Course Introduction

MODULE 5

Evolution of wireless networks and standards, GSM& GPRS: architecture, protocol and channels. UMTS – HSPA – LTE/LTE-A network architecture and protocol.

MODULE 6

Introduction to wireless LANs- architecture, standards (802.11x) and services, introduction to WPAN- architecture of Bluetooth systems, introduction to WWAN- architecture, WiMAX standards, introduction to adhoc and sensor Networks.

MODULE 7

Security and privacy needs of a wireless system, wireless security and standards, IEEE 802.11 security, security in GSM, GPRS, data security.

Introduction to Wireless Communication

Wireless communication is basically transmitting and receiving voice and data using electromagnetic waves in open space. A wireless communication network consists of a large number users in the region of interest or cells connecting to a base station or transceiver system.

"Stay Connected Anywhere Anytime"

Why Wireless communication ?

- *Free from wires*
- *Easy installation*
- *Low installation cost*
- *Communication can reach where wiring is infeasible or costly*
- *Stay connected, flexibility to connect multiple devices*

Types of Wireless communication:

- *Mobile (Cellular Phones)*
- *Portable (Wi Fi)*
- *Fixed (WirelessMAN)*

Application includes:

- *Voice and data communication (GSM 900)*
- *Emergency services e.g. Military surveillance (GSM 1800)*

Challenges:

- *Network support for user mobility e.g. location identification, handover or handoff*
- *Maintaining QoS (quality of service) over unreliable links*
- *Connectivity and Coverage*
- *Cost efficiency*

Outline of the topics in Module 1:

Cellular concept and Frequency reuse

Interference and Channel assignment schemes

Handoff strategies and Tele-traffic engineering

Improving coverage and capacity of cellular system

Trunking/ Tele-Traffic Engineering

Objective behind Cellular concept

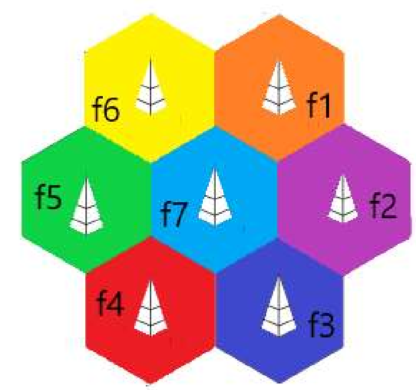
To meet the demands of increasing mobile subscribers through efficient use of the available frequency spectrum.

What is cell?

Cell is mainly the coverage area of a transmitter. It typically depends on the power of the transmitter.

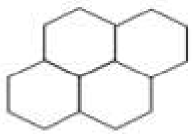
The cellular concept is a system level idea for network planning, where a single high power transmitter is (large cell) replaced with many low power transmitters (small cells), each providing coverage to only a small portion of the service area.

The total available radio channels are divided among the small cells to provide coverage to the entire geographic region. The neighbouring cells are assigned with different group of channels to avoid interference. Here a 7 cell cluster is shown in the Fig. The cluster size N can be 4,7, and 12 etc.

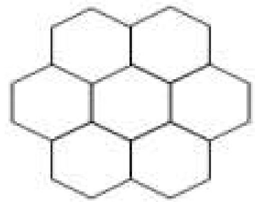


The cluster size $N = i^2 + j^2 + ij$

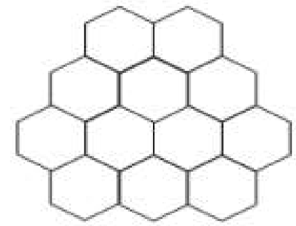
Example: for i = 1, j= 2 N = 7.



4 cells



7 cells

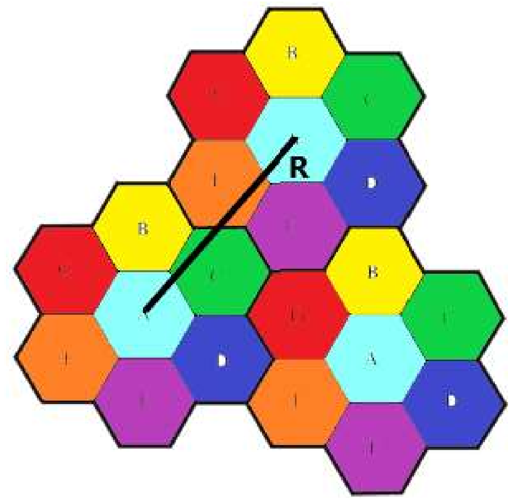


12 cells

What is the need of frequency reuse?

- **Frequency Spectrum is scares and expensive**
- **Number of users or subscribers are increasing in high density**

"Foundation of all modern wireless communication"



Here the same colour represents the co-channel cell. R is the frequency reuse distance.

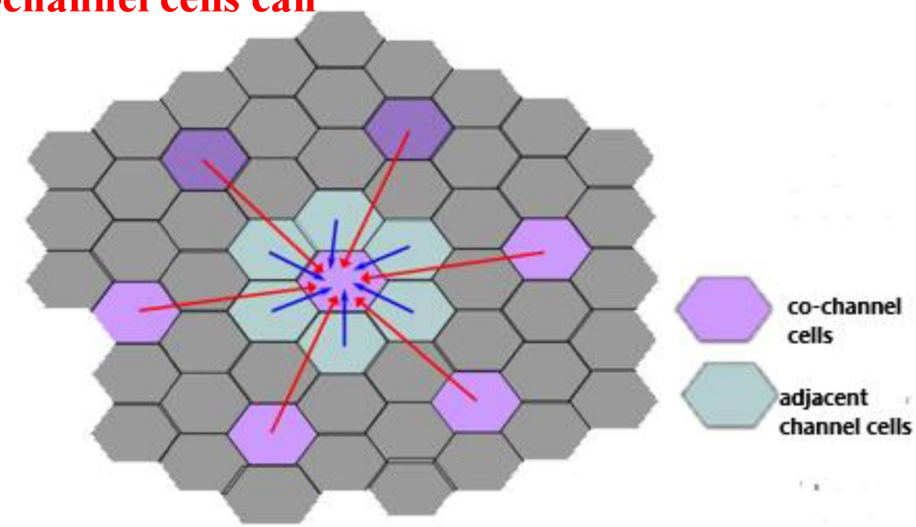
Frequency reuse in Cellular communication

Each cell has a dedicated low power Base Station (BS). Each BS is allocated a group or set of frequency channels to be used in a small geographic region (cell). The BS antennas are designed to provide coverage within this particular cell area. This limits the coverage area within the boundaries of the cell, therefore, the same set of channel can be used to provide coverage to different cells that are at enough large distance to limit interference in a tolerable limit.

Frequency reuse distance or the distance between two co-channel cells can be calculated as $R = r \times \sqrt{3N}$

Where r = cell radius

N = cluster size (i.e. the number of cells in the cluster)



Challenges in frequency reuse:

- *Co-channel Interference*
- *Adjacent channel Interference*

How frequency reuse increases the system capacity?

*Let, assume the total available radio channels **S** are divided among the **N** cells into unique and disjoint channel groups. Each cell is allocated with a set of **k** channels. Then **S = k N.***

Now, this N cells together use the complete set of available radio channels is called a cluster. If this cluster is repeated M times, then the total number of channel available to the entire system is also called the system capacity C = M k N = M S.

M is also called the replication factor.

Example Prob.

Suppose 33 MHz bandwidth is allocated to particular cellular system, which uses two 25 kHz simplex channels for duplex voice and control channels. Calculate the number of channels available per cell if the system uses *N* = 7 cells cluster size.

Given data: *Total bandwidth available for the cellular system = 33 MHz*
Simplex channel bandwidth = 25 kHz
Therefore, duplex channel bandwidth = 2 × 25 kHz = 50 kHz

From this given values, Total number of available channels = 33 MHz/50 kHz = 660 channels
The cluster size (N) is 7. So, the total available channels for each cell is = 660 channels/ 7 ≈ 95 Channels.

Example Prob.

For a typical cell radius of 5 m and cluster size of *N* = 7. Compute the frequency reuse or co-channel distance for this cellular system.

Interference

Co-channel interference *the interference received by the BS from the co-channel cells are co-channel interference.*

Adjacent channel interference *the interference received by the BS from the neighbouring or the adjacent cells are adjacent channel interference.*

Sources of interference

- *Other mobile or mobile users in the same cell.*
- *A call in progress in the neighbouring cell*
- *Other BSs operating in the same frequency band i.e. co-channel interference.*
- *Non-cellular system which unintentionally leaks energy in the cellular frequency band.*

Effects of interference

- *Interference on voice channel leads to cross-talk*
- *Interference on control channel leads to missed or blocked calls*

Co-channel interference and System capacity

Co-channel interference cannot be simply reduced by increasing the transmit power as it will increases interference to neighbouring co-channel cells.

Co-channel reuse ratio: $Q = \frac{D}{r} = \frac{\sqrt{3N}r}{r} = \sqrt{3N}$

- D = *distance between centre of two c-channel.*
- r = *radius of each cell*

Q increases → *D increases* → *System Capacity decreases* → *Transmission quality improves*

Q decreases → *D decreases* → *System Capacity increases* → *Transmission quality degrades*

SIR (Signal –to –Interference Ratio) *is the performance measure of any cellular system.*

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

where, S= desired signal power

i_0= *number of c-channel cells*

i_i= *interference power received from the i-th interfering c-channel cell BS.*

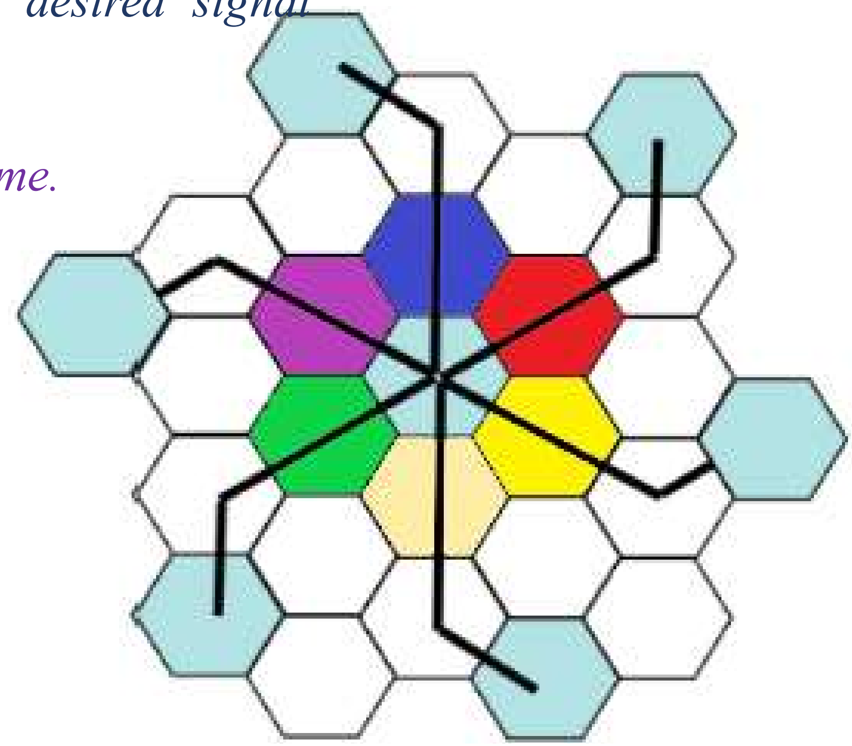
SIR (Signal –to –Interference Ratio $\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i} = \frac{\left(\frac{D}{r}\right)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0}$

n = path loss exponent

Constrains:

- *All the BSs are transmitting same power/where, S= desired signal power*
- *Cell size is approximately same*
- *Throughout the coverage area the path loss exponent same.*

Nearest co-channel cell



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

N =7 for i = 2, j = 1

Adjacent channel interference and System capacity

Signal which ae adjacent in frequency to the desired signal frequency is called adjacent channel and the interference due to them is called adjacent channel interference.

Sources of interference

- *Imperfect receiver filters which allow nearby frequencies to leak into the passband.*
- ***Near-far effect** problem*

Solution to adjacent channel interference

- *Careful filtering and channel assignment*
- *By keeping frequency separation between each adjacent channel*
- *By sequentially assigning successive channels in the frequency band to different cells*

Channel assignment scheme

- **Fixed channel assignment**
- **Dynamic channel assignment**

Fixed channel assignment	**Dynamic channel assignment**
1. Each cell is allocated a set of predetermined set of frequencies/channels *2. Any call attempts within the cell can only be served by the unused channels of the cell* *3. Variation that allows channel borrowing that exits* • *A cell is allowed to borrow unused channels from its neighbours* • *MSC (Main Switching Centre) supervise such borrowing and ensures channel borrowing does not interrupt or interfere any call which is in progress.*	*1. The voice channels are not permanently allocated to any particular cell, each time a call request is made, the serving BSS request a channel form MSC.* *2. MSC then lend channels according to a algorithm which take into account* • *Likelihood of future blocking* • *Frequency reuse distance to avoid co-channel interference* • *Other cost functions* *3. Dynamic channel assignment reduces call blocking probability and thus increases system capacity.*

Handoff Strategies:

When a mobile user or subscriber travels from one cell to another while a call is in progress, the call should be transferred to the new cell BS's automatically by the MSC.

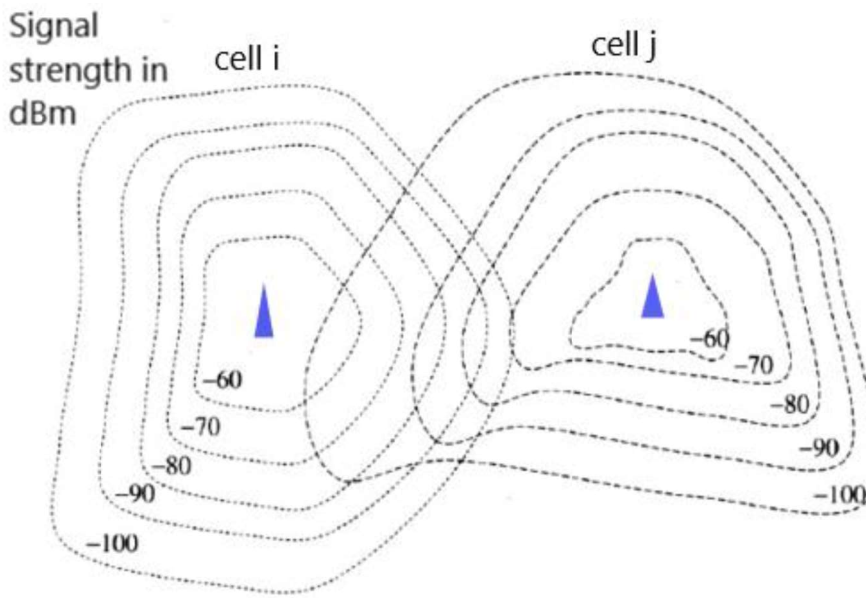


Figure shows the signal strength from the BS.

What is the need for handoff?

Otherwise the call will be disconnected, as the link with the current serving BS becomes too weak ae the mobile user recedes. So in any cellular system processing handoff is an very significant task. Usually a handoff request is prioritized over a new call request.

Hard Handoff: ***Break-before -Make***

Soft Handoff : ***Make-before Break***

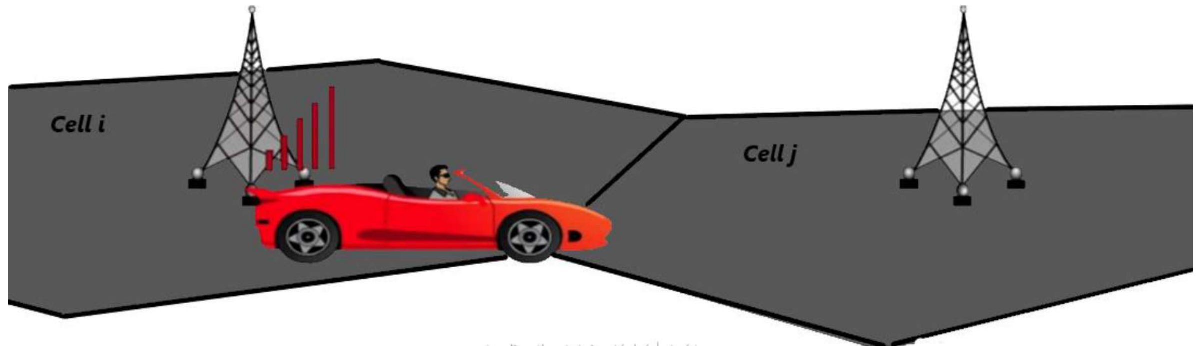


Figure 1 shows the signal strength before handoff

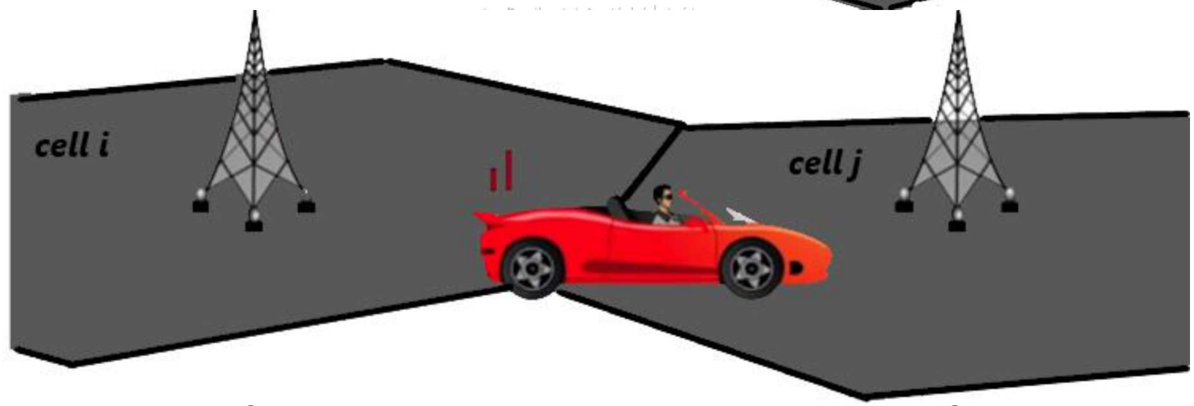


Figure 2 shows the signal strength during handoff

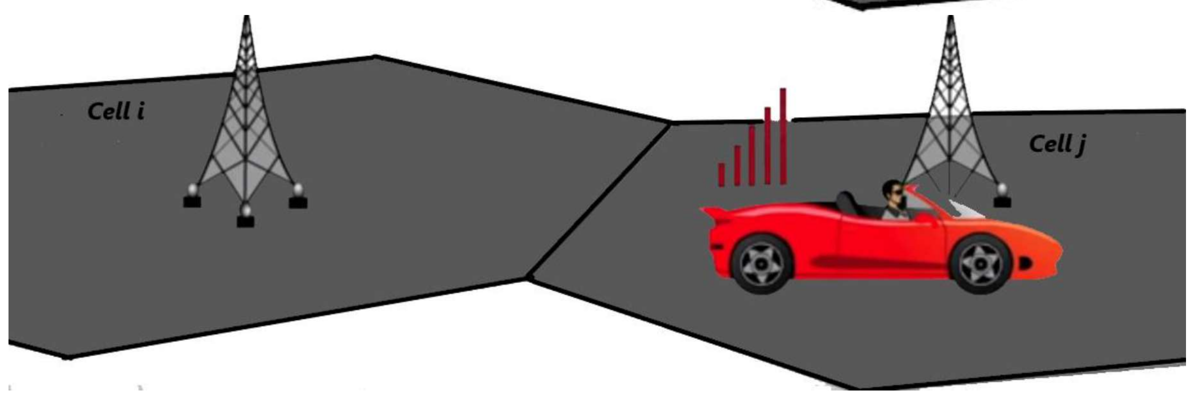


Figure 3 shows the signal strength after handoff

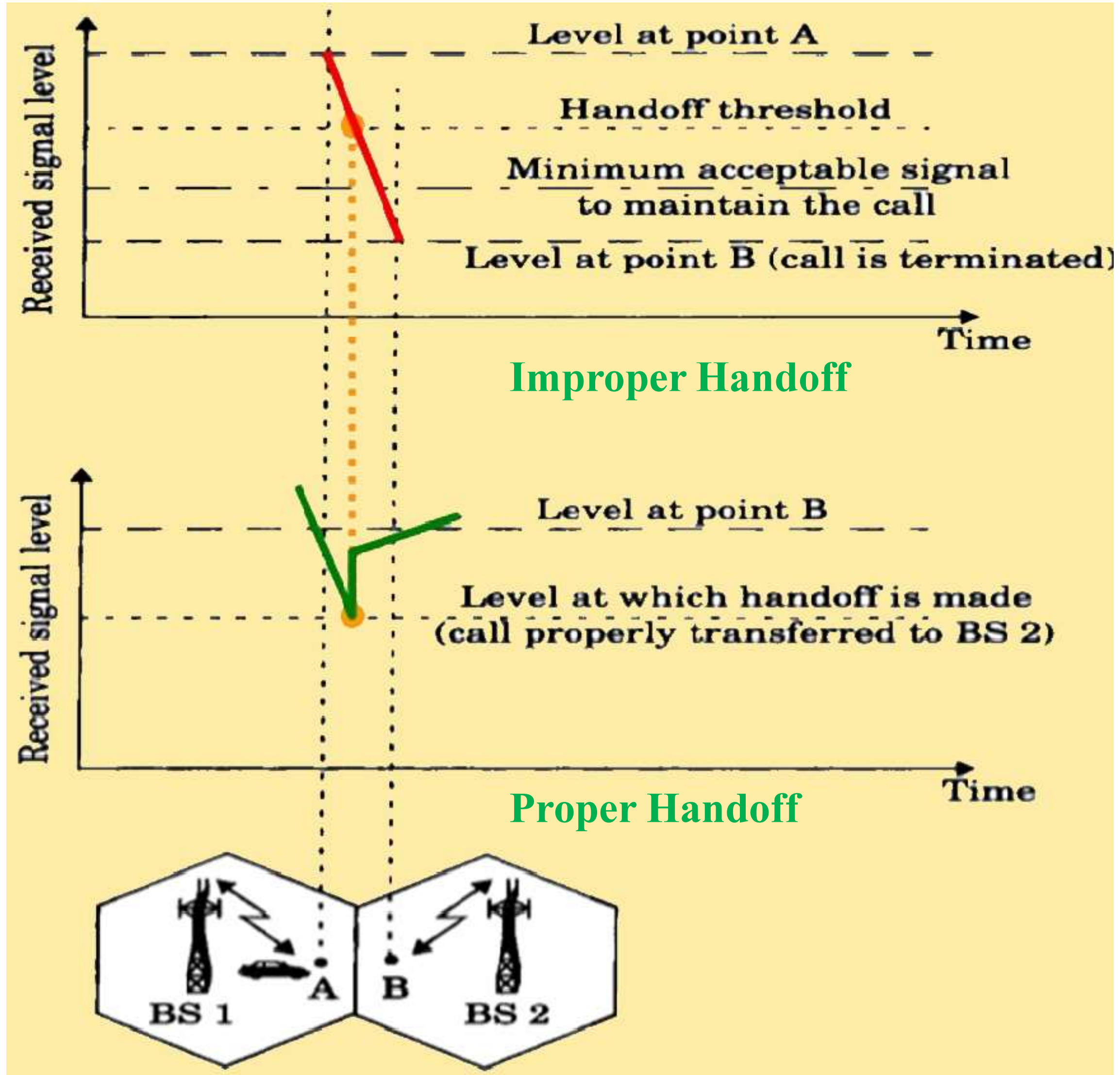
Handoff Strategies:

- *The minimum usable signal for acceptable voice quality is -90 dBm to -100 dBm.*

- *The handoff margin*
  $\Delta = P_{rhandoff} - P_{rminimumusable}$

- *This Δ should not be too large, then unnecessary handoff will burden the MSC.*

- *This Δ should not be too small, then there will be insufficient time to complete handoff before a call is lost.*



MAHO (Mobile Assisted Handoff):

Analog system *the signal strength is continuously measured by the BS and supervised by the MSC.*

Digital system *the signal strength (RSSI) is continuously measured by the (mobile station) MS:*

- *Mobile station or the subscriber unit measures the signal strength and reports to the serving BS.*

- *Handoff is initiated when power received from the BS of a neighbouring cell begins to exceed the power received from the current serving BS for certain levels and time duration*

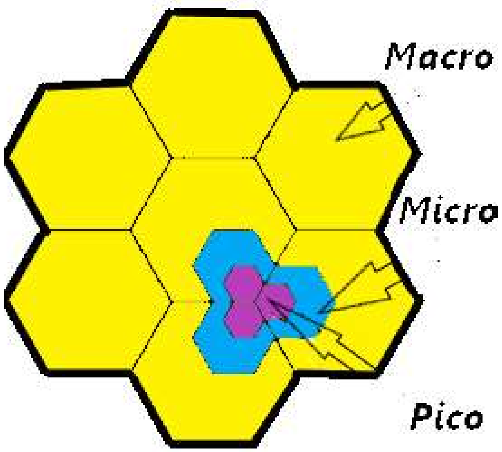
MAHO *is faster and more suited for microcell cellular concept*.

Dwell Time:

- *The time a call is maintained with in a cell without handoff, is called the dwell time.*
- *Even for a static user also the dwell time is finite.*
- *There are number of factor which influence the dwell time*
- *Propagation loss*
- *Interference*
- *Distance between the BS*

Coverage and Capacity Improving Techniques

Cell splitting



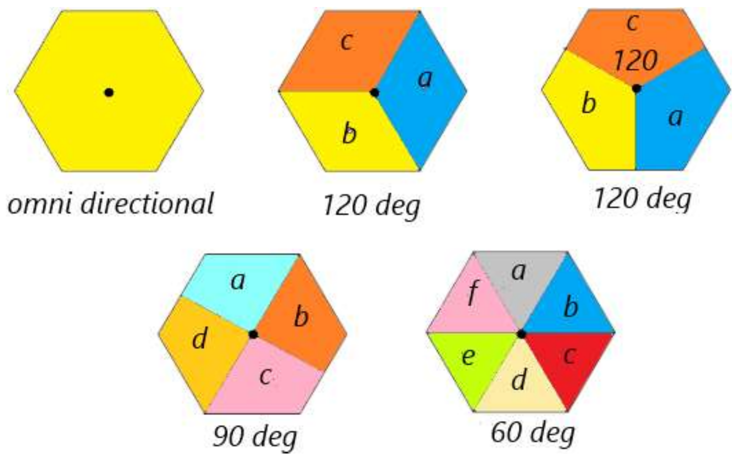
- *In this process cells in area of higher user density can be splits into smaller cells.*
- *A high power transmitter is replaced by many low power transmitters, so each cell has its own BS.*
- *Increased number of BSs increases the system capacity.*
- *It surely reduces the cell radius, but keeping the $\frac{D}{r}$ ratio unchanged.*
- *All cells are not necessarily to be splitted, only traffic overloaded cells to be splitted.*

Disadvantages:

- *More cell implies more boundaries will be crossed, hence increasing handoff.*
- *Different cell size exists, hence special care need to be taken to keep the distance between co-channel cells at the minimum required distance.*
- *As different cell size exists, same transmit power cannot be used for all cells.*

Coverage and Capacity Improving Techniques

Cell Sectoring



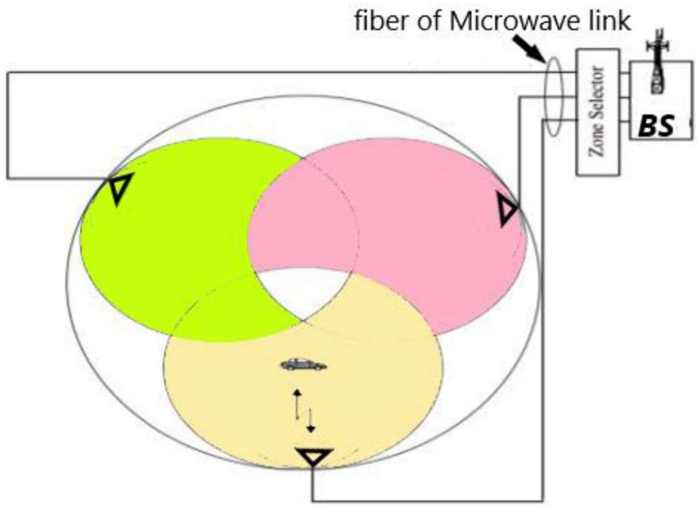
- *In this sectoring method, first the SIR improved by using directional antennas.*
- *A The capacity improvement achieved by reducing the number of cells in a cluster, this in terns increases the frequency reuse factor.*
- *The co-channel interference is also decreased by replacing one high power Omni directional antenna by several directional antennas, each radiating within a specific sector.*
- *A original cluster can be divided into 3 cluster of* 120^0 *or 4 cluster of* 90^0 *or 6 cluster of* 60^0 *and so on.*

Disadvantages:

- *Increased the number of antennas at each BS.*
- *Increased the number of handoffs (sector to sector).*
- *Decrease in trunking efficiency due to sectoring.*

Coverage and Capacity Improving Techniques

Microcell zone concept



- *In this process, cells are conceptually divided into microcells or zones.*
- *Each microcell is connected to the same BS and share the same radio equipment.*
- *The zones are connected by co-axial cables, or optical fiber cable or microwave link to the BS.*
- *Each microzone has a directional antenna, when a mobile travels into the cell it is served by the zone with the strongest signal.*

Advantages:

- *Reduced interference.*
- *No extra handoff.*
- *Increase in capacity.*
- *No loss in trunking efficiency, since all channels are used by all cells.*

Trunking and Grade of Service

The concept of trunking is to accommodate a large number of subscribers to share a relatively small number of channels. The trunking theory was proposed by Erlang.

- *Channels are assigned on demands from a pool of available channels*
- *When a user no longer requires service, channel returned to pool to be allocated to next user*
- *A queue may be used to hold the requesting users until a channel becomes available.*

Types of trunking systems most commonly used.

- System with no queue for call request. If a channel is available no setup time is required and the user is given immediate access to the available channel. If no channel are available the requesting user is blocked without access and is free to try again later. This type of trunking is called **Blocked Calls Cleared – Erlang B**

- System in which a queue is provided to hold calls which are blocked and the call will be in the queue for a certain time and if no channel is available after the waiting time the call request will be block or the call got lost. This type of trunking is called **Blocked Calls Delayed – Erlang C**

Common terms in trunking theory:

Set-up time: *Time required to allocate a trunked radio channel to a requesting subscriber/user.*

Blocked call/lost call: *Call which cannot be completed at time of request due to congestion.*

Holding time: *Time required to allocate a trunked radio channel to a requesting subscriber/user.*

Traffic intensity (*A*): *Average channel occupancy measured in Erlangs.*

Grade of service (GOS):***Erlang B:*** *A measure of congestion, as a probability of a call being blocked.* ***Erlang C:*** *A measure of congestion, as a probability of a call being delayed beyond a certain amount of time.*

Request rate: *Average number of call requests per unit time (λ/sec)*

Erlang B Formula:

Traffic intensity offered by each user $A_u = \lambda H$

where λ *= call request rate i.e. average number of call requests per unit time.*

H *= Holding time i.e. average duration of a call*

Therefore, the total traffic intensity for a system containing U users where no. of channels are not specified $A = UA_u$

For a C channel trunked system, if the total traffic intensity (A) is equally distributed among the channels, then the traffic intensity per channel $A_c = \frac{UA_u}{C}$

The Erlang B formula dictates the probability that a call is blocked and is a measure of GOS for a trunked system which provides no queueing for the blocked calls. The probability of blocking is given by

$$P_r[blocking] = \frac{\frac{A^C}{!C}}{\sum_{k=0}^{C} \frac{A^k}{!k}}$$

This also represents the Grade of Service (GOS).

Erlang C Formula:

The trunked system is one in which a queue is provided to hold calls which are blocked. If aca channel is not available immediately, the call request may be delayed until a channel is available. This type of trunking is called Block calls delayed and described by the Erlang C formula. Erlang C formula determines the probability that a call is blocked after waiting for a specific length of time in the queue .

$$P_r[delay > 0] = \frac{A^C}{A^C + !C\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C}\frac{A^k}{!k}}$$

This gives the probability of a call not having immediate access to channel.

The probability of delay larger than t

$$P_r[delay > t] = P_r[delay > 0]e^{(C-A)T/H}$$

The average delay for all calls in a queued system is given by

$$D = P_r[delay > 0]\frac{H}{C - A}$$

For Erlang C formula GOS is defined in this case is the portability that call is blocked after waiting a specific length of time in the queue.

Questions for review

1. **Explain how frequency reuse improves system capacity.**

2. **State the disadvantages of co-channel and adjacent channel interference.**

3. **Discuss different coverage improving techniques.**

4. **State the difference between hard hand-off and soft-hand off and which one is preferred by an mobile subscriber and why?**

Reference Book

T.S.Rappaport, Wireless Communication -Principle and Practice, 2nd ed. 2013.