Cellular Concepts:

* Early mobile system used single high powered tnx with an antenna mounted on a tall tower to achieve large coverage area.
* Impossible to reuse those same frequencies throghout the system because of Interference.
* To solve this problem of spectral congestion and user capacity, cellular concept is introduced.

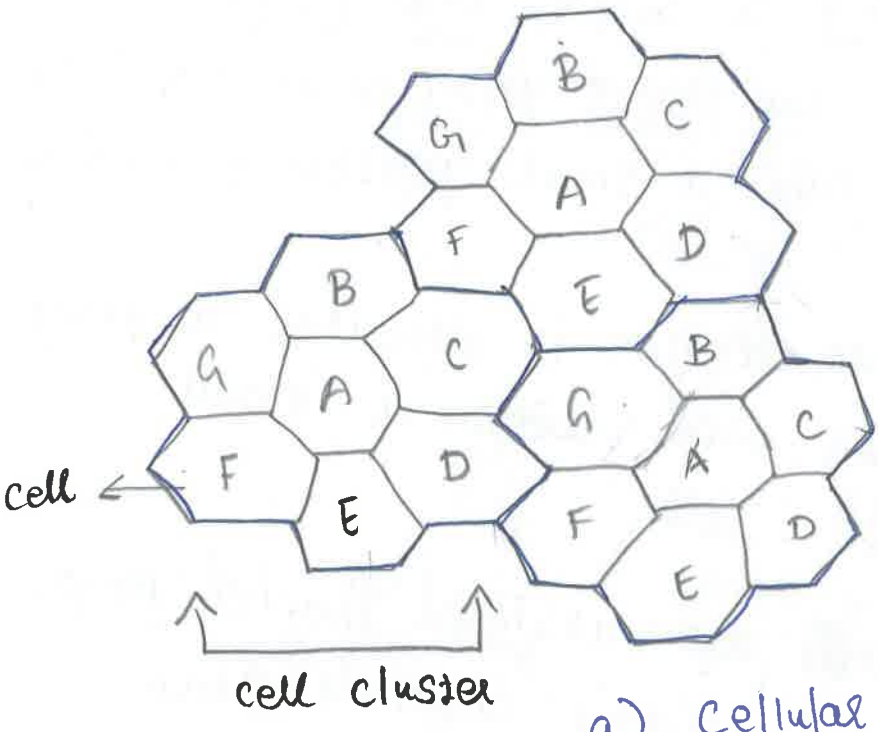
Definition: The cellular concept is a system level idea which calls for replacing a single, high power tnx (large cells) with many low power tnx (small cells) each providing coverage to only a small portion of service area.

Cell: Each cellular base station is allocated a group of radio channels to be used within a small geographical area called a cell.

* BS in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells.
* BS antennas are designed to achieve the desired coverage within the particular cell.

* By limiting the coverage area within the boundaries of the cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits.

* The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency re-use (or) frequency planning.



Here,

cluster size $N = 7$

Freq. reuse factor $= \frac{1}{7}$

a) Cellular frequency Reuse concept.

* Here the cells labeled with the same letter use the same group of channels.

Foot Print: The actual radio coverage of a cell is known as the foot print. It is determined from field measurements (or) Propagation Prediction models.

* Hexagonal cell provides largest area and permits easy and manageable analysis of a cellular system.

* when using hexagons to model coverage areas, BS are depicted as either being in the center of cell [center-excited cells] or on three of the six cell vertices [edge-excited cells].

* Omnidirectional Antennas — center excited cells
  Sectored directional Antennas — corner excited cells.

Capacity Expansion by Frequency Reuse:

* Consider a cellular system which has a total of 'S' duplex channels available for use.

* Let N be the cluster size in terms of the number of cells within it and each cells is allocated a group of K-channel. (K < S)

* 'N' cells in this cluster would then utilize all 'K' available channels. In this sense, N is also refered as 'frequency reuse factor' of the cellular system.

* S channels are divided among N-cells into unique & disjoint channel groups which each have same no. of ch.

* The total no. of available radio channels can be expressed as,

$$\boxed{S = KN} \longrightarrow (1)$$

* The 'N' cells which collectively use the complete set of available frequencies is called a cluster.

* If a cluster is replicated M times within the system the total no. of duplex channels C, can be used as a measure of capacity and is given by,

$$\boxed{C = MKN = MS} \longrightarrow (2)$$

* The capacity of a cellular system is directly prop. to the no. of times a cluster is replicated in a fixed service area.

* Cluster size is typically equal to 4, 7 or 12.

* If the cluster size (N) is reduced while the cell size is kept constant, more clusters are required to cover a given area and hence more capacity is achieved.

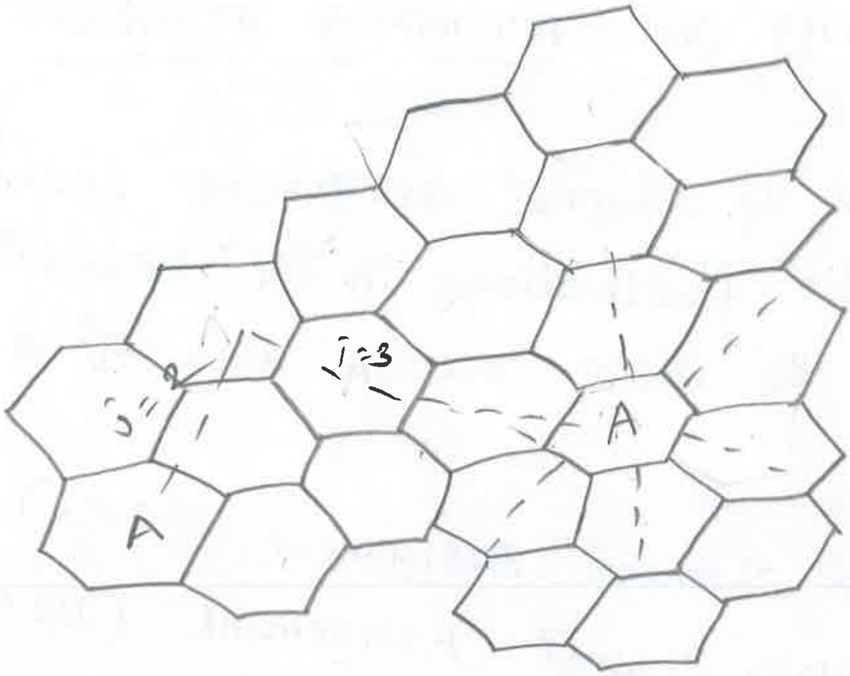
* The freq. reuse factor of a cellular system is given by $1/N$.

<u>Rules for determining the nearest co-channel Neighbours:</u>

<u>Step 1:</u> Move i cells along any chain of hexagons.

<u>Step 2:</u> Turn 60 degree counter clkwise and move j cells.

* The method of locating co-channel cells in the cellular system using the preceding rule is given by, $i=3$ and $j=2$, where the co-channel cells are indicated by 'A'.



* The parameters i & j measure the no. of nearest neighbors btwn co-channel cells. N is related to i & j by eqn,

$$\boxed{N = i^2 + ij + j^2} \longrightarrow (3)$$

* As the distance btwn co-channel cells increases, co-channel interference will decrease.
* If cell size is fixed, the average signal to ~~noise~~ rat co-channel intereference ratio will be independent of the transmitted power of each cell.

<u>Advantages of cellular systems:</u>

→ use of low power transmitter.

→ Allowance of freq. reuse.

Channel Assignment Strategies :

* For efficient utilization of the radio spectrum, a freq. reuse scheme that is consistent with the objectives of increasing capacity and minimizing interference is required.

* The main objective of channel assignment technique is to stabilize the fluctuations in the probability of call blockage over the entire coverage area of a ntk over time.

* Types : a) Fixed channel Assignment (FCA)
  b) Dynamic channel Assignment (DCA)

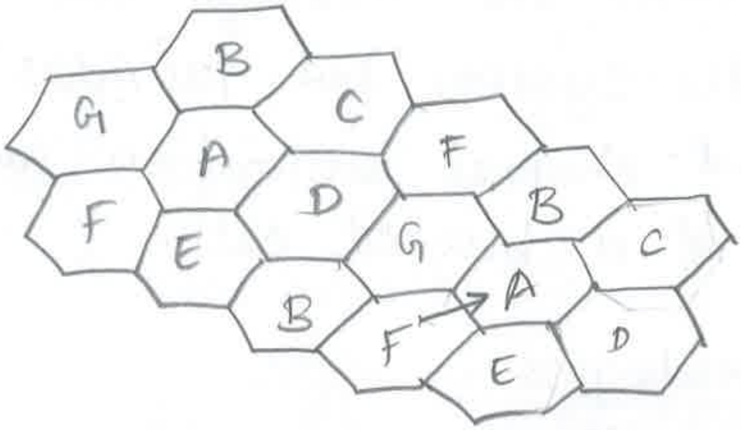
FCA Strategy :

→ In FCA, each cell is allocated a predetermined set of voice channels. Any call attempt within the cell can only be served by the unused channels in that particular cell.

→ If all the channels are occupied, the call is blocked and the subscriber does not receive service. Several variations of the fixed assignment strategies exist.

→ In one approach called the borrowing strategy, a cell is allowed to borrow channels from a neighbouring cell if all its own channels are already occupied.

→ MSC supervises such borrowing procedures and ensure that the borrowing of a channel does not distrupt (or) interfere with any calls in progress in donor cell.



a) Temporary channel borrowing

DCA strategy :-

* Here, voice channels are not allocated to different cells permenently. Each time a call request is made, the serving BS request a channel from MSC.

* Accordingly MSC allocates a given frequency, if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of freq. reuse to avoid co-channel interference.

* DCA reduces the call blocking, which increases the trunking capacity of the system.

* DCA requires MSC to collect real-time data on channel occupancy, traffic distribution and radio signal strength indications (RSSI) of all channels on a continuous basis.

* This increases the storage and computational load on the system but provides the advantage of increased channel utilization and decreased probability of a blocked call.

<u>Handoff Strategies:</u>

* When a mobile moves into different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new BS.

* This handoff operation not only involves identifying a new BS, but also requires that the voice and control signals be allocated to channels associated with new BS.

* Handoff calls can be admitted at a higher priority than new calls. To manage the admission of request based on priority, it is necessary to reserve capacity for admitting handoff requests.

* System designers should specify an optimum signal level at which to initiate a handoff.

* Once a particular signal level is specified as the minimum usable signal for acceptable voice quality at BS receiver, a slightly stronger signal level is used as threshold at which a handoff is made.

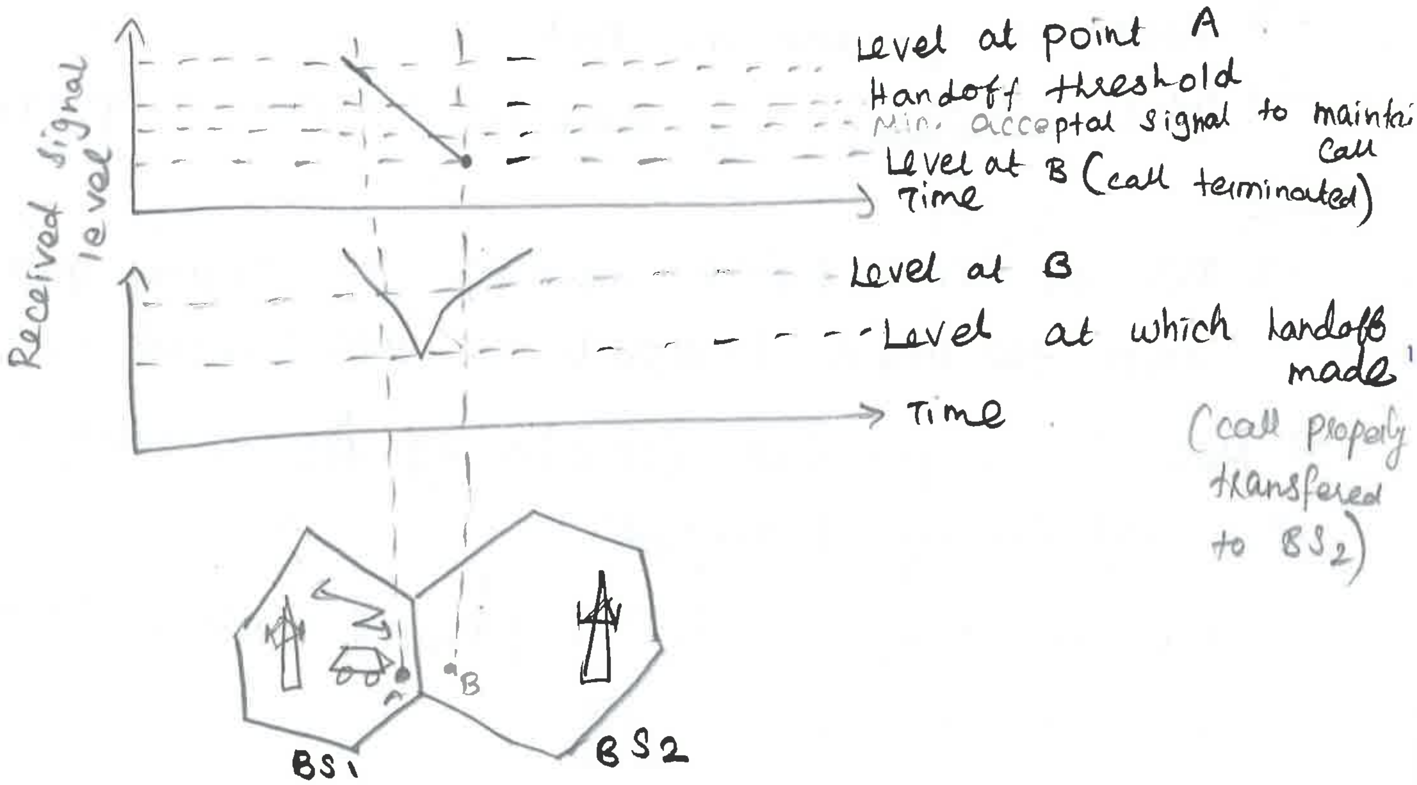
* This margin is given by,

$$\boxed{\Delta = P_r \text{ handoff} - P_r \text{ minimum usable}}$$

Δ cannot be too large or too small.

* If Δ too large → unneccessary handoff → burden MSC.

* If Δ too small → insufficient time to complete a handoff



Dwell time: The time over which a call may be maintained within a cell, without handoff is called a dwell time.

* The dwell time of a particular user is governed by a no. of factors.
  → propagation, interference, distance btwn subscriber and BS, other time varying effects.

* Depending on the information used and the action taken to initiate the handoff, the methods for handoff can be

(i) Mobile Controlled Handoff (MCHO)
(ii) Network " " (NCHO)
(iii) Mobile Assisted Handoff (MAHO)

MCHO:
  → Desirable Method
  → Reduces Burden on ntk
  → But increases the mobile terminal complexity

NCHO:
  → BS or access point monitor the signal quality from the mobile & report the measurement to MSC.
  → MSC is responsible for choosing the candidate BS & initializing handoff.
  → Mobile plays only a passive role in handoff process.

MAHO:

→ Mobile measures the signal levels from various BS using a periodic beacon generated by BS

* Every mobile station measures the received power from surrounding BS & continuously report to serving BS.

* A handoff is initiated when the power received frm BS of neighboring cell begins to exceed the power received frm the current BS.

* Very faster & particularly suited for micocellular environments where handoffs are more frequent.

Intersystem Handoff:-

* During a course of a call, if a mobile moves from one cellular system to different cellular system controlled by different MSC, an intersystem handoff is required.

* Before implementing a intersystem handoff, compatibility btwn two MSCs must be determined.

Prioritizing Handoffs:-

* one method for giving priority to handoff is called guard channel concept, whereby a fraction of the total available channels in a cell is reserved exclusively for

handoff requests frm ongoing calls which may be handed off into the cell.

* Disadvantage: Reduces the total traffic carried, as fewer channels are allocated to originating calls.

→ Queuing of handoff request is another method to decrease the probability of forced call termination due to lack of channels.

* It is possible due to the fact that there is finite time interval btwn the time the received signal level drops below the handoff threshold & the time the call is terminated, due to insufficient signal level.

Practical Handoff Considerations:

* In practical cellular systems, several pblms arise when attempting to design for a wide range of mobile velocities.

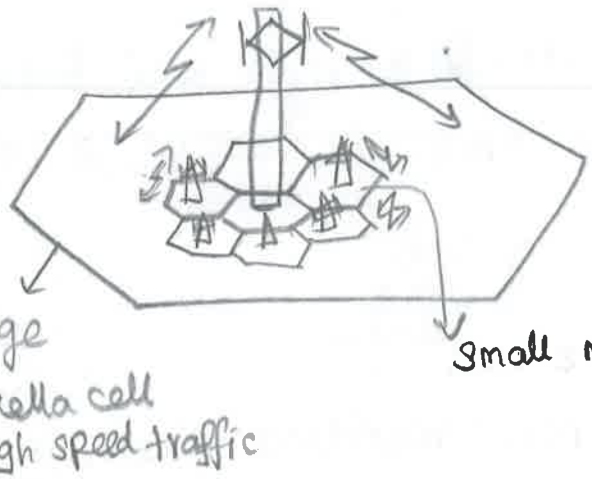
* High speed vehicles pass thro' the coverage region of a cell within a matter of seconds, whereas pedestrain users may never need a handoff during a call.

* with addition of Micro cells, to provide capacity, MSC can quickly become burdened if high speed users are constantly being passed btwn very small cells.

Umbrella cell Approach :-

* By using different antenna heights (same building or tower) and different power levels, it is possible to provide hf for large and small cells which are co-located at single location. This tech. is called umbrella cell approach.

* This approach is used to provide large area coverage to high speed users while providing small area coverage to users traveling at low speeds.



cell dragging :-

* A practical handoff problm in microcell system is known as cell dragging.

* cell dragging result frm pedestrain users that provide a very strong signal to the BS. such a situation occurs in an urban environment when there is a line-of-sight (LOS) radio path btwn subscriber & BS.

* As the user travels away frm BS at a very slow speed, the aveg. signal strength does not decay rapidly.

* Even when the user has traveled well beyond the desired range of the cell, the received signal at BS may be above the handoff threshold, thus handoff may not be made.

* This creates a potential ~~Management~~ interference and traffic management pblm, since the user has meanwhile traveled deep within a neighbouring cell.

* To solve the cell dragging pblm, handoff thresholds & radio coverage parameters must be adjusted carefully.

* In analog cellular systems, $\Delta \simeq 6\,dB$ to $12\,dB$.

  In digital sys. like GSM, $\Delta \simeq 0\,dB$ and $6\,dB$. This provides MSC with substantial time to "rescue" a call that is in need of handoff.

Types of Handoff:

Hard Handoff: If the MSC monitors the strongest signal BS and tranfers the call to that BS, then it is called hard handoff.

Soft Handoff: Mobile communicates with two or more cells at the same time & find which one is a strongest signal BS then it automatically transfers the call to that BS is called soft H/f.

Features:-

→ Efficient use of resources.
→ Capable of recovering from link failures.

→ Fast & lossless
→ Minimum no. of control signal exchanges.
→ Scalable with nkt size

Interference and System capacity:

* Interference - Major limitation in performance of cellular radio systems.

* It causes cross talk, in voice channels where the subscriber hears interference in the background due to an undesired transmission.

Intracell Interference:

→ ~~Due~~ Interference frm other mobile in the same cell.

Intercell Interference:

→ Interference frm other cells.

* In controlled channels, interference leads to missed & blocked calls due to errors in digital signaling.

The two major system generated cellular interference are

i) co-channel interference
ii) Adjacent channel interference.

Co-channel Interference:

* Frequency Reuse - Same set of frequencies are used by several cells. These cells are called co-channel cells. and the interference btwn signals frm these cells is called co-channel interference.

* To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

* When the size of each cell is approximately the same and the base stations transmit the same power, the co-channel interference ratio is independent of the transmitted power & becomes a function of the radius of the cell (R) and the distance btwn centers of the nearest co-channel cells (D).

* By increasing the ratio D/R, the spatial separation btwn co-channel cells relative to coverage distance of a cell is increased.

* The co-channel reuse ratio Q is defined by,

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

If N is small, Q also small, provides larger capacity.

* Let i_0 be the no. of co-channel interfering cells, then the signal interference ratio (S/I) for a mobile receiver which monitors a forward channel can be expressed as

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

S → desired signal power frm desired base station

I_i → Interference power caused by i^{th} interfering co-channel cell base station.

* The avg. received power P_r at a distance d frm the transmitting antenna is,

$$P_r = P_o \left(\frac{d}{d_o}\right)^{-n}$$

$$P_r(dBm) = P_o(dBm) - 10\,n \log\left(\frac{d}{d_o}\right)$$

where $P_o \Rightarrow$ power received at a close-in reference point in the far field region of the antenna at a small distance d_o frm the trnx antenna

$n \Rightarrow$ Path loss exponent. [usually $2 \leq n \leq 5$].

* when the transmit power of each base station is equal and the path loss exponent is the same throughout the coverage area, S/I for a mobile can be approximated as,

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_o} (D_i)^{-n}}$$

where D_i be the distance btwn i^{th} interferer & the mobile.

* The degree of co-channel interference is a function of the location of the mobile within the cell of the serving base station.

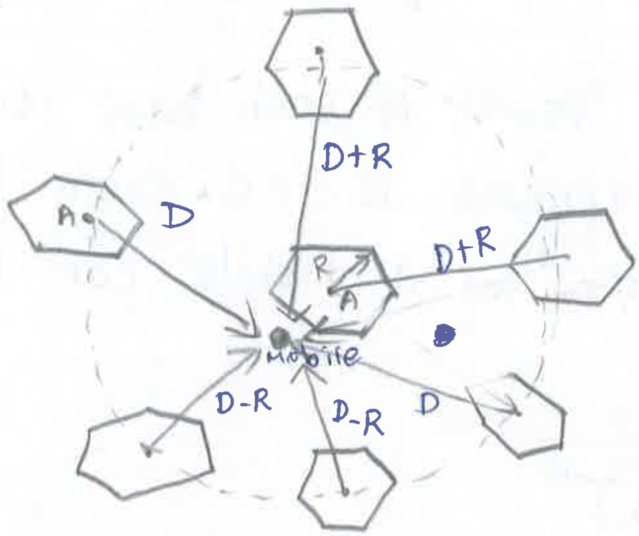
* considering only first layer of interfering cells, if all the interfering BS are equidistant frm the desired station,

and if this distance is equal to the distance D btwn cell centers, then,

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0};$$

* consider that the mobile is at the cell boundary, where it experiences worst case co-channel interference on the frd channel.

* The marked distances btwn the mobile and different co-channel cells are based on approximations made for easy analysis.



* The mobile is at a distance D-R frm two nearest co-channel interfering cells and is exactly D+R/2, D+R, D, D-R/2 distance frm other interfering cells.

* The signal to interference ratio for the worst case can be closely aproximated as,

$$\frac{S}{I} = \frac{R^{-n}}{2(D-R)^{-n} + 2(D+R)^{-n} + 2D^{-n}}$$

WKT, $\frac{D}{R} = Q$, with $n=4$,

$$\boxed{\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}}$$

Channel planning for wireless system:-

→ Radio spectrum divided into channels.

→ control channels - Initializing, Requesting or Paging a call.
Voice channels - dedicated to carrying revenue - generating traffic.

→ 5% of mobile spectrum → control channels to carry data
9% → Voice channels.

Breathing cell Effect:

* CDMA has a single radio channel that carries simult. transmission of single control channel & 64 simultaneous voice channels.
* CDMA has a dynamic, time varying coverage region which varies depending on the instantaneous no. of users on the CDMA radio channel. This effect is known as breathing cell.
* Wireless engineers carefully design for best coverage & interference issues.

Adjacent channel Interference:

→ Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.

→ Due to imperfect receiver filters, which allows nearby freq. to leak into the passband.

→ near-far plm will occur.

→ Minimized thro careful filtering & channel assignment.

→ In practice, BS receivers are preceded by a high Q cavity filter to reject adjacent channel interference.

Power control for reducing interference:

* Power levels in every subscriber is controlled by the serving base stations.

* This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel.

* Power control helps prolong battery life for the subscriber unit & dramatically reduces reverse channel S/I in the system.

Trunking & Grade of service:

* Trunking allows a large no. of users to share, small number of channels in a cell by providing access to each user, on demand from a pool of available channels.

* In trunked radio system, each user is allocated a channel on a per call basis and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

Grade of service: It is a measure of ability of a user to access a trunked system during the busiest hour.

Set-up time: The time required to allocate a trunked radio channel to a requesting user.

Blocked call: Call which cannot be completed at time of request, due to congestion also referred to as a lost call.

Holding Time: Average duration of a typical call. (H)

Traffic Intensity: Measure of channel time utilization which is the average channel occupancy. Denoted by (A)

Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.

Request Rate: The average no. of call requests per unit time. It is denoted by λ $seconds^{-1}$.

Each user generates a traffic intensity of A_u Erlangs given by,

$$\boxed{A_u = \lambda H}$$

$H \Rightarrow$ Averg. duration of a call.

$\lambda \Rightarrow$ Avg. no. of call request per unit time for each user.

* For a system containing U users and an unspecified no. of channels, the total offered traffic intensity A is given as,

$$\boxed{A = UA_u}$$

* In a C channel trunked system, if the traffic is equally distributed among the channels, then the traffic intensity per channel A_c, given by,

$$\boxed{A_c = UA_u / C}$$

Types of Trunked System :

→ Blocked calls cleared

→ Blocked calls delayed

Blocked calls cleared :

→ no queuing for call requests.

→ no setup time, immediate access to every user, if one channel is available.

→ no channel available, requesting user is blocked without access and is free to try again later.

→ This type of trunking is called blocked call cleared and assumes that calls arrive as determined by a Poisson distribution.

* Interms of traffic intensity A, the prob. of blocking is given by Erlang loss formula,

$$\boxed{P_r[\text{blocking}] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = \text{GOS}}$$ → Erlang-B loss formula.

where $C \rightarrow$ no. of trunked channels offered by a trunked radio system

$A \rightarrow$ Total offered traffic

Blocked calls Delayed:

* If channel is not available immediately, the call request may be delayed until a channel becomes available. This type of trunking is called Blocked calls delayed.

* GOS is defined as the prob. that a call is blocked after waiting a specific length of time in the queue.

Erlang C formula for non-zero delay is given by,

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

* If the call is delayed for 't' seconds as wait time, GOS is given by,

$$P_r[\text{delay} > t] = P_r[\text{delay} > 0] \times P_r[\text{delay} > t / \text{delay} > 0]$$

$$\Rightarrow P_r[\text{delay} > 0] \exp(-(C-A)t/H)$$

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

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

where $\frac{H}{C-A}$ is the avg. delay for those calls which are queued.

Trunking Efficiency :- It is a measure of the no. of users which can be offered a particular GoS with a particular config. of fixed channels.

Improving coverage & capacity in cellular system :-

* more channels per unit coverage area.

Three techniques to expand the capacity of cellular system.

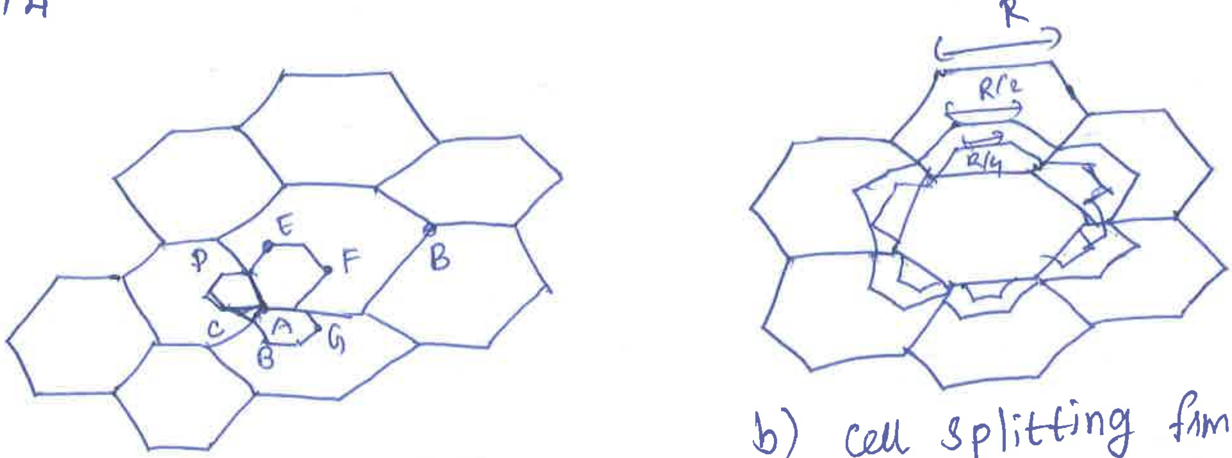
→ cell splitting
→ sectoring
→ coverage zone approaches (A microcell zone concept).

Cell splitting :

→ subdividing a congested cell into smaller cells with its own BS & corresponding reduction in antenna height and transmitted power.

→ Increases the cellular sys. capacity as no. of times the channels are reused.

→ Original cell size R is splitted into R/2 and then to R/4.



a) cell splitting

b) cell splitting from radius R to R/2 & R/4

* The average received power,

P_r [at old cell boundary] $\propto P_{t1} R^{-n}$

and P_r [at new cell boundary] $\propto P_{t2} (R/2)^{-n}$

where, P_{t1} & P_{t2} are transmit powers for larger & smaller base stations resp.

n → Path loss exponent.

* Down tilting of Antenna → limit the radio coverage of newly formed microcells.

Sectoring (Directional Antennas).

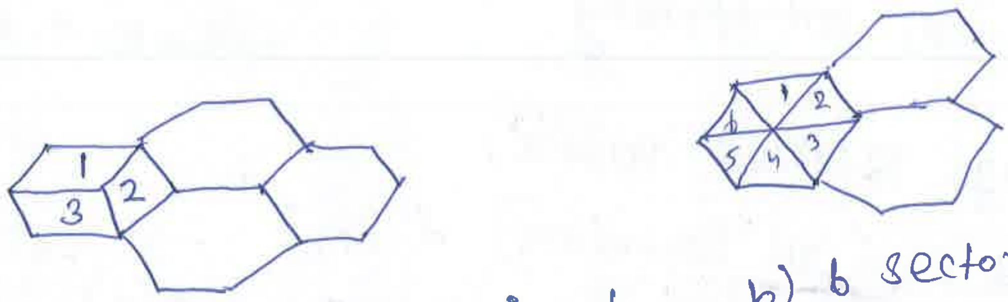
→ It reduces S.I ratio & reduces cluster size & increases the capacity.

→ Reduces the co-channel interference by focusing the radio prop. in only one direction where it is required.

Sector: The area covered by each directional antenna is called as section (or) sector.

Sectoring: The technique for decreasing co-channel interference & thus increasing system performance by using directional antennas is called sectoring.

A cell is normally partitioned in three 120° sectors (or) six 60° sectors.



a) 3 sectors of 120° each

b) 6 sectors of 60° each

Disadv:

→ Each sector → new cell → diff. shape

→ Handoff increases

→ decreases trunking efficiency.

A Microcell Zone Concept:

→ corner excited BSs used to reduce the no. of handoffs & eliminate partitioning of channels btwn sectors of a cell.

→ Here 3 zone cities are connected to a single BS & share the same radio freq.

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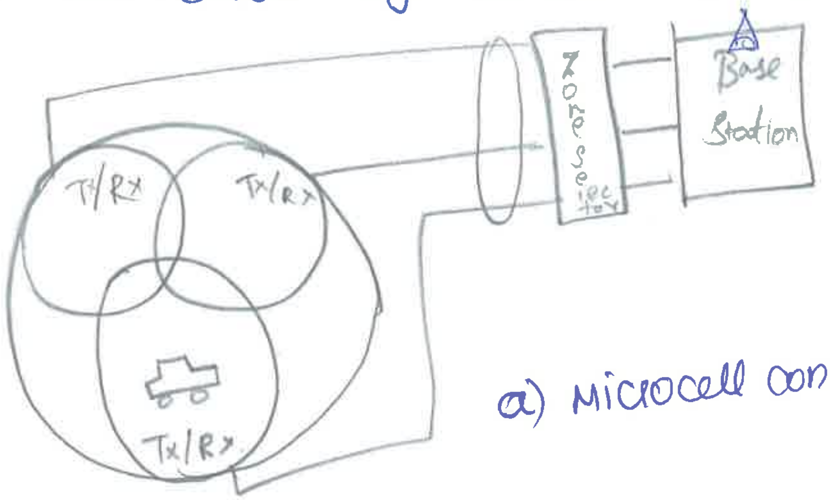
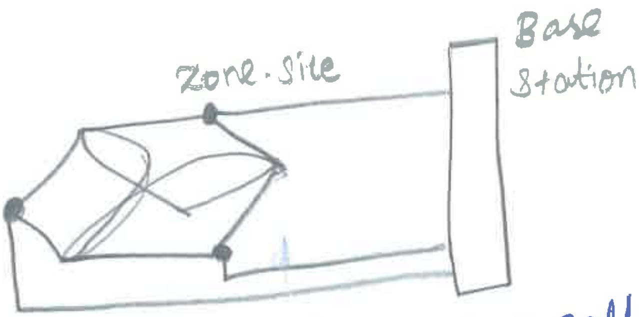
* The BS determines which of the zone-site has the best reception from the mobile & uses that zone-site to transmit the signal on the downlink.

* zones - connected by co-axial cable.



a) Microcell concept



b) Lee's Micro cell zone concept.

Adv :

→ large BS is replaced by zone transmitter reduces co-channel interference.

→ Improves signal quality.

→ Increase the channel capacity without degradation in trunking efficiency caused by sectoring.