EEC173B/ECS152C, Winter 2006

Fundamentals of Wireless Communications

- #4: Spread Spectrum
- #5: Multiplexing
- #6: Frequency Reuse (Cellular Concept)

Case Study: Wireless cellular networks

- #7: Handoff

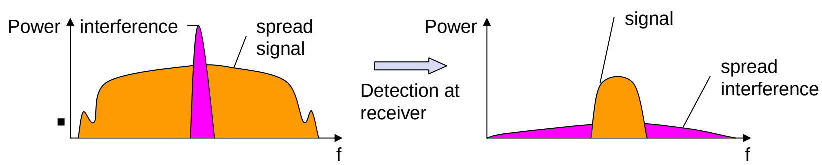
Acknowledgment: Selected slides from Prof. Schiller

How do we overcome limitations imposed by the radio channel?

- Flat fading countermeasures
  - Fade Margin
  - Diversity
  - Coding and Interleaving
  - Adaptive Techniques
- Delay Spread Countermeasures
  - Equalization
  - Multicarrier
  - Spread Spectrum
  - Antenna Solutions

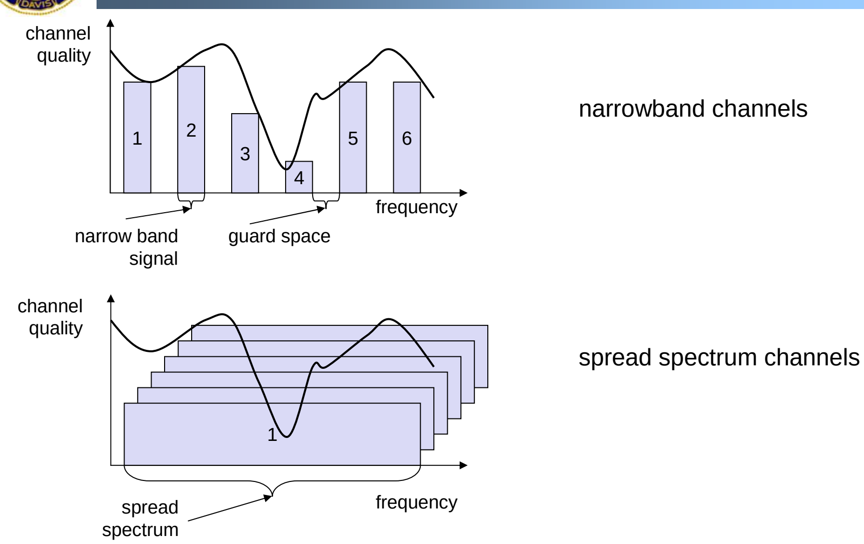
#4: Spread Spectrum Technology

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code
- Protection against narrow band interference



3

Spreading and frequency selective fading



4

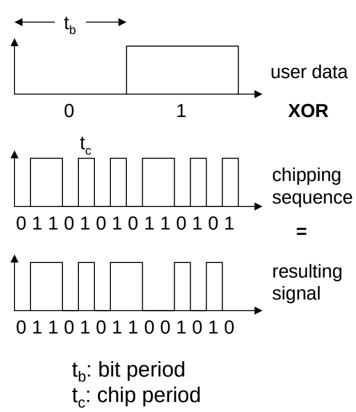
Spread Spectrum

- Spread spectrum increases the transmit signal bandwidth to reduce the effects of flat fading, ISI and interference.
- SS is used in all wireless LAN products in the ISM band
  - Required for operation with reasonable power
  - Minimal performance impact on other systems
  - IEEE 802.11 standard
- There are two SS methods: direct sequence and frequency hopping
  - Direct sequence multiplies the data sequence by a faster chip sequence.
  - Frequency hopping varies the carrier frequency by the same chip sequence

5

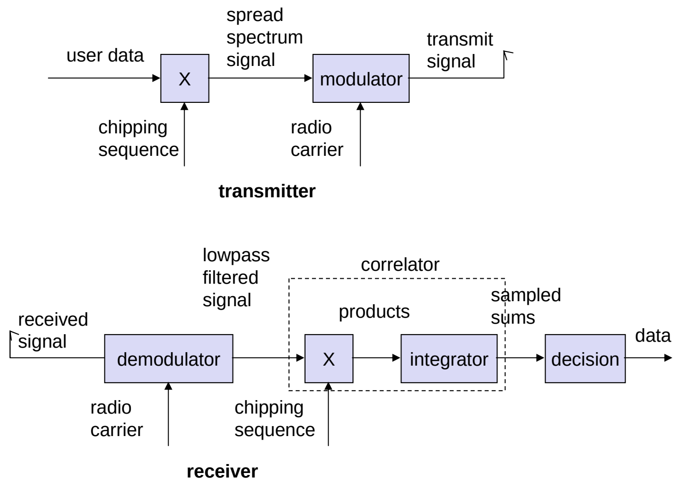
Direct Sequence Spread Spectrum (DSSS)

- XOR of the signal with pseudo-random number (chipping sequence)
  - Many chips per bit (e.g., 128) result in higher bandwidth of the signal
- Advantages
  - Reduces frequency selective fading
  - In cellular networks
    - Base stations can use the same frequency range
    - Several base stations can detect and recover the signal
    - Soft handover
- Disadvantages
  - Precise power control necessary



6

DSSS



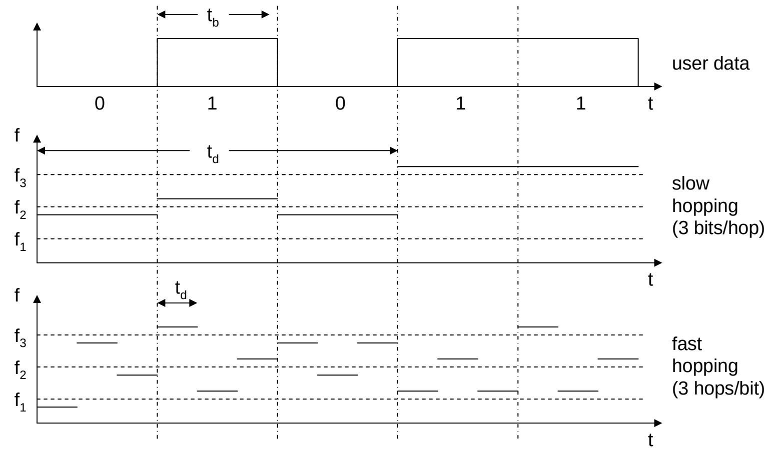
7

Frequency Hopping Spread Spectrum (FHSS)

- Discrete changes of carrier frequency
  - Sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency
- Advantages
  - Frequency selective fading and interference limited to short period
  - Simple implementation
  - Uses only small portion of spectrum at any time
- Disadvantages
  - Not as robust as DSSS
  - Simpler to detect

8

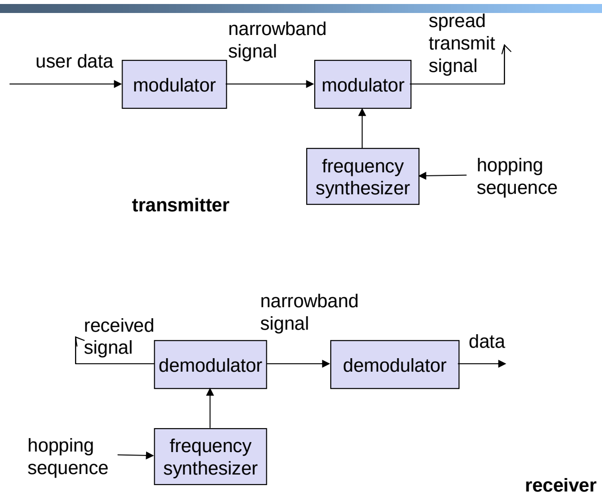
FHSS (Frequency Hopping Spread Spectrum) II



t_b: bit period t_d: dwell time

9

FHSS



10

EEC173B/ECS152C, Winter 2006

Fundamentals of Wireless Communications

- #4: Spread Spectrum
- #5: Multiplexing
- #6: Frequency Reuse (Cellular Concept)

Case Study: Wireless cellular networks

- #7: Handoff

Acknowledgment: Selected slides from Prof. Schiller

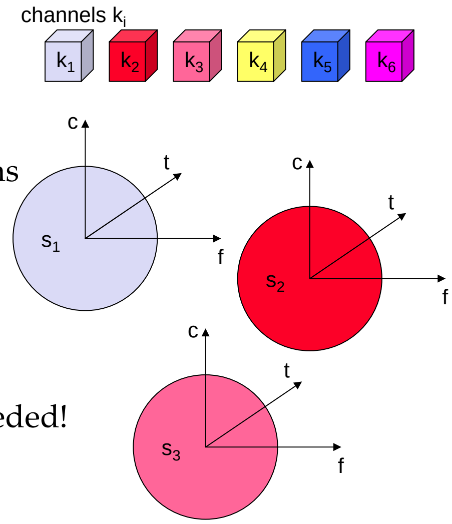
#5: Multiple Access

Single shared (broadcast) wireless communication channel

- Only one can send successfully at a time
- Two or more simultaneous transmissions
  - Interference
- How to share the wireless media?
- Design goals
  - Fairness among users
  - High efficiency
  - Low delay
  - Fault tolerance
- Design choice
  - Fully centralized (controlled) vs. decentralized

Multiplexing

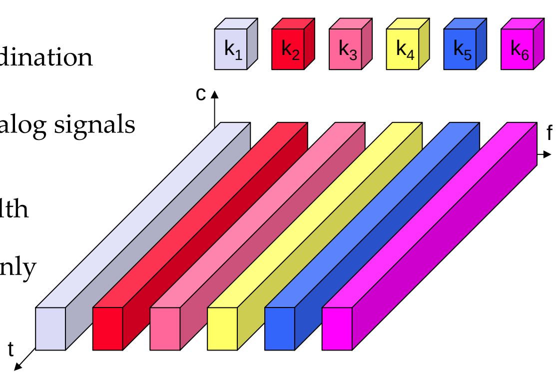
- Goal: multiple use of a shared medium
- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)
- Important: guard spaces needed!



13

Frequency multiplex

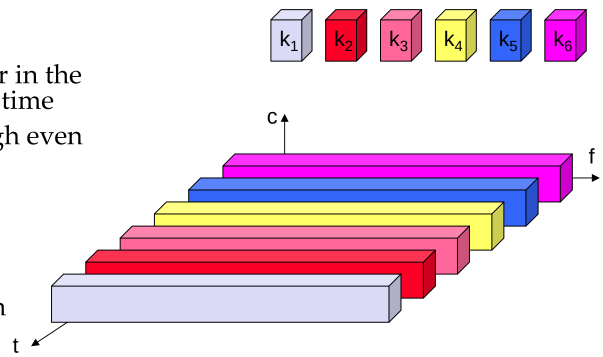
- Separation of the whole spectrum into smaller frequency bands and allocate to different users
- A channel gets a certain band of the spectrum for the whole time
- Advantages:
  - No dynamic coordination necessary
  - Works also for analog signals
- Disadvantages:
  - Waste of bandwidth if the traffic is distributed unevenly
  - Inflexible
  - Guard spaces



14

Time multiplex

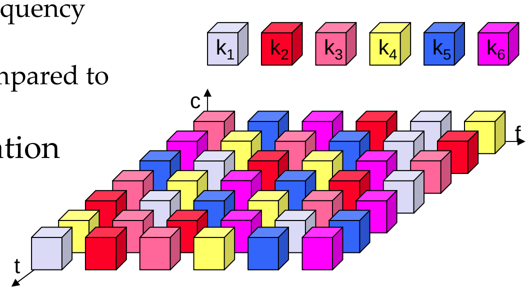
- A channel gets the whole spectrum for a certain amount of time
  - Time is divided into slots which are allocated to different users
- Advantages:
  - Only one carrier in the medium at any time
  - Throughput high even for many users
- Disadvantages:
  - Precise synchronization necessary



15

Time and frequency multiplex

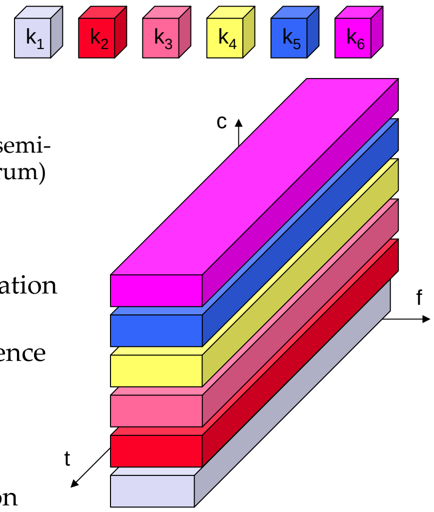
- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time
- Example: GSM
- Advantages:
  - Better protection against tapping
  - Protection against frequency selective interference
  - Higher data rates compared to code multiplex
- But: precise coordination required



16

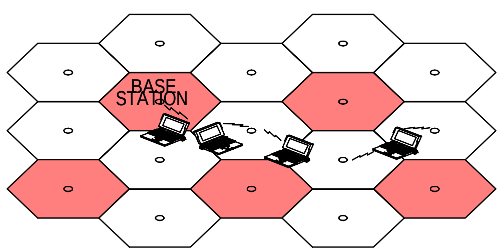
Code multiplex

- Time and bandwidth are used simultaneously by different users
- Each channel has a unique code
  - Signal modulated by orthogonal or semi-orthogonal codes (e.g., spread spectrum)
- Advantages:
  - Bandwidth efficient
  - No coordination and synchronization necessary
  - Good protection against interference and tapping
- Disadvantages:
  - Lower user data rates
  - More complex signal regeneration



17

#6: Frequency Reuse



- Frequencies (or time slots or codes) are reused at spatially-separated locations.
- Introduces interference => system capacity is interference-limited.
- Mainly designed for circuit-switched communications, e.g., cellular network

18

Cell structure

- Implements space division multiplex: base station covers a certain transmission area (cell)
- Mobile stations communicate only via the base station
- Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies

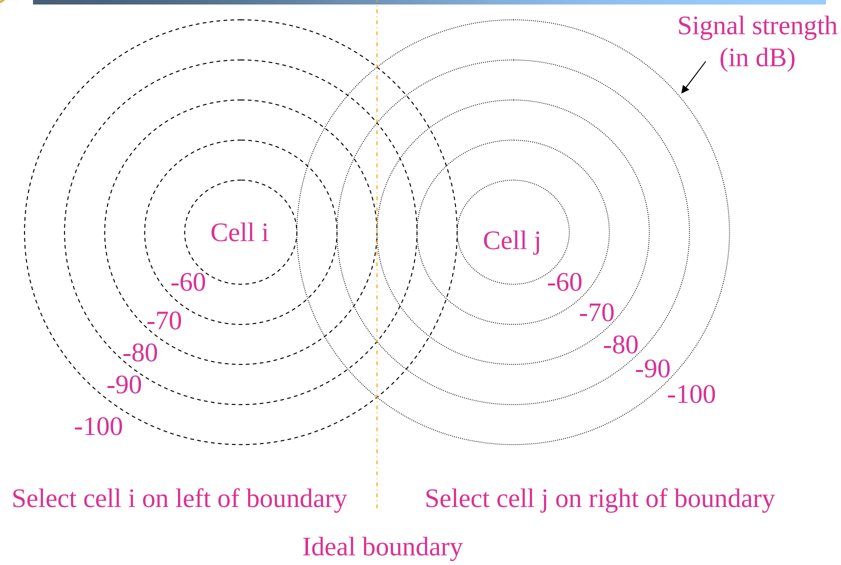
19

Cellular Concept

- Advantages of cell structures:
  - Higher capacity, higher number of users
  - Less transmission power needed
  - More robust, decentralized
  - Base station deals with interference, transmission area etc, locally
  - Base stations perform centralized control functions. (call setup, handoff, routing, etc.)
- Problems:
  - Fixed network needed for the base stations
  - Handover (changing from one cell to another) necessary
  - Interference with other cells

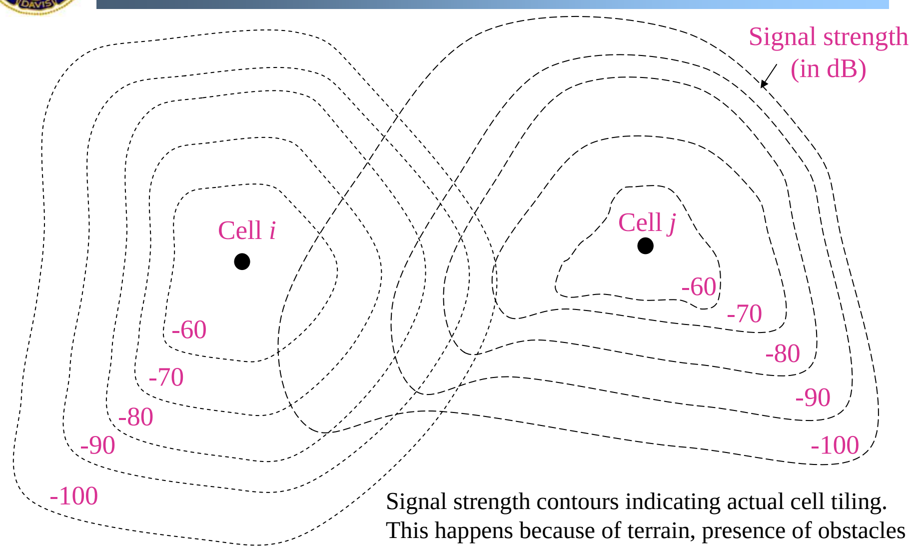
20

Signal Strength



21

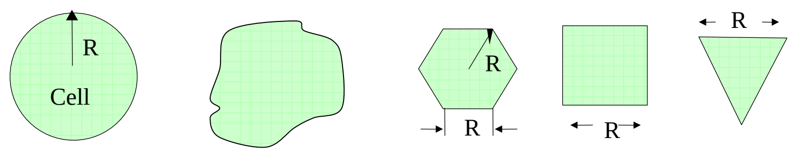
Signal Strength (In Practice)



Signal strength contours indicating actual cell tiling. This happens because of terrain, presence of obstacles and signal attenuation in the atmosphere.

22

Cell Shape

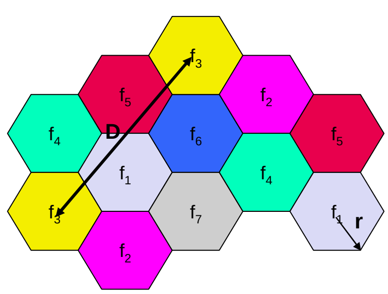


(a) Ideal cell (b) Actual cell (c) Different cell models

23

Frequency Planning (1)

- Each cell size has a radius, *R*
- Frequency reuse only with a certain distance, *D*, between the base stations
- Standard model using 7 frequencies:
  - Cluster size, $N = 7$



24

Design Considerations

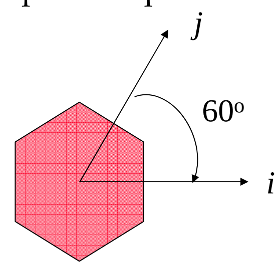
- Reuse distance (D)
  - Distance between two cells using the same frequency (time slot/code)
  - Smaller reuse distance packs more users into a given area, but also increases their co-channel interference
- Cell Radius (R)
  - Decreases the cell size increases the system capacity, but complicates network functions of handoff and routing

Frequency Planning (2)

- N cannot be just any number!
- The cluster size (or the number of cells per cluster, or the total number of frequencies per cluster) is given by

$$N = i^2 + ij + j^2$$

where i and j are integers.

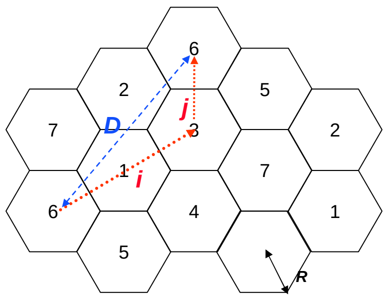


N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, …, etc.

The popular value of N being 4 and 7.

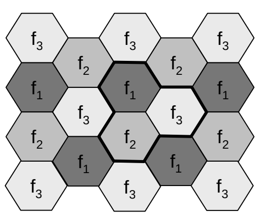
Illustration

- *i* and *j* are positive integers. To find the nearest co-channel neighbor of a particular cell, you have to (1) move *i* cells along any chain of hexagons and then (2) turn 60 degrees counter-clockwise and move *j* cells.

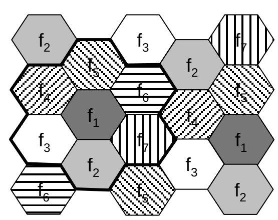


- For $N = 7$, i=2, j=1

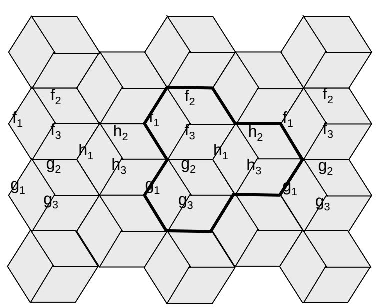
Illustration



3 cell cluster

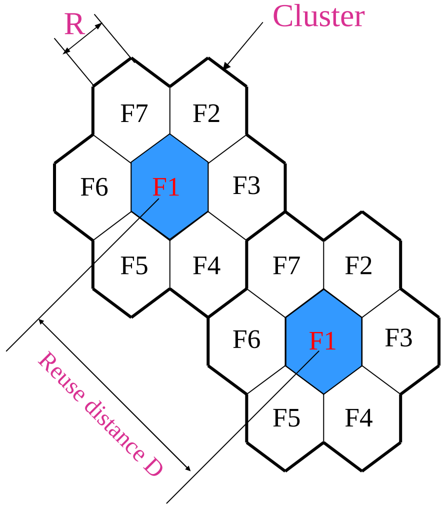


7 cell cluster



3 cell cluster
with 3 sector antennas

Reuse Distance



- For hexagonal cells, the reuse distance is given by

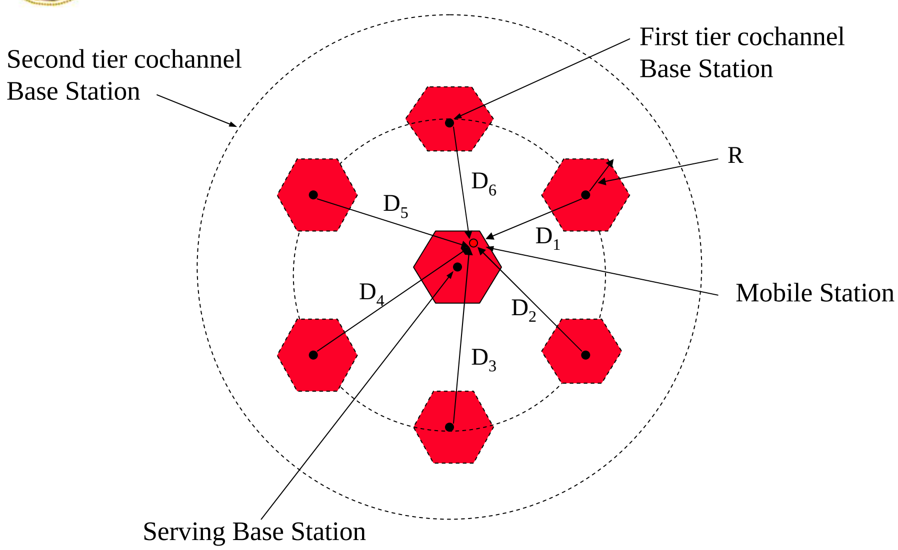
$$D = \sqrt{3N}R$$

where R is cell radius and N is the reuse pattern (the cluster size or the number of cells per cluster).

- Reuse factor is

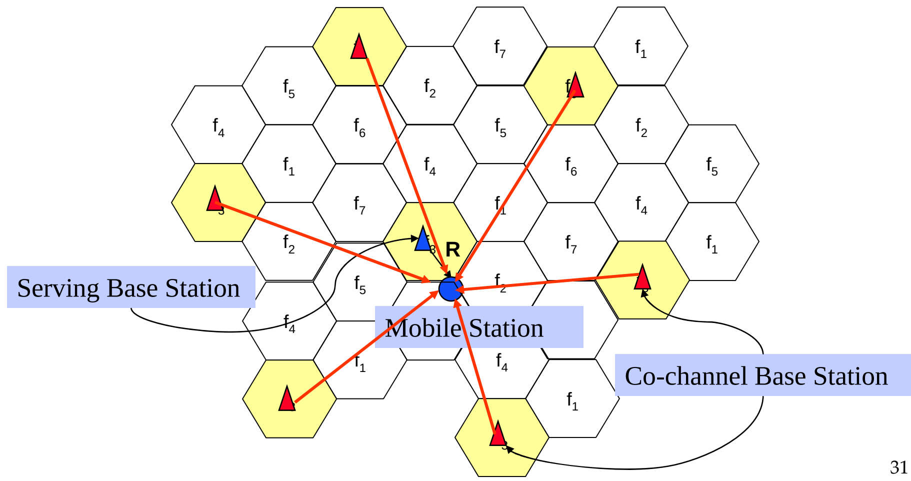
$$\frac{D}{R} = \sqrt{3N}$$

Co-Channel Interference



Worst Case Co-channel interference

- Worst-case co-channel interference happens when a user is at a cell boundary
- Example: N=7



31

Estimating Co-Channel Interference

Carrier or signal to interference ratio (C/I) is given by:

$$C/I = \frac{Carrier}{Interference} = \frac{C}{\sum_{k=1}^{M} I_k}$$

where I is co-channel interference and M is the maximum number of co-channel interfering cells.

For M = 6, C/I is given by

$$\frac{C}{I} = \frac{R^{-\alpha}}{\sum_{k=1}^{6} (D_k)^{-\alpha}}$$

where α is the propagation path loss exponent.

32

C/I or SIR

(Cont'd) Assuming $D_i = D$ for i = 1,2, ….6

$$\frac{C}{I} = \frac{R^{-\alpha}}{6D^{-\alpha}} = \frac{\left(D/R\right)^{\alpha}}{6}$$

- General approximation for SIR (in dB), considering only 1st ring of interferers:

$$SIR = 10\log\frac{\left(D/R\right)^{\alpha}}{M}$$

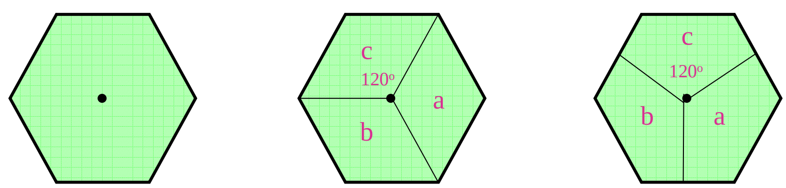
where M = number of interferers (depending on antenna used, etc.)

Example

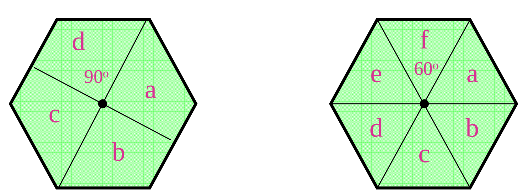
- If a carrier-to-interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) α=4, and (b) α=3? Assume that there are six co-channel cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximation.

Solution

Cell Sectoring by Antenna Design



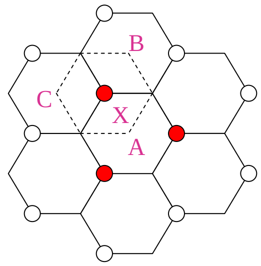
(a). Omni (b). 120^o sector (c). 120^o sector (alternate)



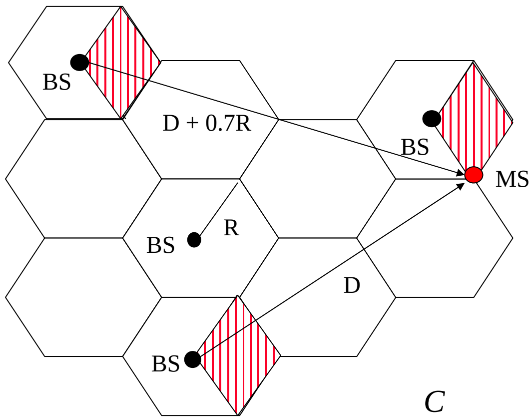
(d). 90^o sector (e). 60^o sector

Cell Sectoring by Antenna Design

- Placing directional transmitters at corners where three adjacent cells meet



Worst case for forward channel interference in three-sectors



$$\frac{C}{I} = \frac{C}{q^{-\gamma} + (q + 0.7)^{-\gamma}}$$

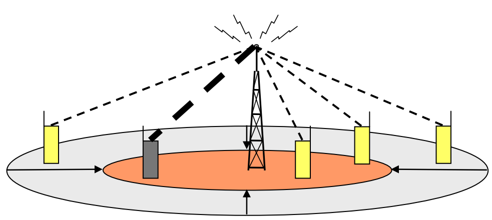
Frequency Assignment

- Fixed frequency (channel) assignment – FCA
  - Each cell is assigned a fixed number of channels (frequencies)
  - Channels used for both handoffs and new calls
  - Problem: different traffic load in different cells
- Reservation channels with FCA
  - Each cell reserves some channels for handoff cells
- Channel borrowing
  - A cell may borrow free channels from neighboring cells
- Dynamic frequency (channel) assignment – DCA
  - Base station chooses frequencies depending on the frequencies already used in neighbor cells
  - More capacity in cells with more traffic
  - Assignment can also be based on interference measurements

39

Cell Breathing

- CDM systems: cell size depends on current load
- Additional traffic appears as noise to other users
- If the noise level is too high users drop out of cells



40

EEC173B/ECS152C, Winter 2006

Fundamentals of Wireless Communications

- #4: Spread Spectrum
- #5: Multiplexing
- #6: Frequency Reuse (Cellular Concept)

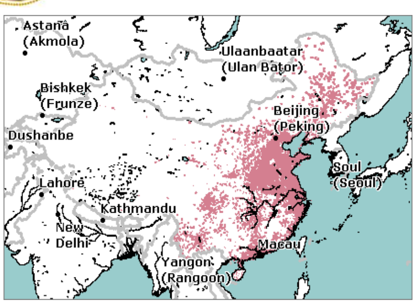
Case Study: GSM Wireless cellular networks

- #7: Handoff

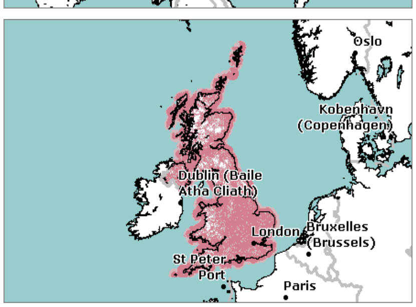
Acknowledgment: Selected slides from Prof. Schiller

Example coverage of GSM networks (www.gsmworld.com)

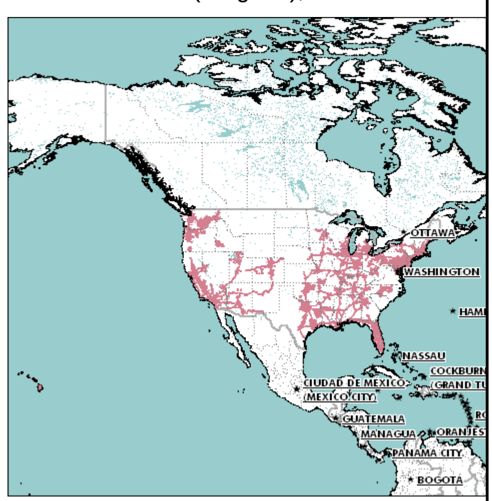
China Mobile



Vodafone, UK

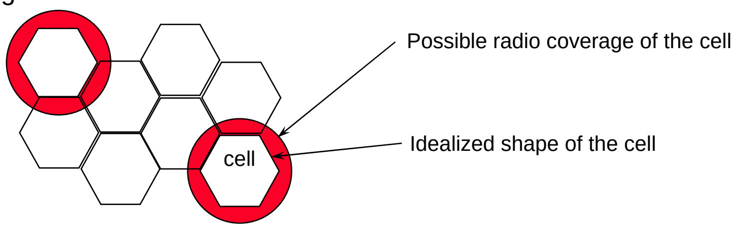


AT&T Wireless (Cingular), North America



GSM Cellular network

Segmentation of the area into cells



- Use of several carrier frequencies
- Not the same frequency in adjoining cells
- Cell sizes vary from some 100 m up to 35 km depending on user density, geography, transceiver power etc.
- Hexagonal shape of cells is idealized (cells overlap, shapes depend on geography)
- If a mobile user changes cells
  - handover of the connection to the neighbor cell

43

#7: Handoffs (or Handover)

- Required to support mobility when the user moves into a different cell
- Involves
  - Identifying a new BS in new cell
  - Find uplink/downlink channel pair from new cell to carry on the call
  - Drop the link from the old BS

44

Handoffs: Design Issues (1)

- Optimal BS selection:
  - BS nearest to MT may not necessarily be the best in terms of signal strength, especially new the cell boundaries
- Ping-pong Effect
  - Call gets bounced back and forth between two BS (a series of handoffs)
- Data loss
  - Interruption due to handoff may cause a loss in data
  - Delay in relinquishing channel in old cell and resume in new call may be acceptable for voice, but cause data loss

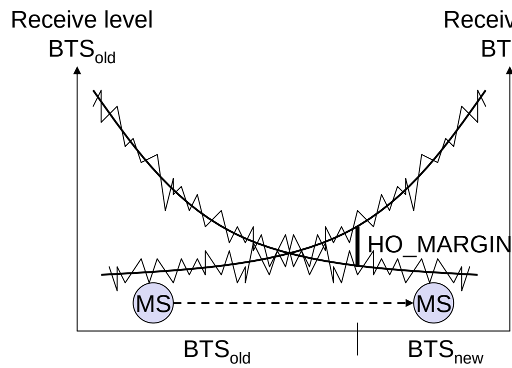
45

Handoff: Design Issues (2)

- Detection of handoff requirement
  - Mobile-initiated: MT monitors signal strength from BS and requests a handoff when signal drops below a threshold)
  - Network-initiated: BS forces a handoff when signals from an MT weaken, queries neighboring BS about signal strength from the MT and deduce which BS to handoff too
  - Mobile-assisted scheme: combination of mobile- and network-initiated schemes. MT evaluates signal strength, but final handoff decision is made by BS

46

Handover Decision



47

Handoff Quality

- Handoff delay:
  - Signaling during a handoff causes delay in transfer
  - If delay is too large, SINR may fall below minimum threshold, causing call to be dropped
- Duration of interruption
  - Hard handoff: channel pair from old BS cancel and then channel pair from next BS is used to continue the call
- Handoff success: probability of successful handoffs
  - Depends on number of available channel pairs, capacity to switch before SINR falls below threshold
- Probability of unnecessary handoff
  - E.g., Ping-Pong effect
  - Increase signaling overhead, leading to unwanted delays and interruptions

48