Course Title

Advanced Wireless Communication

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Wireless System Definitions

Mobile Station

A station in the cellular radio service intended for use while in motion at unspecified locations. They can be either handheld personal units (portables) or installed on vehicles (mobiles)

Base station

A fixed station in a mobile radio system used for radio communication with the mobile stations. Base stations are located at the center or edge of a coverage region. They consists of radio channels and transmitter and receiver antennas mounted on top of a tower.

[4]. Khaled B. Letaief ; Wei Chen ; Yuanming Shi ; Jun Zhang ; Ying-Jun Angela Zhang,"The Roadmap to 6G: AI Empowered Wireless Networks",0163-6804/19/$25.00 © 2019 IEEE

Wireless System Definitions

Control Channel
Radio channel used for transmission of call setup, call request, call initiation and other beacon and control purposes.

Forward Channel
Radio channel used for transmission of information from the base station to the mobile

Reverse Channel
Radio channel used for transmission of information from mobile to base station

[4]. Khaled B. Letaief ; Wei Chen ; Yuanming Shi ; Jun Zhang ; Ying-Jun Angela Zhang,"The Roadmap to 6G: AI Empowered Wireless Networks",0163-6804/19/$25.00 © 2019 IEEE

Wireless System Definitions

Simplex Systems
Communication systems which provide only one-way communication
Keyboard-Monitor

Half Duplex Systems
Communication Systems which allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can either transmit or receive information.
walkie-talkie

Full Duplex Systems
Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD).
Telephone

Wireless System Definitions

Handoff
The process of transferring a mobile station from one channel or base station to an other.

Mobile Switching Center
Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connections the cellular base stations and the mobiles to the PSTN (telephone network). It is also called Mobile Telephone Switching Office (MTSO)

Subscriber
A user who pays subscription charges for using a mobile communication system

Transceiver
A device capable of simultaneously transmitting and receiving radio signals

[4]. Khaled B. Letaief ; Wei Chen ; Yuanming Shi ; Jun Zhang ; Ying-Jun Angela Zhang,"The Roadmap to 6G: AI Empowered Wireless Networks",0163-6804/19/$25.00 © 2019 IEEE

Cells

- A cell is the basic geographic unit of a cellular system
  - The term *cellular* comes from the honeycomb shape of the areas into which a coverage region is divided
  - Cells are base stations transmitting over small geographic areas that are represented as hexagons
  - Size varies depending on the landscape

Clusters

- A cluster is a group of cells
  - No channels are reused within a cluster

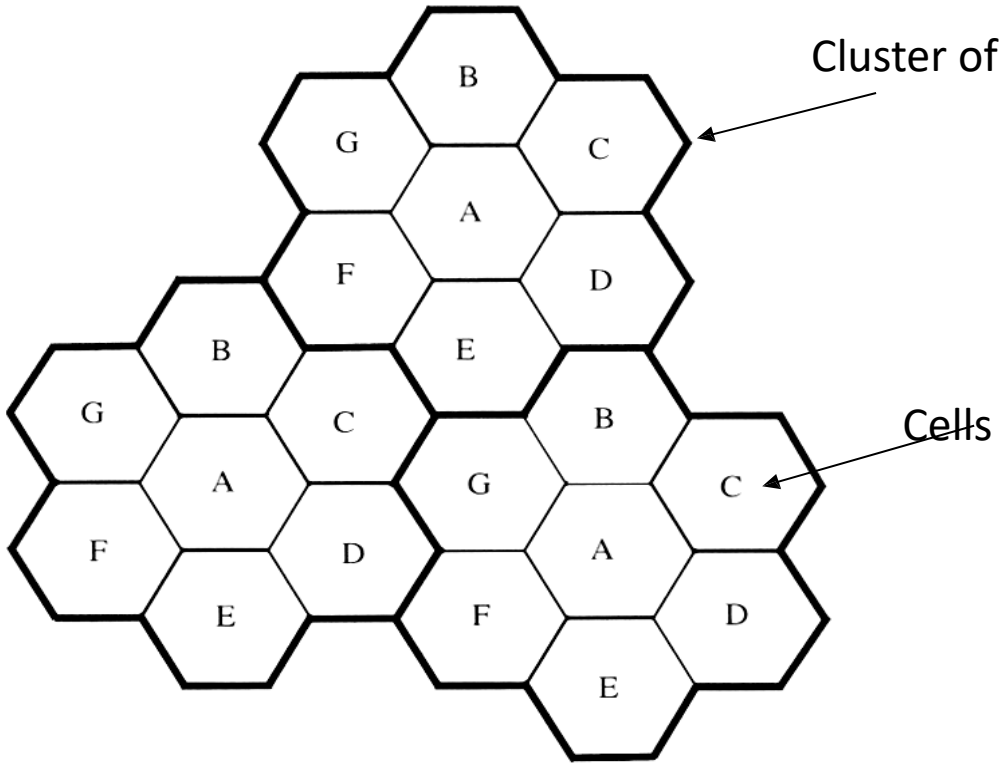
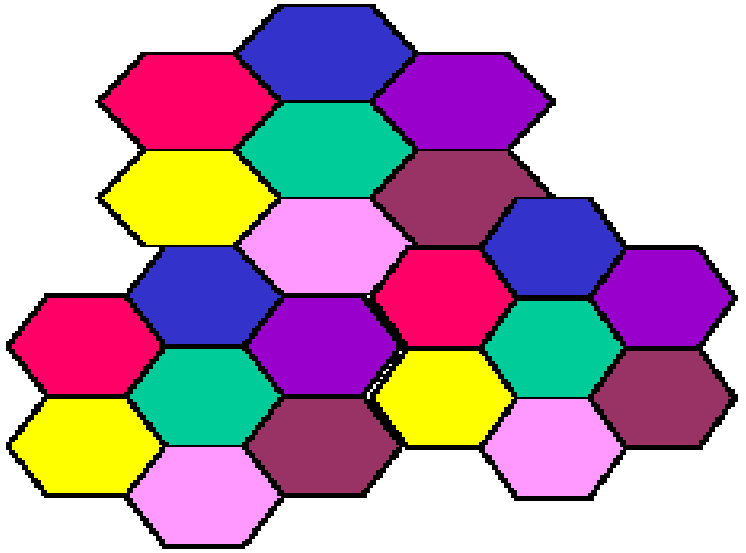


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, *N*, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

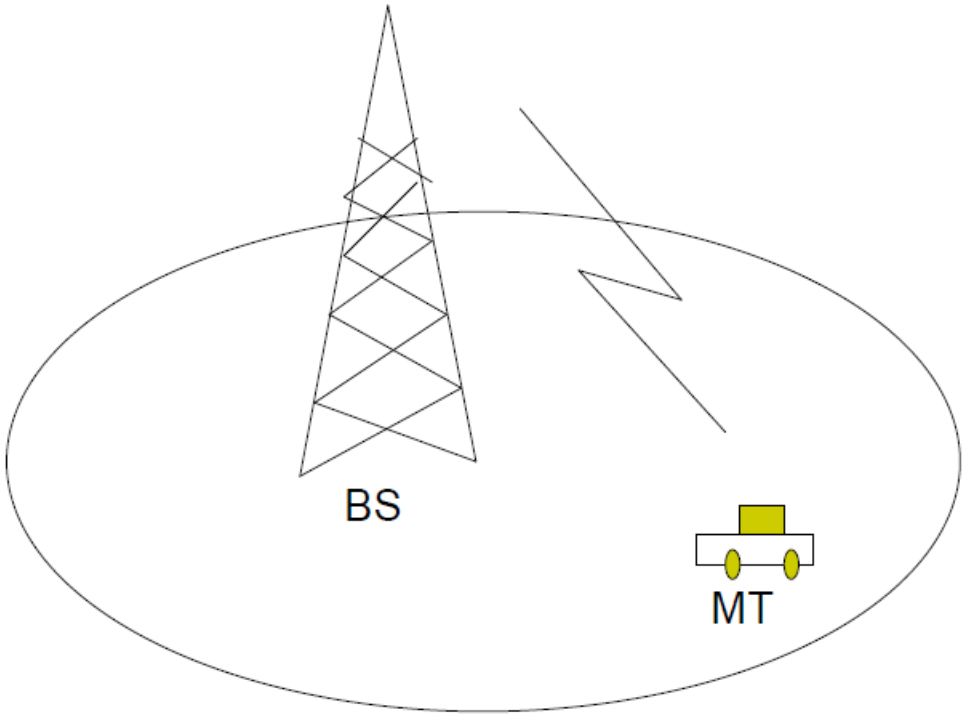
Cellular Concept

- Proposed by Bell Labs 1971
- Geographic Service divided into smaller “cells”
- Neighboring cells do not use same set of frequencies to prevent interference
- Often approximate coverage area of a cell by a idealized hexagon
- Increase system capacity by frequency reuse.



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Cluster Size

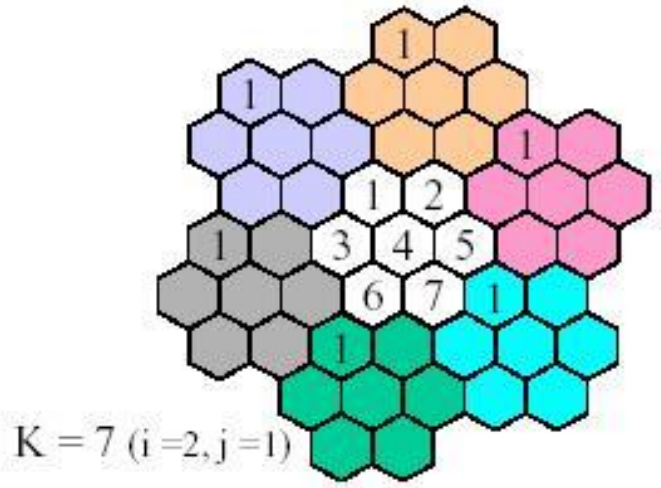
- From geometry of grid of hexagons only

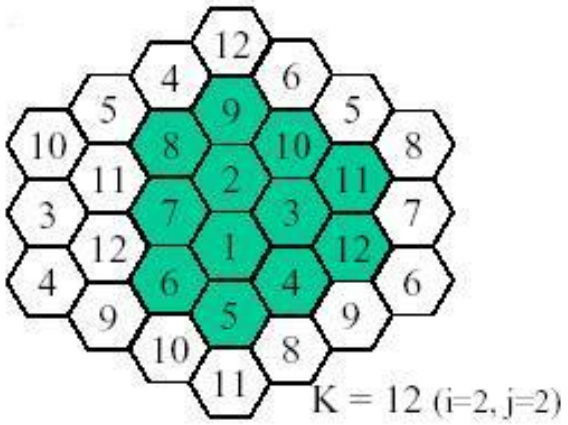
  certain values of K are possible if replicating

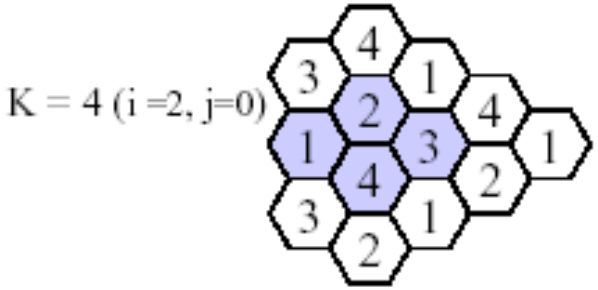
  cluster without gaps

- $K = i^2 + ij + j^2$ where i and j are non-negative integers

The cluster size must satisfy:
$N = i^2 + ij + j^2$ where i, j are non-negative integers.







- **Fixed channel assignment**
  - each cell is allocated a predetermined set of voice channel
  - any new call attempt can only be served by the unused channels
  - the call will be *blocked* if all channels in that cell are occupied

- **Dynamic channel assignment**
  - channels are not allocated to cells permanently.
  - allocate channels based on request.
  - reduce the likelihood of blocking, increase capacity.

Cell Footprint

- The actual radio coverage of a cell is known as the cell footprint.
  - Irregular cell structure and irregular placing of the transmitter may be acceptable in the initial system design. However as traffic grows, where new cells and channels need to be added, it may lead to inability to reuse frequencies because of co-channel interference.
  - For systematic cell planning, a regular shape is assumed for the footprint.

Frequency Reuse

Concept of Frequency Reuse

- The **cellular network** is divided into small areas called **cells** (usually hexagonal in shape for easy tiling).
- Each cell is served by a **base station (BS)** with its own set of frequencies.
- To avoid interference:
  - **Adjacent cells** are allocated **different frequency bands**.
  - The **same frequency band** can be reused in cells that are far apart.
- **Definition**: Frequency Reuse is the practice of **reusing radio frequencies in non-adjacent cells** within a cellular system to increase spectrum efficiency.

Frequency Reuse Factor

Frequency Reuse Factor

The **frequency reuse factor (N)** represents the **number of cells in a cluster** that collectively use the total available frequency spectrum.

For example:

If N = 7, then the spectrum is divided into **7 subsets**, and each cell in a cluster uses one subset.

After 7 cells, the pattern repeats.

Formula for cluster size:

$$N = i^2 + j^2 + i \cdot j$$

Where:

i, j = integers ($i \geq 0, j \geq 0$) that define the shift pattern of reused frequencies.

Common values: **N = 3, 4, 7, 9, 12, 19**

Frequency Reuse Factor

Advantages of Frequency Reuse

- **Efficient Spectrum Utilization** – Limited frequency bands can support a large number of subscribers.
- **Increased Capacity** – More users can be served by reusing frequencies in distant cells.
- **Scalability** – Easy to expand by adding new cells and applying the same reuse concept.

Frequency Reuse Factor

Challenges of Frequency Reuse

Co-Channel Interference (CCI):

Occurs when the same frequency is reused too close.

Mitigated by increasing **reuse distance (D)** between co-channel cells.

Formula for reuse distance:

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

Where:

D = distance between co-channel cells

R = cell radius

N = cluster size

Trade-off:

Smaller N → higher capacity but more interference.

Larger N → less interference but lower capacity.

Frequency Reuse

- Geometry of the hexagonal cells is such that to cover adjacent areas completely, N can have only some of the values.
- N should satisfy the relationship,

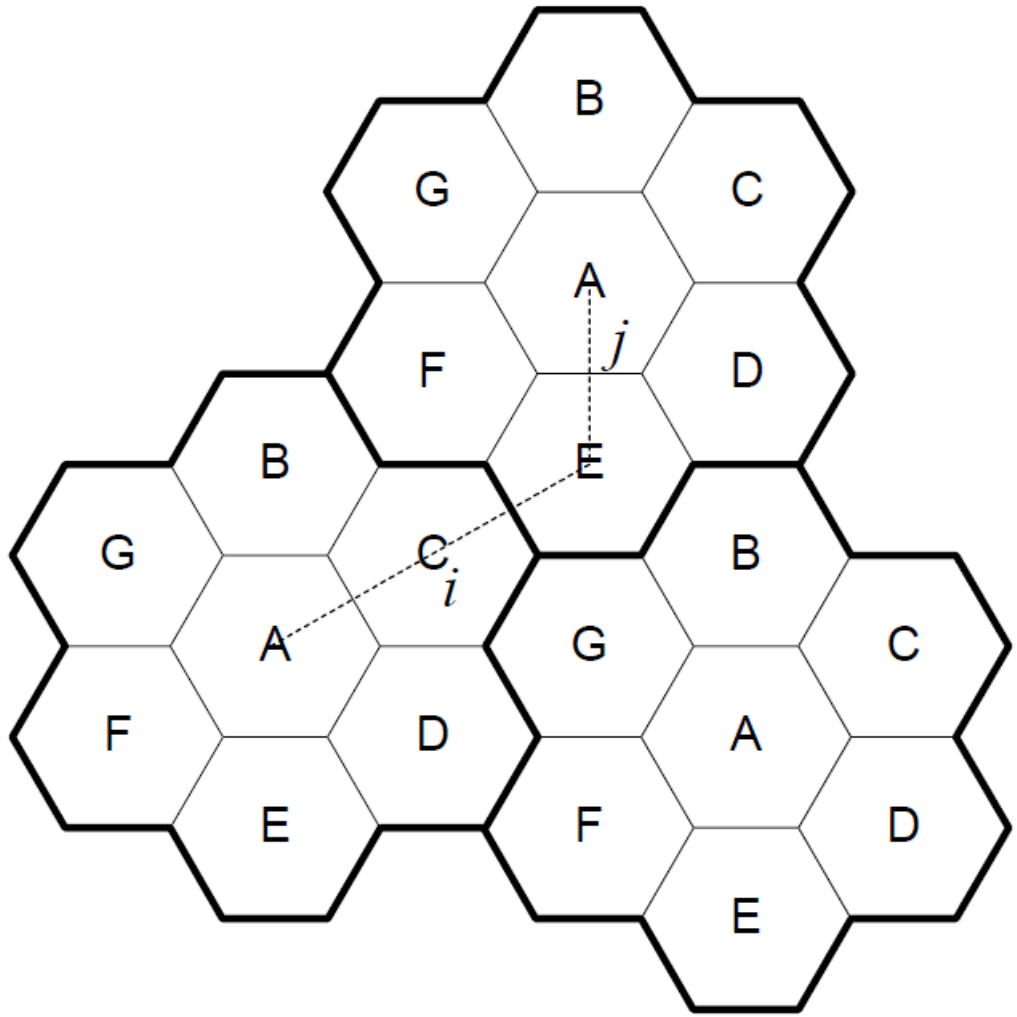
$$N = i^2 + i\,j + j^2$$

where i and j are positive integers. Typical values of N are 4,7,12 etc.

- To draw the cell pattern given *i* and *j* and to find nearest co-channel neighbour

1. Move *i* cells across hexagons.
2. Turn 60º CCW and move *j* cells.

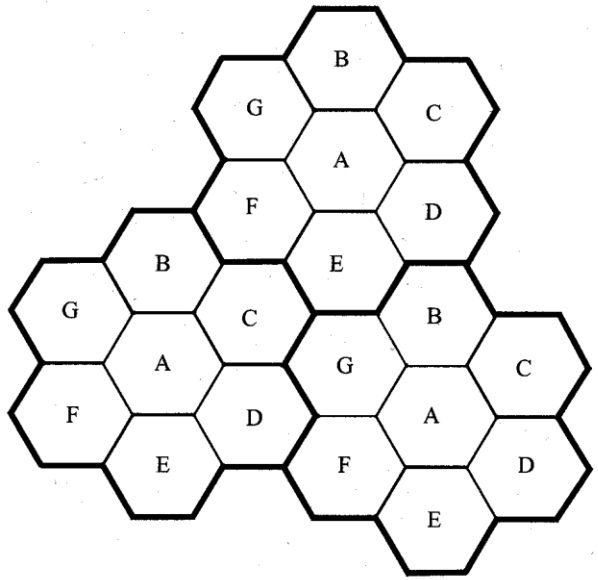
Frequency Reuse (N=7, i=2, j=1)



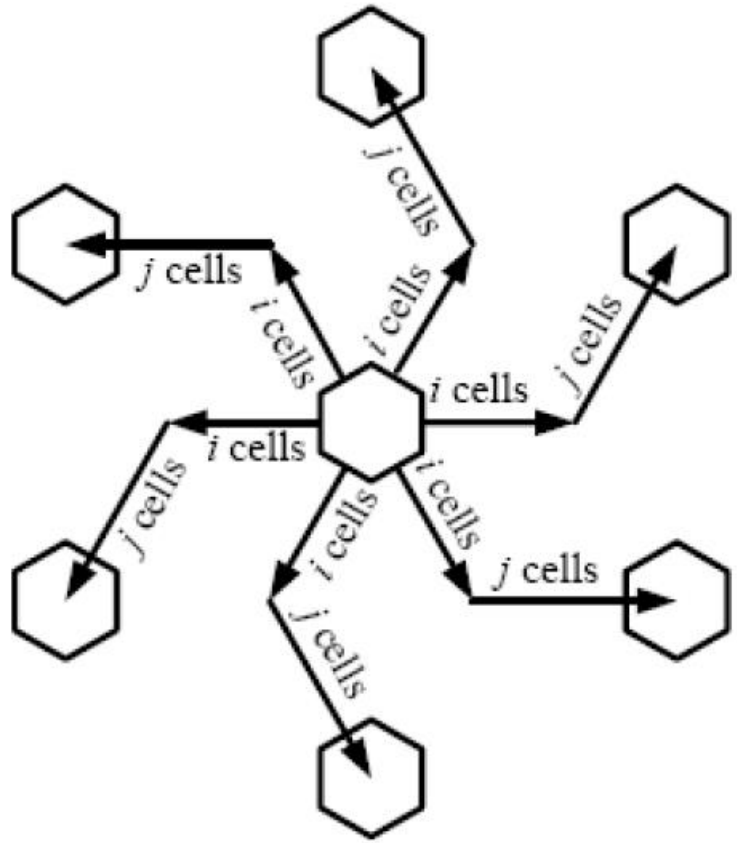
Frequency Reuse

- Each cellular base station is allocated a group of radio channels within a small geographic area called a *cell*.
- Neighboring cells are assigned different channel groups.
- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.
- Keep interference levels within tolerable limits.
- Frequency reuse or frequency planning

  - •seven groups of channel from A to G
  - •footprint of a cell - actual radio coverage
  - •omni-directional antenna v.s. directional antenna

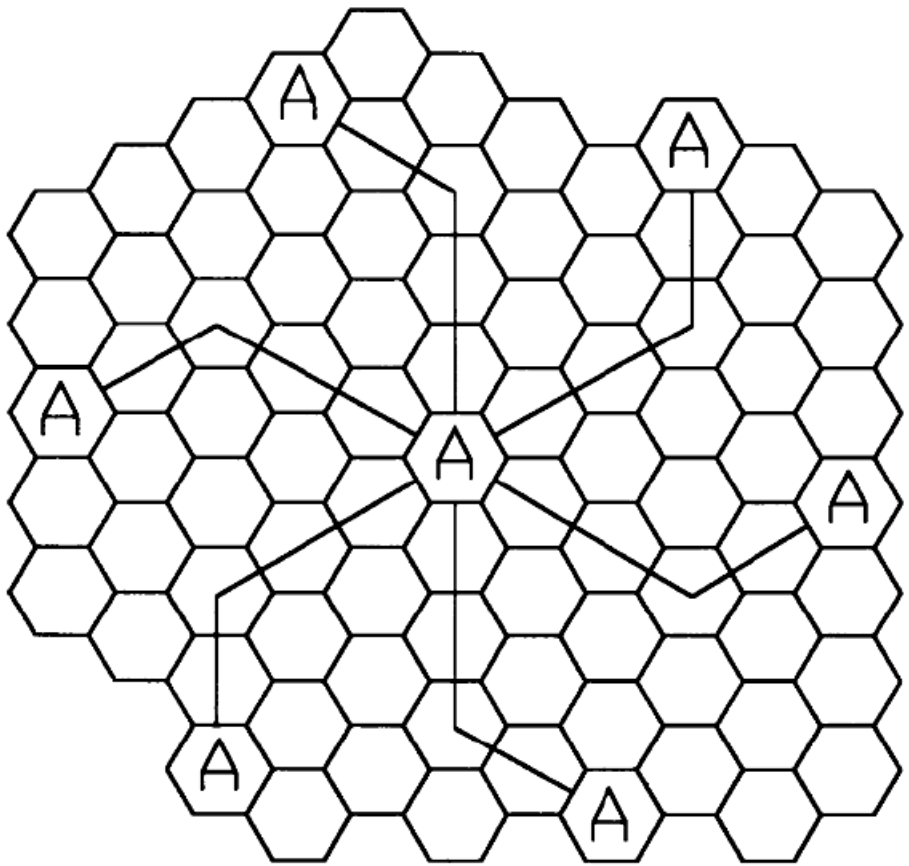


Frequency Reuse



Nearest co-channel

Example N=19
(i=3, j=2)



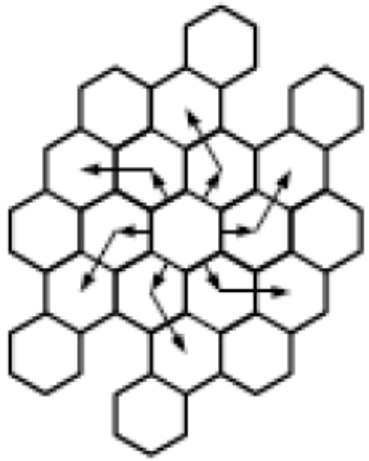
To find the nearest co-channel neighbors of a particular cell:

- move i cells along any chain or hexagon.
- then turn 60 degrees counterclockwise and move j cells.

Nearest co-channel

$i = 1, j = 1$

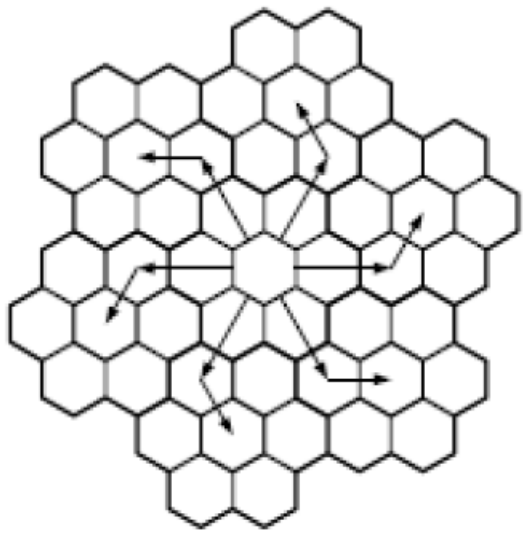
$N = 3$



$i = 2, j = 0$

$N = 4$





$i = 2, j = 1$

$N = 7$

Cellular Concept

- Let T = total number of duplex channels

  K cells = size of cell cluster (typically 4, 7,12, 21)

  N = T/K = number of channels per cell

- For a specific geographic area, if clusters are replicated M times, then total number of channels

  – system capacity = M *x* T

Cellular Concept

If a total of 33MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses 25 kHz simplex channels to provide full duplex voice and control channels.

1. Compute the number of channels available per cell for a system cluster size N= 4, 7 and 12 cells
2. Compute the total channel capacity of the network if only 50 base stations are to be installed.
3. Compute the reuse distance

Cellular Concept

Given

- Total spectrum = **33 MHz = 33,000 kHz**
- Channel spacing (simplex) = **25 kHz**
- Full-duplex (FDD) uses **uplink + downlink ⇒ 50 kHz per full-duplex channel**
- Cluster sizes N = **4, 7, 12**
- **50** base stations (cells)
- Coverage area = **250 km²**
- Hexagonal cells: area $A = \frac{3\sqrt{3}}{2} R^2$

Cellular Concept

- **1) Total number of channels in the system**
- Full-duplex channels:
- $\text{Total FD channels} = 33, \frac{000\ k}{z50\ \text{kHz}} = \boxed{660}$
- **2) Channels available per cell**
- $\text{Channels per cell} = \frac{660}{N}$
- $N = 4$: $\frac{660}{4} = \boxed{165}$
- $N = 7$: $\frac{660}{7} = 94.285 \ldots \Rightarrow \boxed{94}$ (round down to assign whole channels)

Cellular Concept

- **Total channel capacity of the 50-cell network**
- $\text{Network capacity} = (\text{channels/cell}) \times 50$
- $N = 4$: $165 \times 50 = \boxed{8{,}250}$ full-duplex channels
- $N = 7$: $94 \times 50 = \boxed{4{,}700}$ full-duplex channels *(If you didn't floor per cell and spread leftovers system-wide:* $660/7 \times 50 \approx 4{,}714$*; but per-cell assignment typically uses integers → 4,700.)*
- $N = 12$: $55 \times 50 = \boxed{2{,}750}$ full-duplex channels

Cellular Concept

4) **Reuse distance** D for each N

(a) Area per cell and cell radius R

$$A_{\text{cell}} = \frac{250}{50} = 5 \text{ km}^2$$

$$A_{\text{hex}} = \frac{3\sqrt{3}}{2} R^2 \Rightarrow R = \sqrt{\frac{2A}{3\sqrt{3}}} = \sqrt{\frac{2 \times 5}{3\sqrt{3}}} \approx \boxed{1.387 \text{ km}}$$

(b) Reuse distance D

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

- $N = 4$: $D = 1.387 \times \sqrt{12} \approx 1.387 \times 3.464 \approx \boxed{4.806 \text{ km}}$
- $N = 7$: $D = 1.387 \times \sqrt{21} \approx 1.387 \times 4.583 \approx \boxed{6.357 \text{ km}}$
- $N = 12$: $D = 1.387 \times \sqrt{36} = 1.387 \times 6 \approx \boxed{8.324 \text{ km}}$

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If a total of 33MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses 25 kHz simplex channels to provide full duplex voice and control channels.

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Example: A total of 33 MHz are allocated to a system which uses 2x25 kHz for full duplex (i.e., each channel is 50 kHz). What is the number of channels per cell?

Number of channels per system

$$\frac{33{,}000\text{kHz}}{2 \times 25\text{kHz}} = 660 \text{ channels}$$

a. For reuse $N = 4$:

$$\frac{660}{4} = 165 \text{ channels / cell}$$

For reuse $N = 7$:

$$\frac{660}{7} = 95 \text{ channels / cell}$$

Hand-off

- Handoff occurs when the mobile telephone network automatically transfers a call from radio channel to radio channel as a mobile crosses adjacent cells
  - During a call, two parties are on one voice channel
  - The system switches the call to a stronger-frequency channel in a new site without interrupting the call or alerting the user

Handoff Strategies

- When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station.
- Handoff operation
  - identifying a new base station
  - re-allocating the voice and control channels with the new base station.
- Handoff Threshold
  - Minimum usable signal for acceptable voice quality (-90dBm to -100dBm)
  - Handoff margin $\Delta = P_{r,handoff} - P_{r,minimumusable}$ cannot be too large or too small.
  - If Δ is too large, unnecessary handoffs burden the MSC
  - If Δ is too small, there may be insufficient time to complete handoff before a call is lost.

Handover / Handoff

- Δ=handoff threshold - Minimum acceptable signal to maintain the call
- Δ too small:
  - Insufficient time to complete handoff before call is lost
  - More call losses
- Δ too large:
  - Too many handoffs
  - Burden for MSC

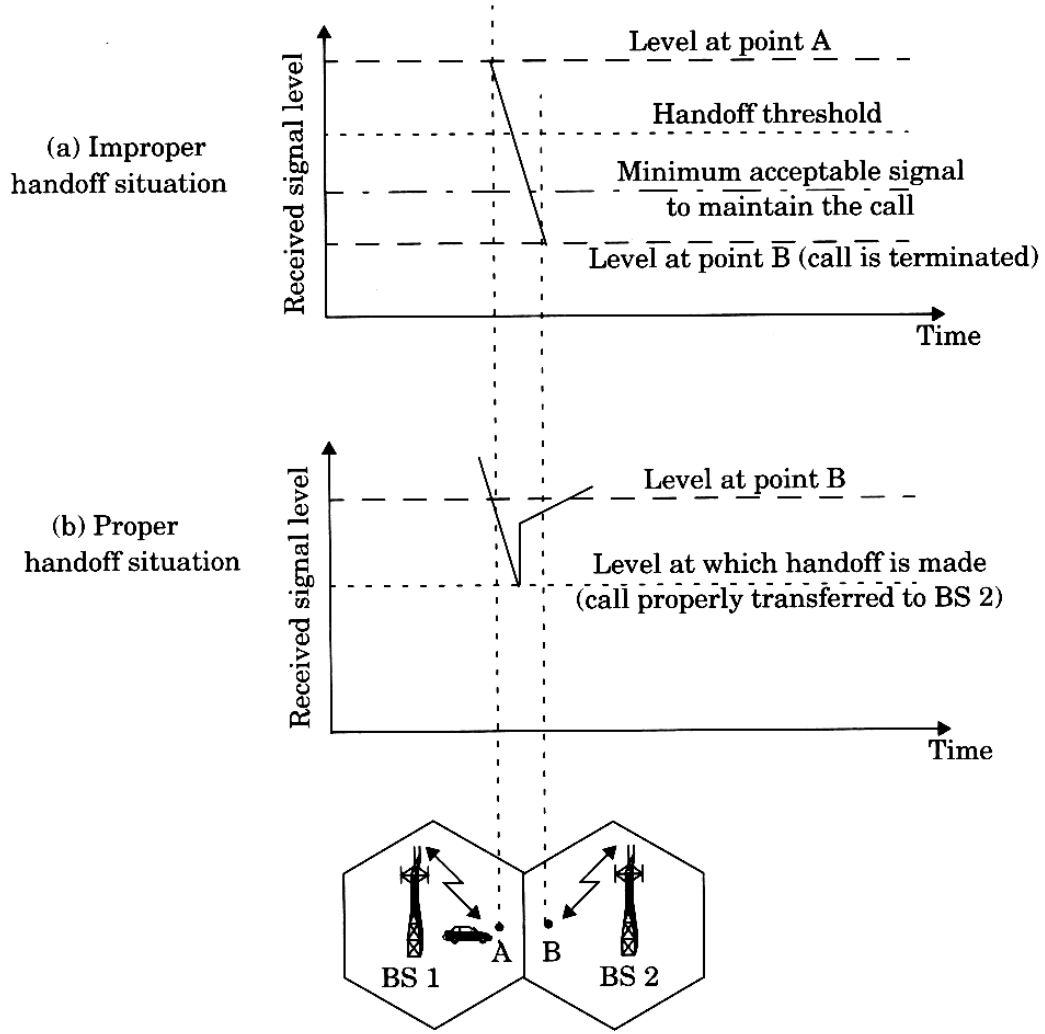


Figure 3.3 Illustration of a handoff scenario at cell boundary.

Umbrella Cells

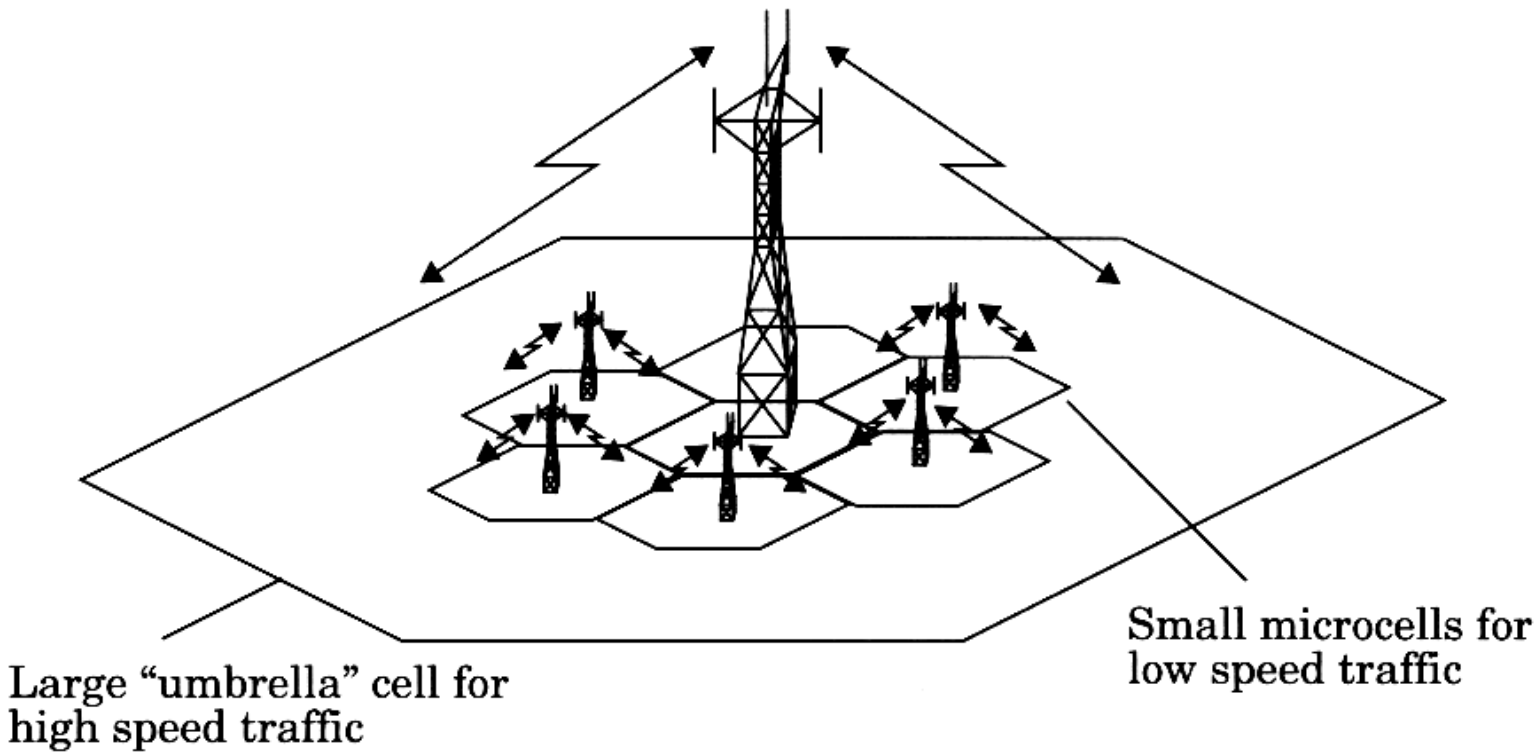


Figure 3.4 The umbrella cell approach.

Handoff (cont)

Hard Handover:- When mobile(in Call) switches to a new sector/Cell which is on different frequency , then it performs hard Handover. It is basically an inter-frequency handover.

SOft Handover:- When mobile (in Call) switches to a new sector/cell which is on the same frequency then it is called a soft handover.

System Expansion Techniques--Cell splitting

- Cell splitting increases the number of BSs in order to increase capacity. There will be a corresponding reduction in antenna height and transmitter power.
- Cell splitting accommodates a modular growth capability. This in turn leads to capacity increase essentially via a system re-scaling of the cellular geometry without any changes in frequency planning.
- Small cells lead to more cells/area which in turn leads to increased traffic capacity.

Cell Splitting

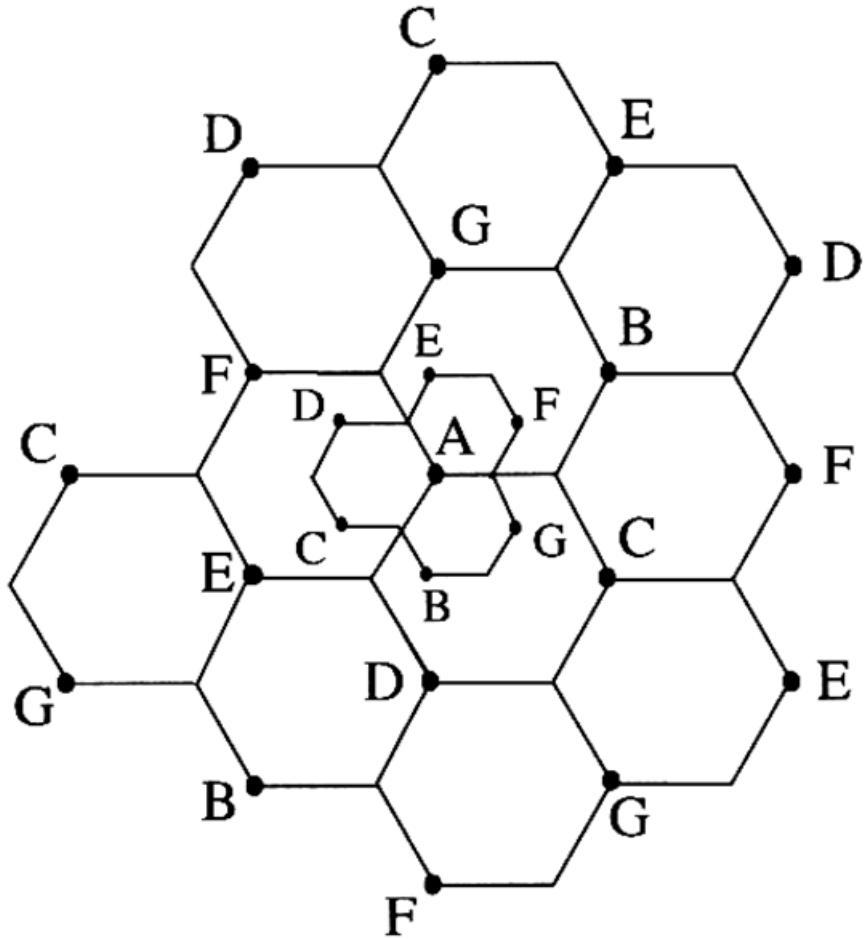


Illustration of cell Splitting

System Expansion Techniques --Sectorization

- Keep the cell radius but decrease the *D/R* ratio. In order to do this, we must reduce the relative interference without increasing the transmit power.
- Sectorization relies on antenna placement and directivity to reduce co-channel interference. Beams are kept within either a 60° or a 120° sector.

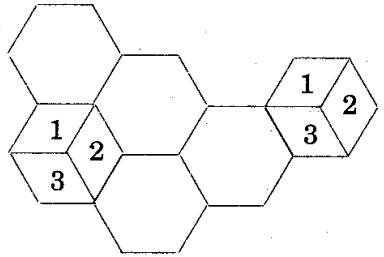
Sectoring

- Decrease the *co-channel interference* and keep the cell radius *R* unchanged
  - Replacing single omni-directional antenna by several directional antennas
  - Radiating within a specified sector

The factor by which the co-channel interference is reduced depends on the amount of sectoring used.

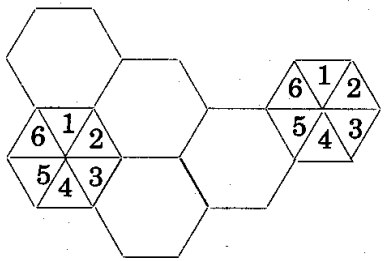
A cell is normally partitioned into three 120° sectors or six 60° sectors as shown in Figure (a) and (b).

120° sectored cell



(a)

60° sectored cell



(b)

Co-channel Interference and System Capacity

- Frequency reuse - there are several cells that use the same set of frequencies
  - co-channel cells
  - co-channel interference

- To reduce co-channel interference, co-channel cell must be separated by a minimum distance.

Problem 1.1:

If a total of 33MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses 25 kHz simplex channels to provide full duplex voice and control channels.

1. Compute the number of channels available per cell for a system cluster size N= 4, 7 and 12 cells
2. Compute the total channel capacity of the network if only 50 base stations are to be installed.
3. Finde the frequency reuse distance D if the if an area of 250 square kilometer is to be covered assuming the use of hexagonal cell shape.