsuccessful handover
  - Handover blocking probability
  - Handover probability
  - Rate of handover – number of handovers per unit time
  - Interruption duration
  - Handover delay

Handover Strategies Used to Determine Instant of Handover

- Relative signal strength
  - With or without hysteresis and/or threshold
- Prediction techniques



(a) Handoff decision as a function of handoff scheme

Power Control

- Why is it desirable to include dynamic power control in a cellular system?
  - Received power must be sufficiently above the background noise for effective communication
  - Desirable to minimize power in the transmitted signal from the mobile
    - Co-channel interference
    - Health concerns
    - Battery power
  - In spread spectrum systems using CDMA it is crucial for the decoding to equalize the received power level from all mobile units at the BS

Types of Power Control

- Open-loop power control
  - Depends solely on mobile unit
  - Uses the pilot signal
  - Not as accurate as closed-loop, but can react quicker to fluctuations in signal strength (important in CDMA)
- Closed-loop power control
  - Adjusts signal strength in reverse channel based on metric of performance
  - BS makes power adjustment decision and communicates to mobile on control channel
- Example: GSM uses closed-loop with 8 power classes in BS (2.5-320 W) and 5 in mobile station (0.8-20 W)

First-Generation Analog (examples)

- Advanced Mobile Phone Service (AMPS)
  - In North America, two 25-MHz bands allocated to AMPS (to/from base station), below 900 MHz
  - Each band split in two to encourage competition
  - Channel spacing 30 kHz, 832 channels
- Nordic Mobile Telephone System (NMT)
  - Mainly in Scandinavia, but later spread
  - Two systems: 450 MHz and 900 MHz
  - Channel spacing 12.5 kHz, 1999 channels (NMT900)

AMPS Parameters

Base station transmission band	869 to 894 MHz
Mobile unit transmission band	824 to 849 MHz
Spacing between forward and reverse channels	45 MHz
Channel bandwidth	30 kHz
Number of full-duplex voice channels	790
Number of full-duplex control channels	42
Mobile unit maximum power	3 watts
Cell size, radius	2 to 20 km
Modulation, voice channel	FM, 12-kHz peak deviation
Modulation, control channel	FSK, 8-kHz peak deviation
Data transmission rate	10 kbps
Error control coding	BCH (48, 36,5) and (40, 28,5)

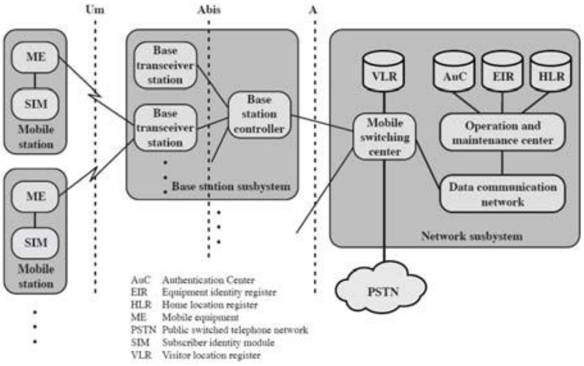
Differences Between First and Second Generation Systems

- Digital traffic channels in second generation
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction in second-generation digital traffic
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users
- Higher data rates

Global System for Mobile Communications, GSM

- Developed to provide a common 2G technology for Europe
- Now mainly in Europe and Pacific Asia but also in North America.
- Standardized functional elements (equipment from different manufacturers can be combined)
- Today probably the most popular standard for new implementations
- Subscriber Identity Module (SIM) concept of great importance

GSM Network Architecture



Mobile Station

- Mobile station communicates across air interface with base station transceiver in same cell as mobile unit
- Mobile equipment (ME) – physical terminal, such as a telephone or PCS
  - ME includes radio transceiver, digital signal processors and **subscriber identity module (SIM)**
- GSM subscriber units are generic until SIM is inserted
  - SIMs roam, not necessarily the subscriber devices

Base Station Subsystem (BSS)

- BSS consists of base station controller and one or more base transceiver stations (BTS)
- Each BTS defines a single cell
  - Includes radio antenna, radio transceiver and a link to a base station controller (BSC)
- BSC reserves radio frequencies, manages handover of mobile unit from one cell to another within BSS, and controls paging

Network Subsystem (NS)

- NS provides link between cellular network and public switched telecommunications networks
  - Controls handovers between cells in different BSSs
  - Authenticates users and validates accounts
  - Enables worldwide roaming of mobile users
- Central element of NS is the mobile switching center (MSC)

Mobile Switching Center (MSC) supported by 4 databases

- Home location register (**HLR**) database – stores information about each subscriber that **belongs** to it
- Visitor location register (**VLR**) database – maintains information about subscribers **currently physically** in the region
- Authentication center database (AuC) – used for **authentication** activities, holds **encryption** keys (note: no encryption in PSTN end)
- Equipment identity register database (EIR) – keeps track of the type of equipment at the mobile station. Blocking stolen mobile phones, un-approved phones, …

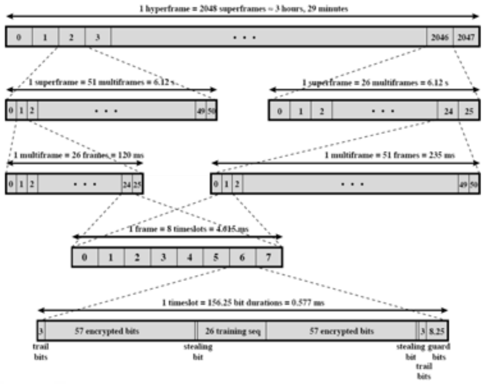
GSM Radio Link

- 2 x 25MHz allocated
- Combines FDMA and TDMA
- 125 channels full duplex, spaced 200kHz,

TDMA Format – Time Slot Fields

- **Trail bits** – allow synchronization of transmissions from mobile units
- **Encrypted bits** – encrypted data
- **Stealing bit** - indicates whether block contains data or is "stolen"
- **Training sequence** – used to adapt parameters of receiver to the current path propagation characteristics
  - Strongest signal selected in case of multipath propagation
- **Guard bits** – used to avoid overlapping with other bursts

GSM TDMA Format – Time Slot Fields



Speech and Data Encoding

- **Speech coding**
  - RPE-LPE, regular pulse excited - linear predictive coding
  - Bits divided into 3 classes with different protection
  - 22.8 kbps resulting data rate
  - spread into different time slots, interleaving
  - Gaussian minimum shift keying (GMSK) is used
- **Data encoding**
  - Error correcting code
  - Interleaving
  - 9.6, 4.8 or 2.4 kbps

Freq. Hopping and Delay Equalization

- Frequency hopping
  - **Slow frequency hopping** (hop for each TDMA frame)
  - Suppresses multipath fading and co-channel interference
- Delay equalization
  - Several users with different distance share same TDMA frame
  - Base station provides control signal, mobile unit adjusts timing
  - Tail and guard bits provide margin

Functions Provided by Protocols

- Protocols above the link layer of the GSM signaling protocol architecture provide specific functions:
  - Radio resource management
  - Mobility management
  - Connection management
  - Mobile application part (MAP)
  - BTS management

CDMA in 2G cellular networks

- Alternative to TDMA
- Uses DS-SS
- Overview given, then look into IS-95

Advantages of CDMA Cellular

- **Frequency diversity** – frequency-dependent transmission impairments have less effect on signal
- **Multipath resistance** – chipping codes exhibit low cross correlation and low autocorrelation
- **Privacy** – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- **Graceful degradation** – system only gradually degrades as more users access the system

Drawbacks of CDMA Cellular

- **Self-jamming** – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- **Near-far problem** – signals closer to the receiver are received with less attenuation than signals farther away. Shows importance of power control.
- **Soft handoff** – requires that the mobile acquires the new cell before it relinquishes the old; this is more complex than hard handoff used in FDMA and TDMA schemes

Mobile Wireless CDMA Design Considerations

- **RAKE receiver** – when multiple versions of a signal arrive more than one chip interval apart, RAKE receiver attempts to recover signals from multiple paths and combine them
  - This method achieves better performance than simply recovering dominant signal and treating remaining signals as noise
  - The notation RAKE…
- **Soft Handoff** – mobile station temporarily connected to more than one base station simultaneously. Possible because no spatial separation of frequencies used.

Principle of RAKE Receiver

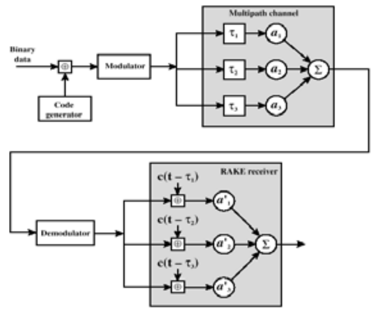
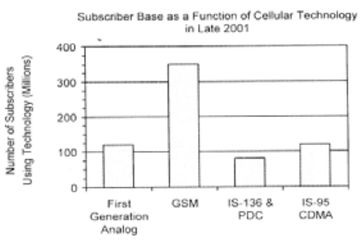


Figure 10.18 Principle of RAKE Receiver [PRAS98]

Interim Standard 95 CDMA (IS-95)

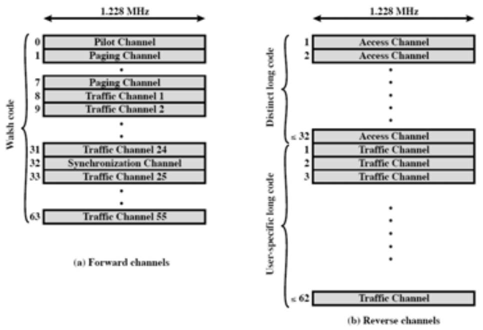
- Also called cdmaOne
- Used mainly in North America, but also in South America and Southeast Asia
- Subscriber comparison at end of 2001:



Types of Channels Supported by Forward Link

- **Pilot** (channel 0) - allows the mobile unit to acquire timing information, provides phase reference and provides means for signal strength comparison
- **Synchronization** (channel 32) - used by mobile station to obtain identification information about cellular system
- **Paging** (channels 1 to 7) - contain messages for one or more mobile stations
- **Traffic** (channels 8 to 31 and 33 to 63) – the forward channel supports 55 traffic channels, up to 14.4 kbps

IS-95 CDMA Channel Structure



3G Wireless Communication Systems

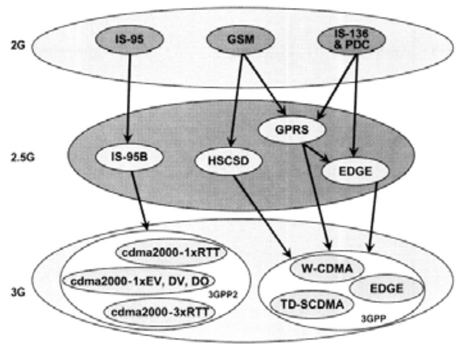
- Provide fairly high-speed wireless communication, supporting multimedia, data, video and voice
- In Sweden 4 operators have “3G license”: Tele2, Telenor, 3 and Telia

ITU’s View of Third-Generation Capabilities

- Voice quality comparable to the public switched telephone network
- 144 kbps data rate available to users in high-speed motor vehicles over large areas
- 384 kbps available to users standing or moving slowly over small areas, and support for 2.048 Mbps for office use
- Symmetrical / asymmetrical data transmission rates
- Support for both packet switched and circuit switched data services
- An adaptive interface to the Internet to reflect efficiently the common asymmetry between inbound and outbound traffic
- More efficient use of the available spectrum in general
- Support for a wide variety of mobile equipment
- Flexibility to allow the introduction of new services and technologies

Upgrade paths 2G ---> 3G

From T.S. Rappaport “Wireless Communications”, Prentice Hall 2002



CDMA Design Considerations

- ***Bandwidth*** – limit channel usage to 5 MHz
- ***Chip rate*** – depends on desired data rate, need for error control, and bandwidth limitations; 3 Mcps or more is reasonable
- ***Multirate*** – advantage is that the system can flexibly support multiple simultaneous applications from a given user and can efficiently use available capacity by only providing the capacity required for each service

W-CDMA Parameters

Channel bandwidth	5 MHz
Forward RF channel structure	Direct spread
Chip rate	3.84 Mcps
Frame length	10 ms
Number of slots/frame	15
Spreading modulation	Balanced QPSK (forward) Dual channel QPSK (reverse) Complex spreading circuit
Data modulation	QPSK (forward) BPSK (reverse)
Coherent detection	Pilot symbols
Reverse channel multiplexing	Control and pilot channel time multiplexed. I and Q multiplexing for data and control channels
Multirate	Various spreading and multicode
Spreading factors	4 t0 256
Power control	Open and fast closed loop (1.6 kHz)
Spreading (forward)	Variable length orthogonal sequences for channel separation. Gold sequences 2^{18} for cell and user separation.
Spreading (reverse)	Same as forward, different time shifts in I and Q channels.
Handover	Soft handover

3G Evolution

- Driving forces
  - Staying competitive
  - Better service and new services
  - Cost-efficient provision of current and new services
- Services
  - Internet and IP technology
  - Traditional telephony services (Going toward IP-based services from circuit switching to packet switching)
  - Wide-spectrum of service needs
- Cost and Performance
  - IP technology can be used to introduce new services, and don't require an extensive special design of the system.
  - All users with different services need to be served efficiently.

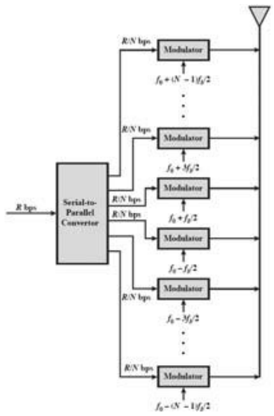
3G Evolution

- HSPA (High speed packet access)
  - Evolution from WCDMA and backward compatible
  - Adding few features to existing standards, similar to GSM
  - WCDMA, HSDPA, HSPA are in commercial operation.
- Long-term evolution (LET) radio interface starting in 2004 by 3GPP
  - Intended to be a mobile system taking industries to be 2020s.
  - No need to backward compatible with WCDMA and HSPA.
  - Radio interface is purely optimized for IP transmission , no requirement to support GSM circuit-switching services (but WCDMA has).
  - Influenced by WCDMA and HSPA.
  - Using multiple carrier and multiple antennas technologies.

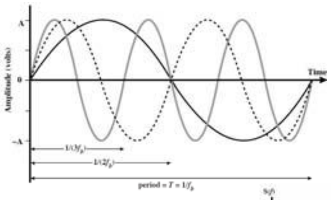
Orthogonal Frequency Division Multiplexing (OFDM)

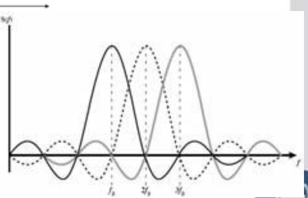
- OFDM (also referred as multicarrier modulation)
  - Multiple carrier signals at different frequencies
  - Similar to FDM but subchannles are delicated to a single user
  - Distribute the data over multiple carriers at precise frequencies
- Promising technology for high-speed transmission
  - LTE

OFDM



Three subcarriers in T/F domain





Questions and problems, WS chapter 10

- Recommended questions in ch. 10:
  - 2, 3, 5, 6, 9, 10, 11, 12, 13
- Recommended problems in ch. 10:
  - 1, (3), 5, 8, 12, 13, 15a-d