Cellular Wireless Networks

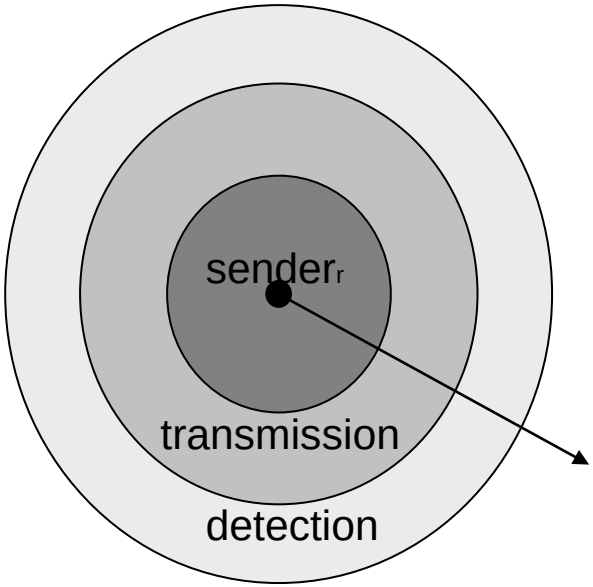
- Examples of wireless networks
  - –Cellular telephony
  - –Satellite networks
  - –Metropolitan-area data networks
  - –Local-area networks
  - –Infostations (mobile hosts traveling through fixed network)
  - –Ad hoc networks (mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure)
  - –Other networks: Personal area networks, sensor networks, home networks, smart dust, ubiquitous computing environments, ambient intelligence buildings, etc

Ιδιαιτερότητες ασύρματων δικτύων

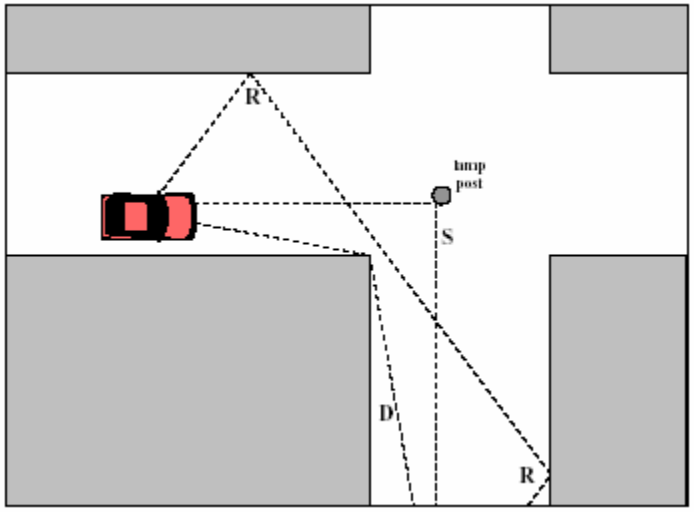
1. Χαμηλός ρυθμός μετάδοσης
2. Υψηλή μεταβλητότητα του ρυθμού μετάδοσης
3. Κινητικότητα
4. Ετερογενή δίκτυα
5. Κίνδυνοι ασφαλείας
6. Περιορισμένη ενέργεια
7. Κίνδυνοι απώλειας δεδομένων
8. Μικρή επιφάνεια διεπαφής

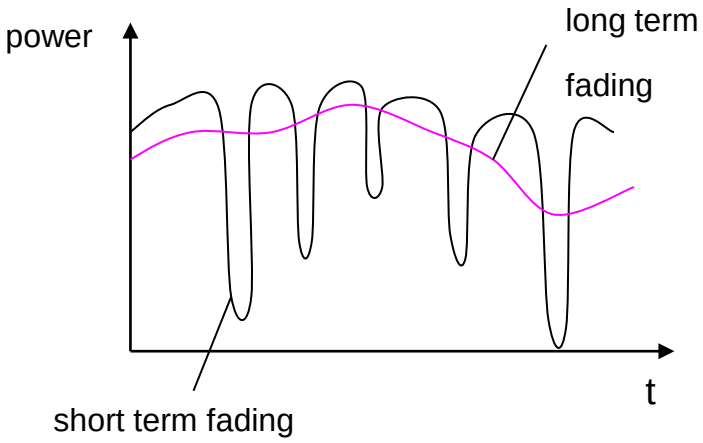
Αλλά και ευκολία μεταφοράς (επικοινωνία anywhere. any time)

Ισχύς σήματος

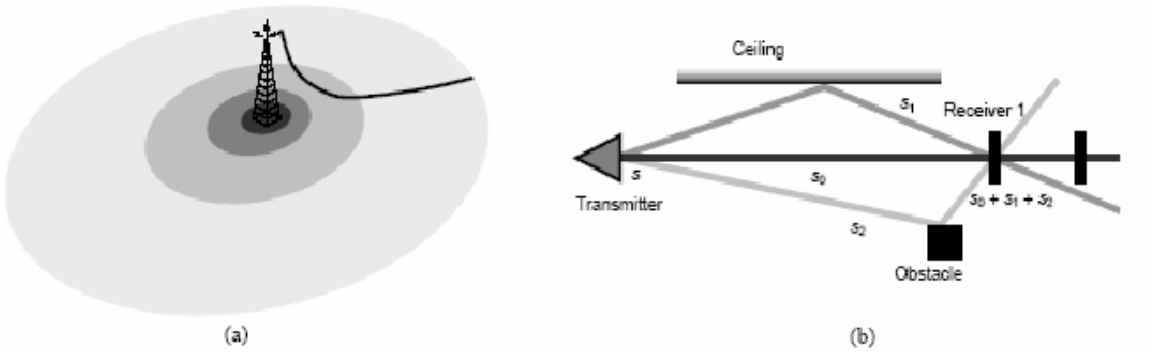


Διάδοση του σήματος





$$P_R(d) \propto \frac{G \times P_T}{f^2 \times d^\alpha}$$



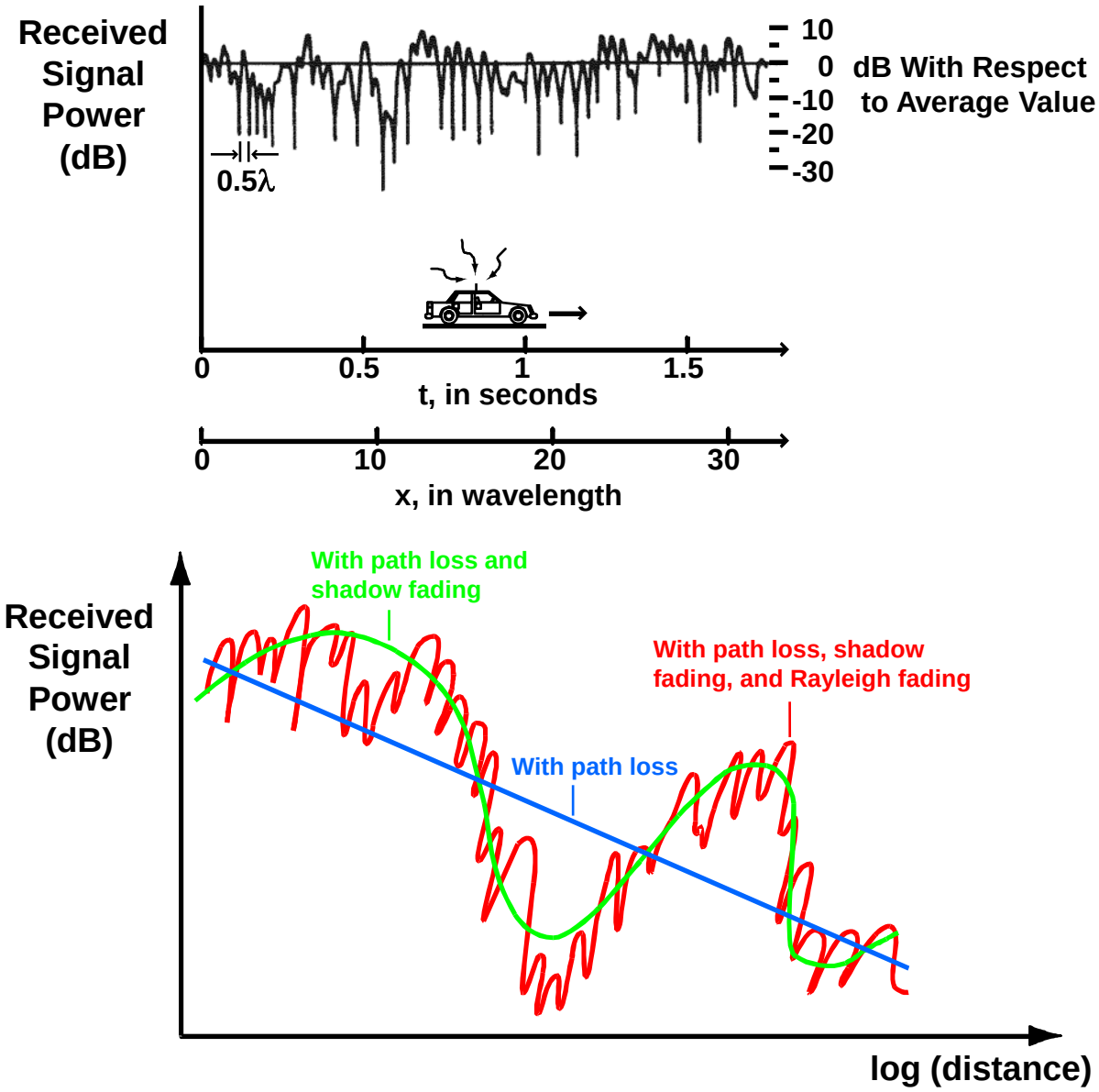
Path loss. (a) Propagation loss. (b) Multipath fading.

Environment	Propagation loss exponent α
Free space	2
Urban cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building with line of sight	1.6 to 1.8
Obstructed in building	4 to 6

For example, typical ranges of IEEE 802.11b is:

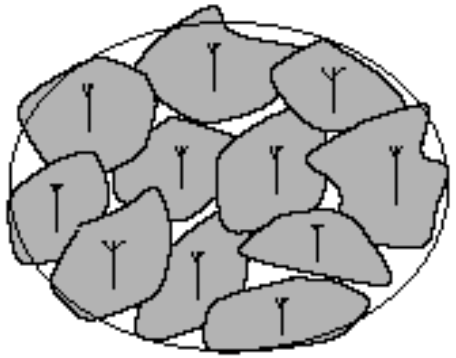
- 30-50 m at 11 Mbps
- 40-60 m at 5.5 Mbps
- 80-120 m at 2 Mbps

A problem with propagation loss is that it becomes much more significant at higher frequency, see equation (2.1). For example, increasing the signal frequency by a factor of 10 reduces the received power by a factor of 100. What this means in practice is that the networks operating at a higher frequency require larger number of "cells" to cover the same area. E.g., IEEE 802.11a wireless LAN, which operates at 5 GHz, requires much greater number of access points than an IEEE 802.11b 2.4 GHz system to cover the same area.


Received Signal Power (dB)
10
0
-10
-20
-30
dB With Respect to Average Value
0.5λ
0
0.5
1
1.5
t, in seconds
0
10
20
30
x, in wavelength
Received Signal Power (dB)
With path loss and shadow fading
With path loss, shadow fading, and Rayleigh fading
With path loss
log (distance)

Cellular Network Organization

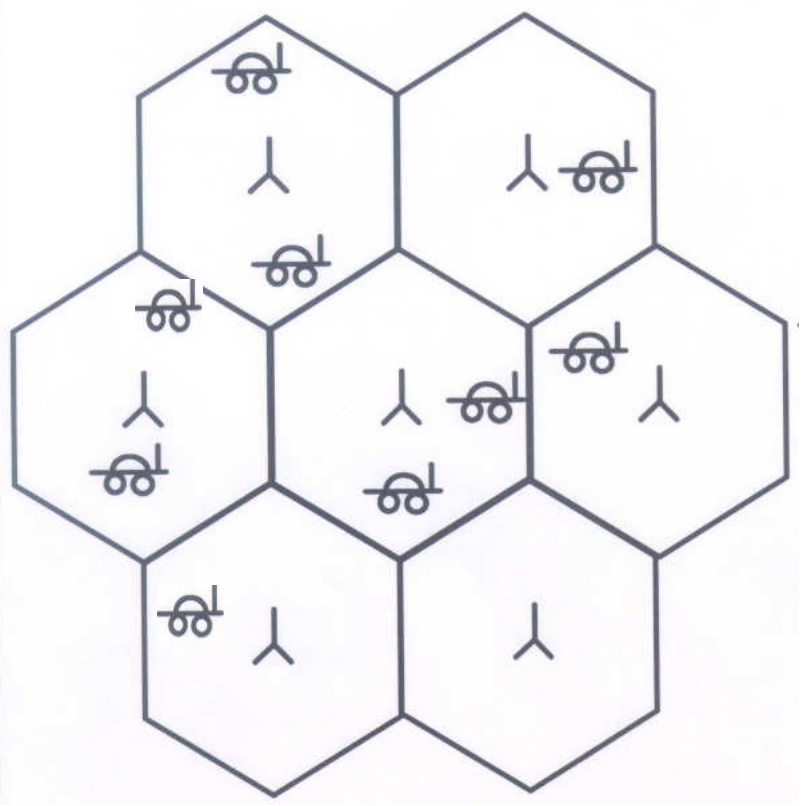
- Use multiple low-power transmitters (100 W or less)
- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver, and control unit
  - Certain channels (e.g. bands of frequencies) allocated to each cell
  - Cells set up such that antennas of all neighbors are approximately equidistant (hexagon



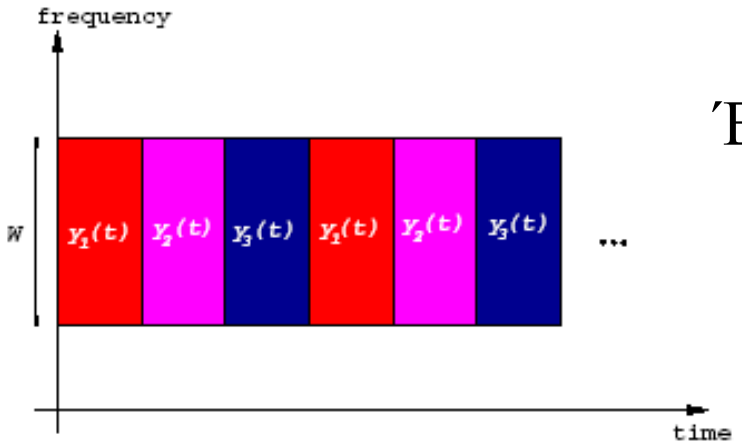
Σταθμός βάσης (base station)

Κινητός σταθμός (mobile station)

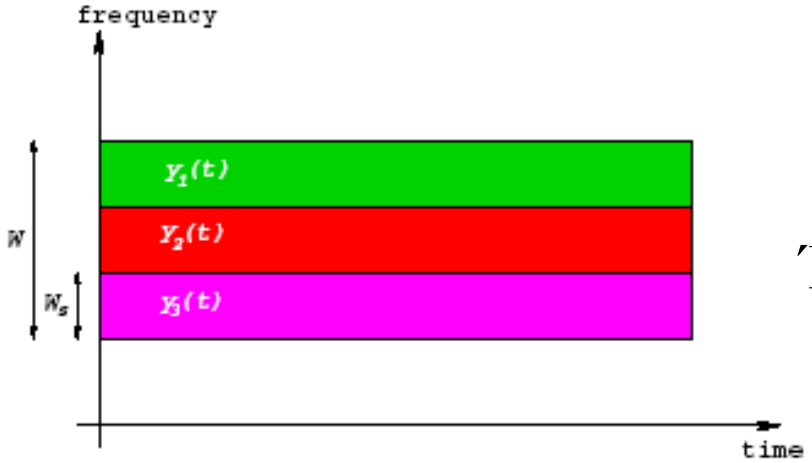
MSC ή MTSO — **Κινητό Κέντρο Μεταγωγής (Mobile Switching Center ή Mobile Telephone Switching Office)**



Μέθοδοι πολυπλεξίας

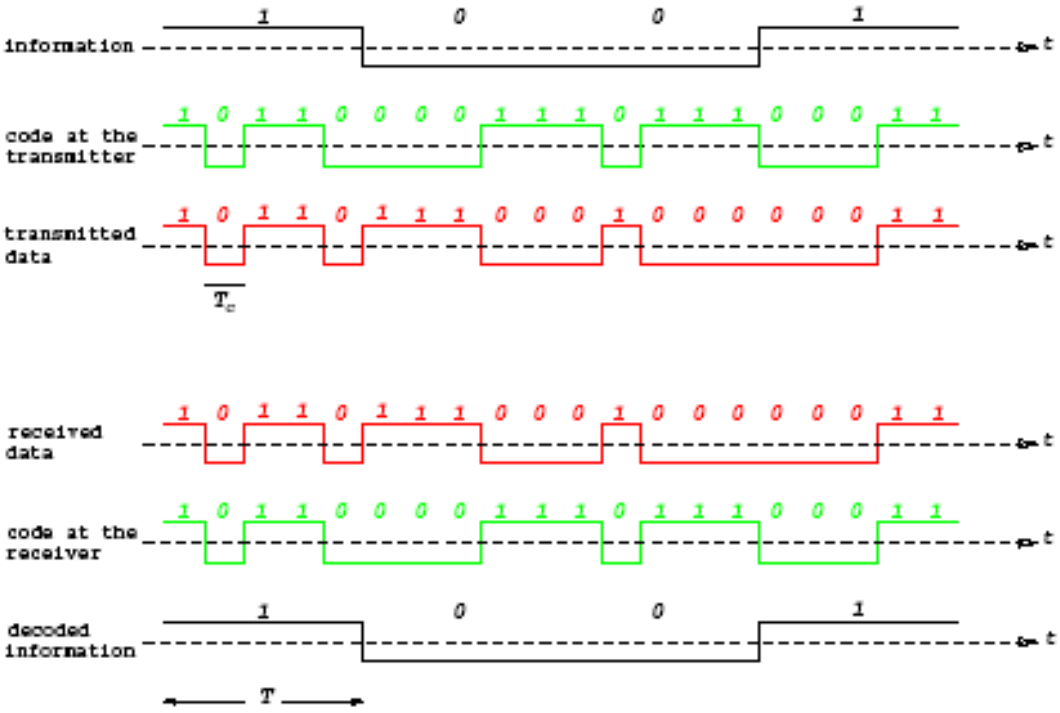


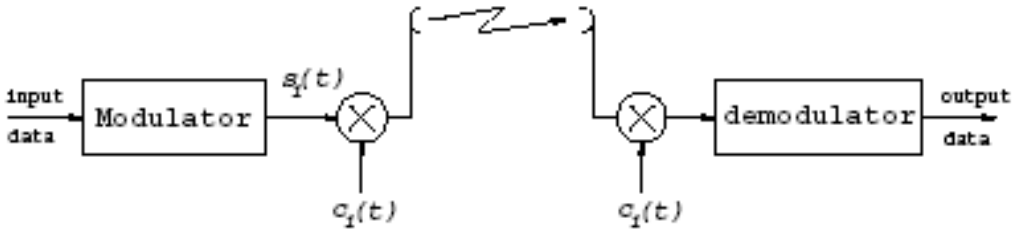
Ένα TDMA σύστημα με 3 χρήστες



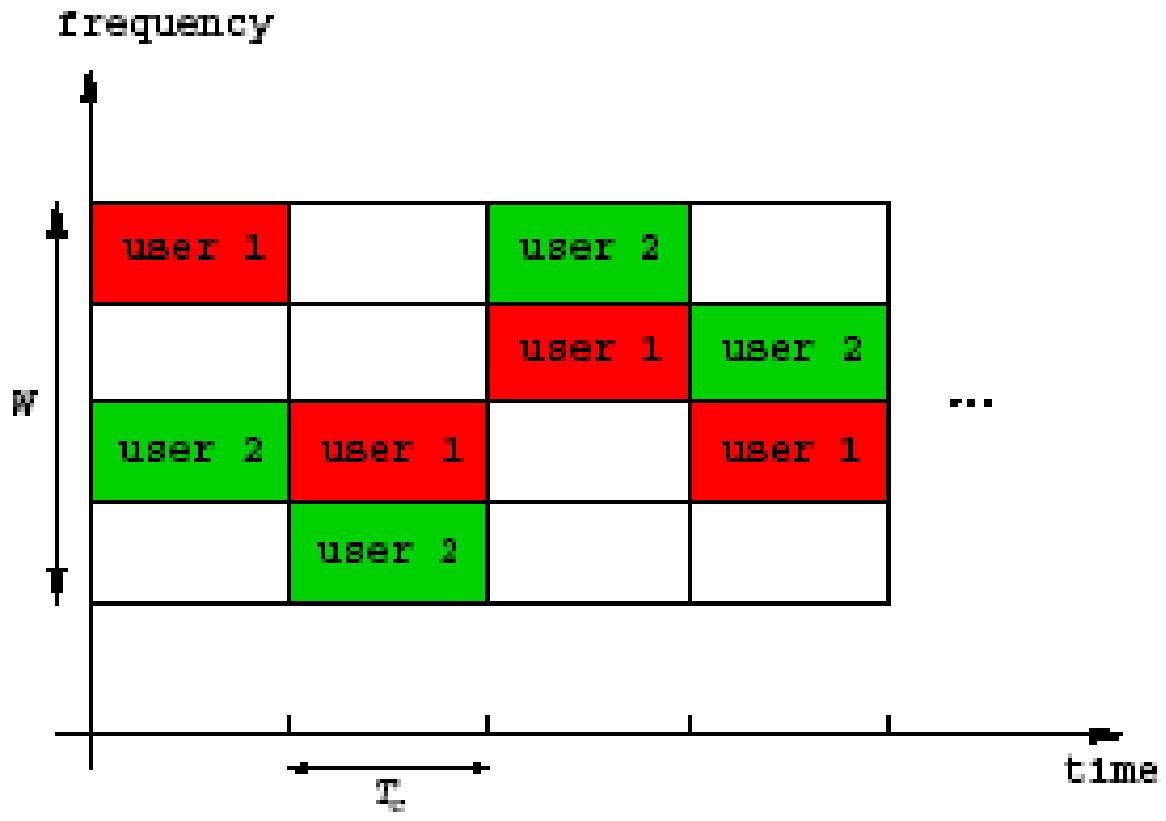
Ένα FDMA σύστημα με 3 χρήστες.

Direct Sequence CDMA (DS-CDMA)





Frequency Hopping CDMA



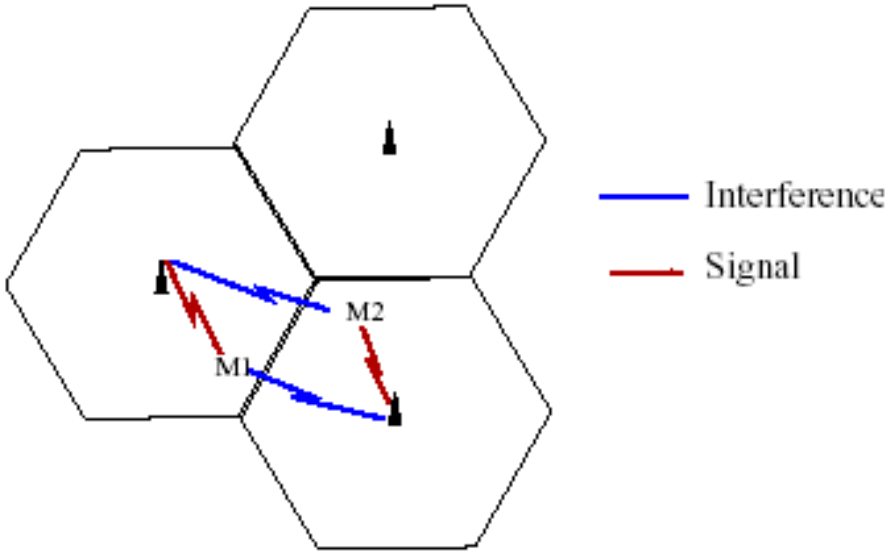
Frequency Reuse

Cellular systems are interference-limited, not noise limited.

- Adjacent cells assigned different frequencies to avoid interference
- Objective is to reuse frequency in nearby cells
  - 10-50 channels (TDM, FDM or CDMA) assigned per cell
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells

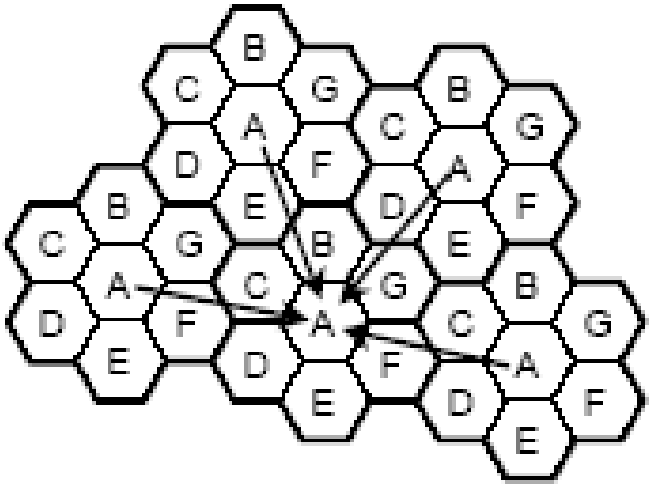
Co-channel interference

Another transmission on same frequency channel impinges on receiver.



Reuse distance: minimum distance between two cells that can use the same frequency channel with acceptable levels of cochannel interference.

$$SIR = \frac{P_{desired}}{\sum_i P_{interference,i}}$$



$$SIR = \frac{GP_T f^{-2} d_1^{-\alpha}}{GP_T f^{-2} d_2^{-\alpha}} = \left(\frac{d_2}{d_1}\right)^{\alpha}$$

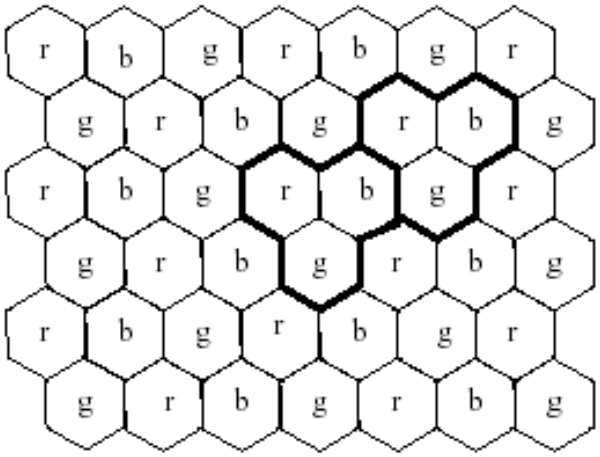
The issue is to determine how many cells must intervene between two cells using the same frequency

Cochannel interference

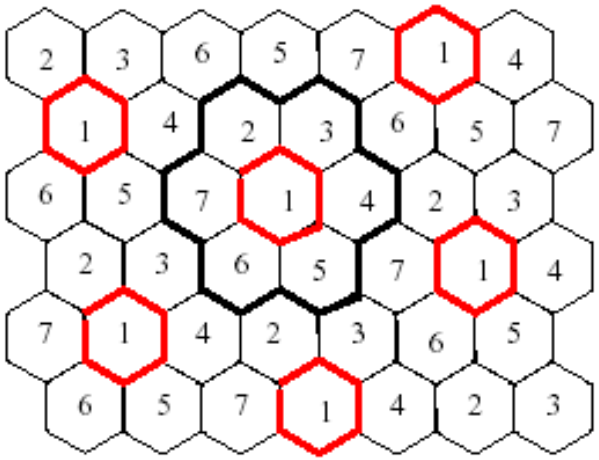
- Desired C/I ratio determines the **reuse distance.**
- Let D = distance between cochannel transmitters and R= cell radius.
- D/R= (6C/I)^(1/4).
- Eg: If C/I=18dB is required (signal about 60 times stronger than interference), then D/R=4.4.
- Digital techniques can withstand higher levels of interference, maybe C/I of 9db => D/R=2.6.

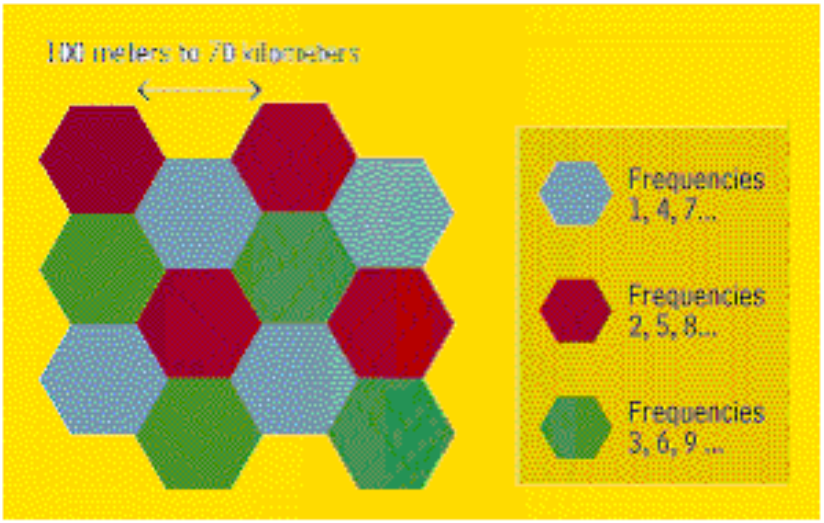
Reuse patterns

Reuse distance 2



Reuse distance 3

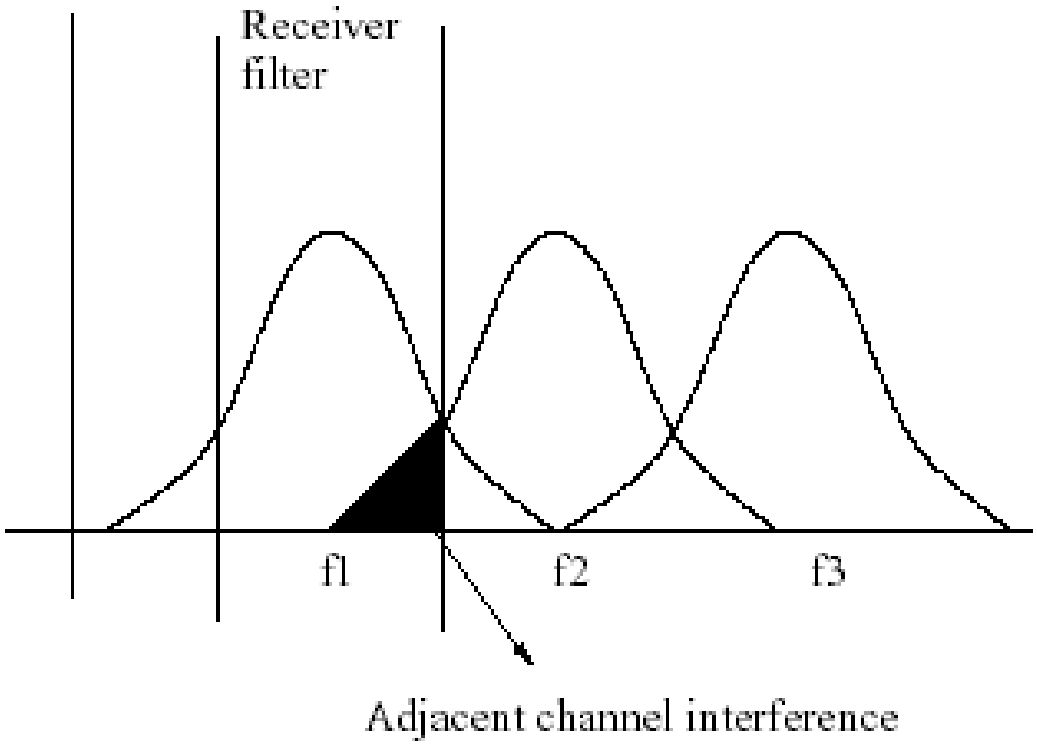




Σε ένα ιδανικό κυψελικό δίκτυο με απόσταση επαναχρησιμοποίησης συχνοτήτων ίση με 2, σε κάθε κυψέλη διατίθεται το 1/3 του διαθέσιμου εύρους ζώνης.

Στο GSM, το εύρος ζώνης κάθε κυψέλης χωρίζεται σε FDMA υπο-ζώνες εύρους 200KHz η κάθε μία. Η κάθε υπο-ζώνη στην συνέχεια χωρίζεται μέσω TDMA σε 8 κανάλια, το καθένα από τα οποία εξυπηρετεί μία κλήση.

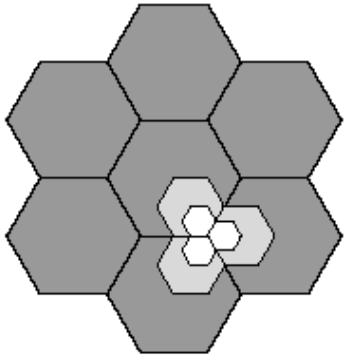
Adjacent channel interference: energy from other channels spills over into the carrier's channel.



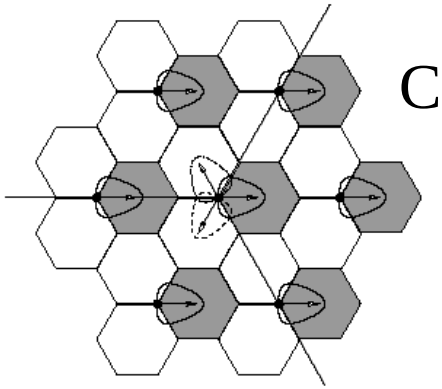
Adjacent channel interference can be controlled with transmit and receive filters

Approaches to Cope with Increasing Capacity

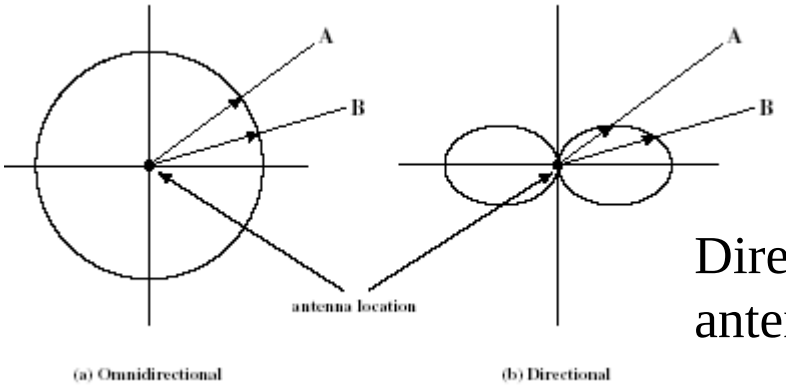
- Adding new channels
- Channel borrowing – channels are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided using directional antennas into a number of sectors, each with their own set of channels
- Microcells – antennas move to buildings, lamp posts. **Very Small Cells, possibly an antenna in every room**



Cell splitting

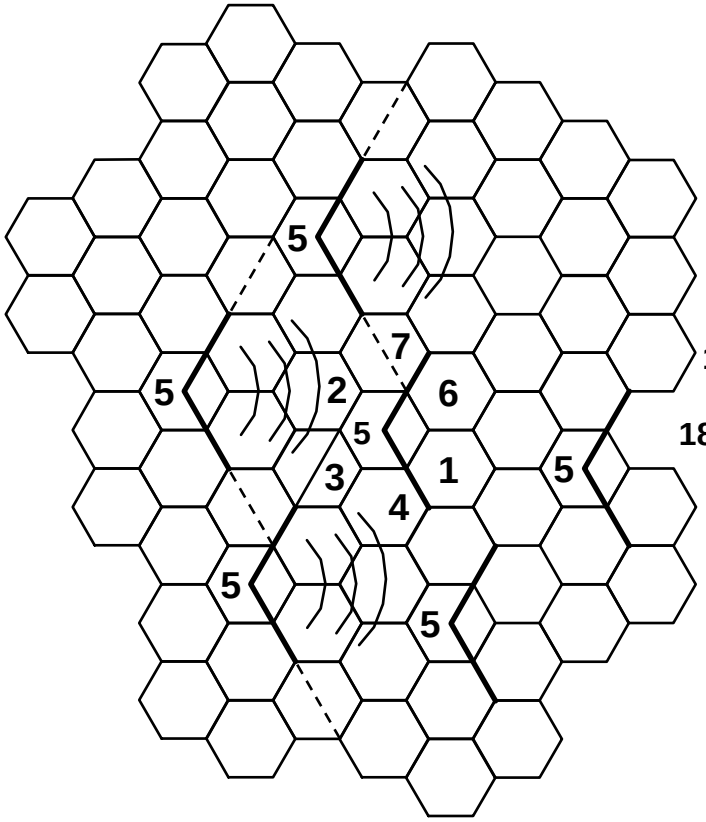


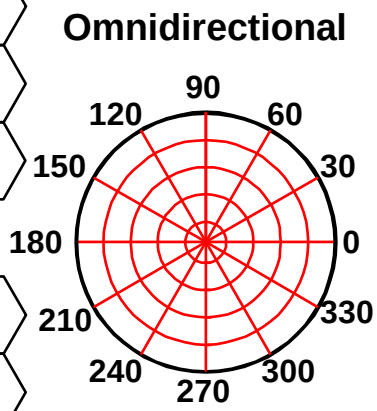
Cell sectoring

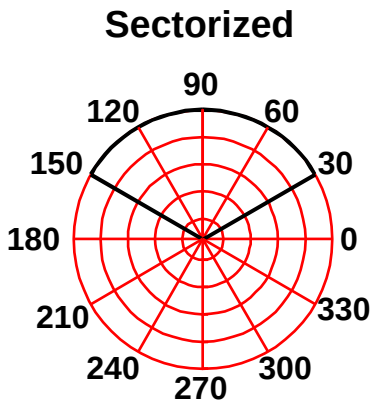


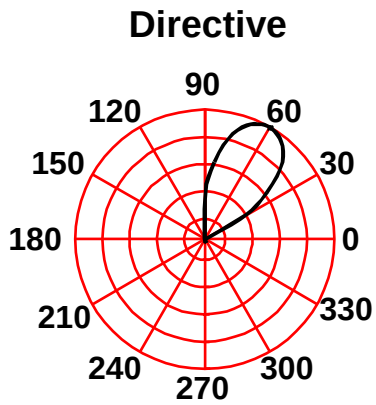
Directional antennas

SECTORIZATION

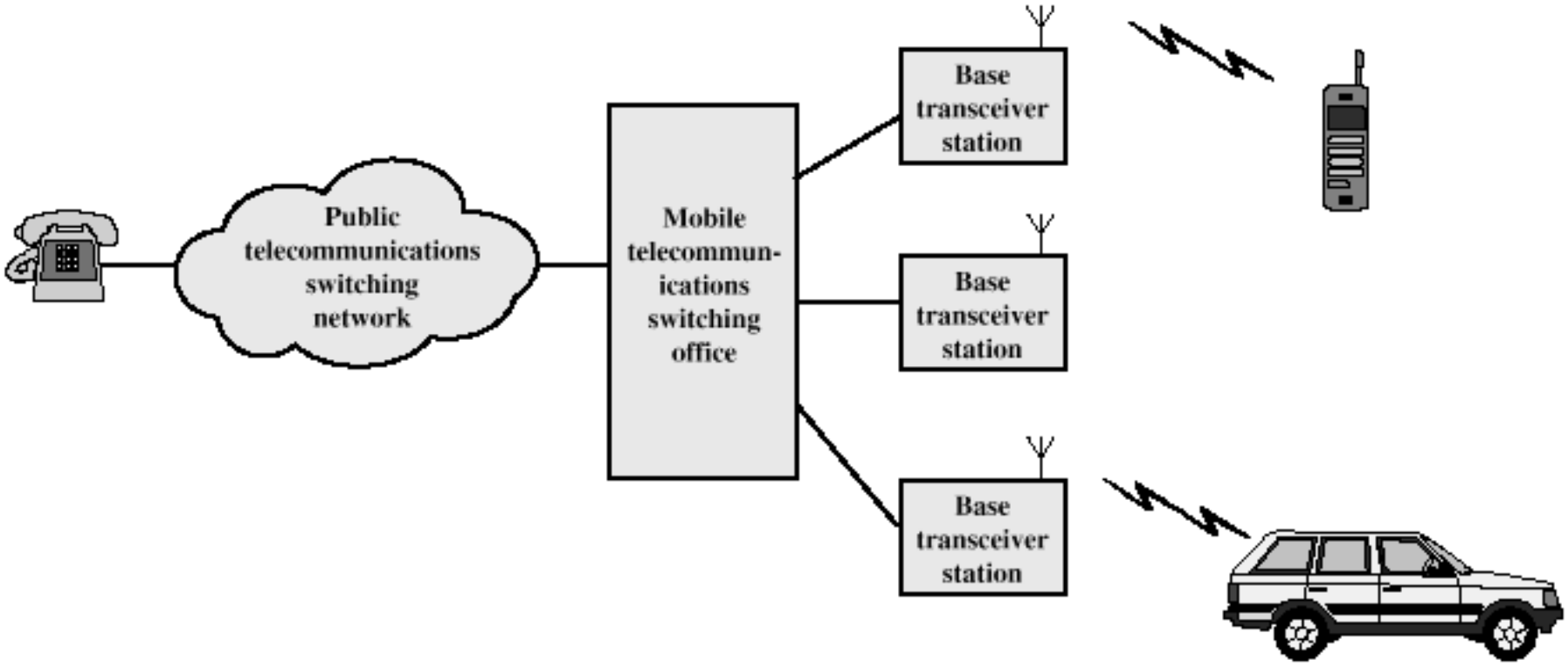








- 120° sectoring reduces interference from co-channel cells.
- Out of the 6 co-channel cells in the first tier, only 2 interfere with the center cell.
- If omni-directional antennas were used at each base station, all 6 co-channel cells would interfere with the center cell.



•Base Station (BS) – includes an antenna, a controller, and a number of receivers

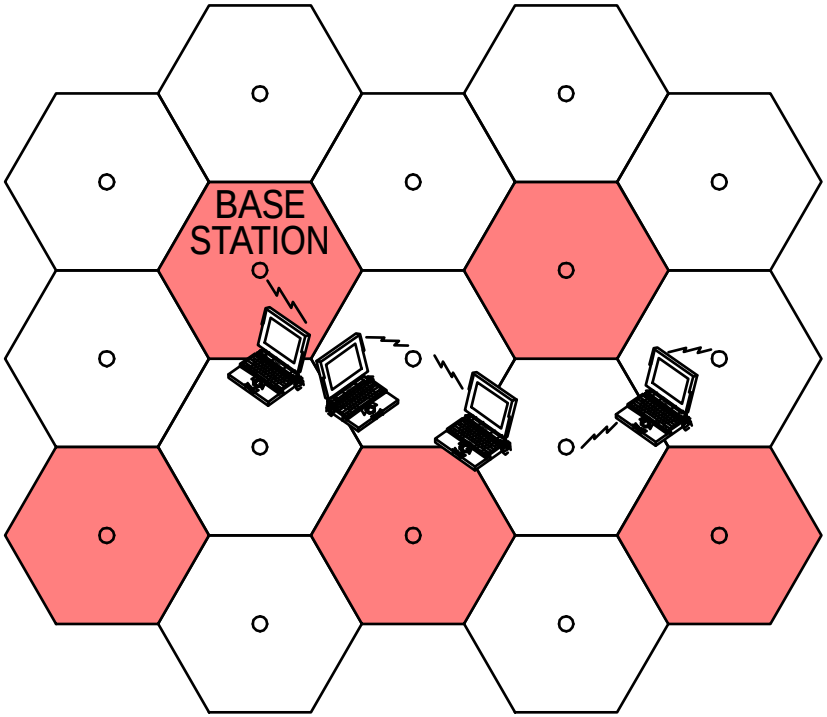
•Mobile telecommunications switching office (MTSO) – connects calls between mobile units. Also called MSC (Mobile Switching Center). Responsible for handoffs

•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 (out-band or in-band through stealing bits)

–Traffic channels – carry voice or data connection between users

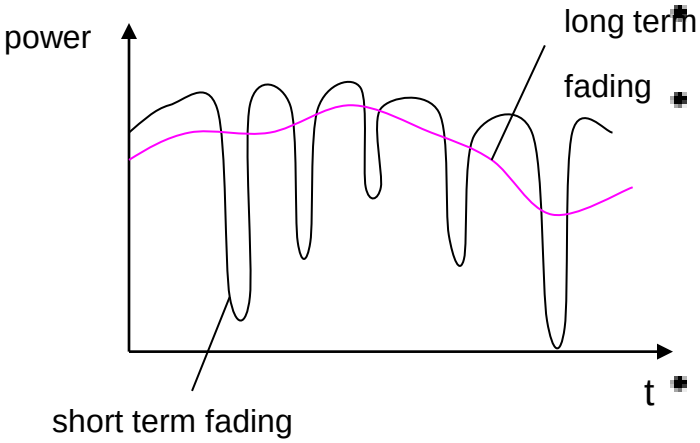
Handoffs (ή handovers)



Who detects the need for handoff?

- **Mobile initiated**: Mobile makes quality measurements on various channels, picks the best one, and switches, with network's cooperation.
- **Network initiated**: Base stations make measurements of signal strengths, and report back to MSC, which makes the decision to handoff.
- **Mobile assisted**: Network and mobile both make measurements. Portable reports signal strengths from nearby base stations. Network makes the decision.

Handoff detection



- Parameters that are used to decide: Word Error Rate (WER), signal strength, channel quality indicators (eg. SNR)
- WER needs time to accumulate.
- Signal strength can be known immediately, but due to fast or slow fades, is not always a reliable indicator. Some kind of averaging must be performed.
- Usually want to prevent a mobile from making a handoff too quickly after a successful handoff.

•Usually relative signal strength with hysteresis and threshold is used. Also, prediction techniques.

Hard handoff

- Let *Sx* and *Sy* be the signal strengths from base stations *Bx* and *By* (respectively) to a user.
- The algorithm may look like this:

  If *(Sy − Sx) > D* and *serving station is Bx*
  then handoff to *By*
  else if *(Sx − Sy) > D* and *serving station is By*
  then handoff to *Bx*
  else do not handoff.

- *D* is called the hysteresis margin.
- A big margin means more delay. Also, the user has a poor quality link during the delay, and will be causing extra interference to neighboring cells, since he is near the edge of the cell. Especially problematic in systems with power control.
- A small margin means more of a pingpong effect.

Soft handoff

- Conditional decision is made to handoff. In the meantime, the mobile is attached to both stations.
- Each mobile has an *active set* of stations. A base station is added to the active set if the signal strength from it exceeds the *add threshold*. It is removed from the active set is the strength has been lower than the *drop threshold* for a time longer than *T_drop*.
- Parameters have to be set carefully.
- **Advantages**: Less pingpong effect. Smoother handoff. No delay. Lower probability of dropped calls.
- **Disadvantages**: More channels are being locked up. Downlink interference is increased since many base stations are transmitting what needs to be transmitted by one.

Channel assignment and handoff

- Channel assignment schemes have to deal with two types of calls: **new calls** and **handoff calls**.
- If no channel is found, a new call is said to be **blocked**, while a handoff call is **dropped**.
- Generally considered less desirable to drop a call already in progress than to block a new call.
- Grade of service= Prob(blocking) + a Prob(dropping)
- Preference should be given to handoff calls.

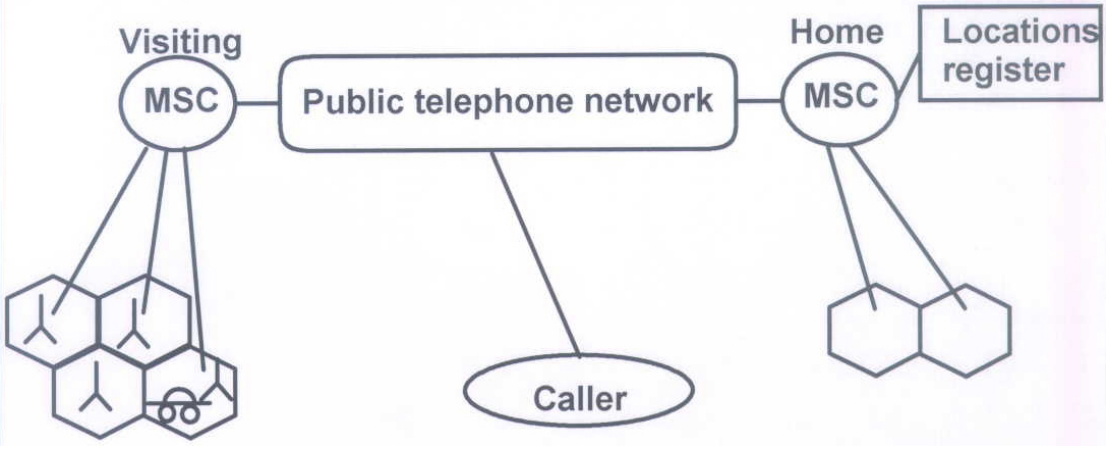
- **Guard channels**: Reserve a certain number of channels for handoff calls exclusively. New calls do not have access to these, but handoff calls have access to both regular channels and guard channels.
- Adaptively change the number of guard channels.
- **Queuing** of calls.

Power Control

- It is 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, in order to reduce cochannel interference, alleviate health concerns, save battery power
  - In SS systems using CDMA, it's desirable to equalize the received power level from all mobile units at the BS (the so called near-far problem)
- **Open-loop power control** (depends solely on mobile unit; not as accurate as closed-loop, but can react quicker to fluctuations in signal strength)
- **Closed-loop power control** (BS makes power adjustment decision and communicates to mobile on control channel)

Mobile Switching Center (MSC) 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
- Equipment identity register database (EIR) – keeps track of the type of equipment that exists at the mobile station



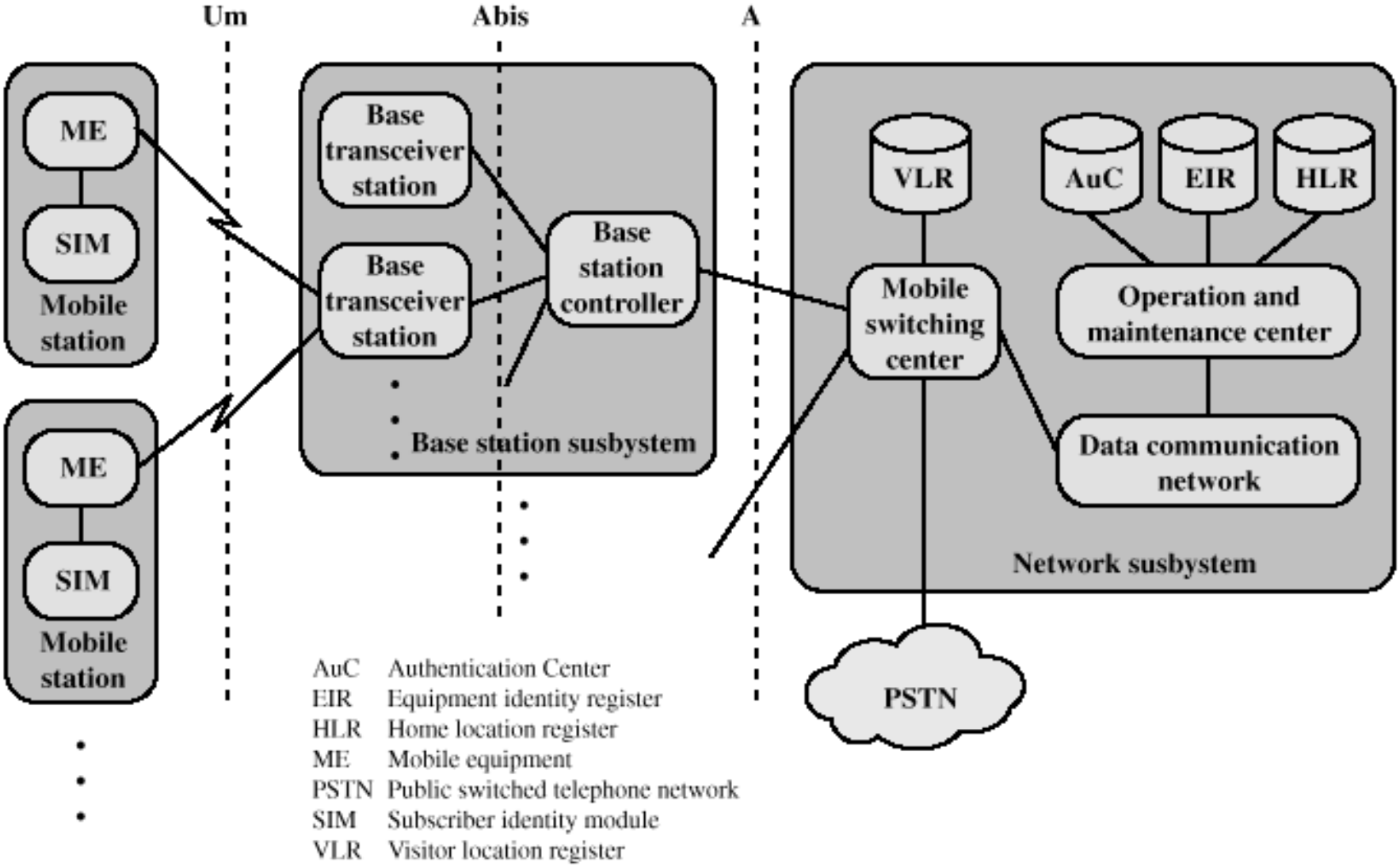


Figure 10.14 Overall GSM Architecture