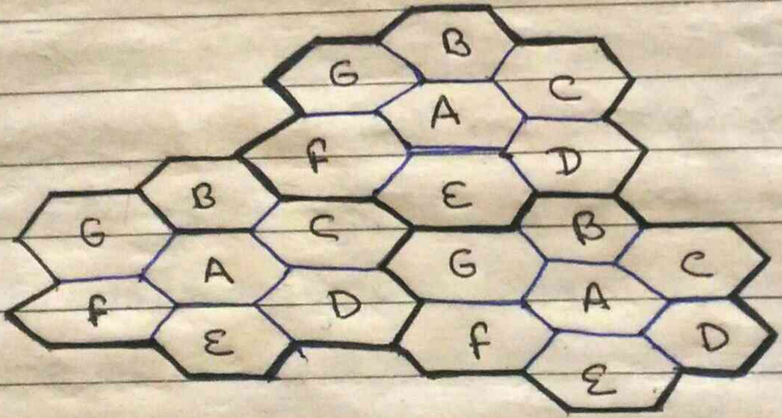
The Cellular Concept

Terminologies :

1. **Cell** → Each cellular base station is allocated a group of channels to be used within a small geographic area called a cell.

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



Cells labelled with the same letter use the same group of channels

Cluster Size, N=7.

3. **Footprint** → The actual radio coverage of a cell is called its footprint.

4. **Dwell Time** → Time over which a call may be maintained within a cell, without handoff

It is a system level idea which calls for replacing a single high power Tx ~~with~~ many low power Tx (small cells) each providing coverage to only a small portion of service area.

↳ Cellular Concept provides:-

1. Solution to the problem of congestion and user capacity.
2. Very high capacity in a limited spectrum allocation without any major technological changes.
3. Replacement of high power transmitter with many low power transmitters.
4. Each transmitter provides a coverage to a small portion of service area. Each base station is allocated a portion of total no. of channels. To avoid interference, neighbouring base station is provided different channels.

↳ Frequency Reuse ⇒:- In a cellular system, each base station is allocated a group of radio channels which are to be used within a cell. Neighbouring cells are provided entirely different ~~cells~~ channels.

- The base antennas are desined to achieve coverage within a particular cell and coverage is limited outside the boundary of the cell.

∴ Thus by limiting the coverage area withing the boundaries of a cell, the same frequencies can be used by different cells which are separated from one another by large distances to keep interference within tolerable limits.

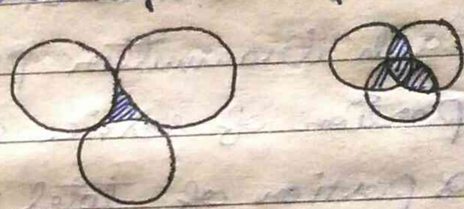
- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called "freq. reuse" or "freq. planning".

(iv) When considering a geographical shape, which covers the entire region without overlapping & with equal area to serve the weakest point within footprint

↳ Shape of the Cell → • Hexagonal shape is used since it permits easy and manageable analysis of cellular system.

• Actual footprint of base station is amorphous but still regular shape is required for systematic design.

• Circular shape is not taken as a cell because adjacent circles can't be overlaid upon map without leaving gaps or overlapping.



• A cell must be designed to serve the weakest point within the footprint which are typically edges of the cell.

(i) Hexagon is used for the cell structure because for a given distance b/w the center of a polygon & its farthest point, hexagon has the largest area of the three figures namely ~~rectangle~~ (square), an equilateral triangle and hexagon.

(ii) Also by using hexagon geometry, a fewer no. of cells can cover a larger geographical area.

(iii) Also the hexagon closely approximates a circular radiation pattern which would occur for an omnidirectional base station antenna and free space propagation.

• Base stations used are:-

a) → Center excited cells

b) → Edge excited cells (transmitters on 3 of 6 cell vertices)

- Total no. of Radio Channels :- No of duplex channels

$$\boxed{S = KN}$$

K → no. of channels alloted to a cell
N → no. of cells in a cluster

- Capacity of the System.

$$\boxed{C = MKN = MS}$$

M → no. of times cluster is replicated

- Frequency Reuse Factor → • If cluster size N is reduced keeping the cell size constant, results in larger value of C.

- Frequency reuse factor is given by $\frac{1}{N}$.

- N → fn. of how much interference

↳ Frequency Reuse Distance → frequency reuse is limited by co-channel interference between cells and the cochannel interference is a major problem in communication.

So it is desirable to use a minimum freq. reuse distance D to reduce this co-channel interference. This distance depends on many factors :-

(i) The no. of co-channels in the vicinity of the centre cell.

(ii) Type of geographic terrain contour.

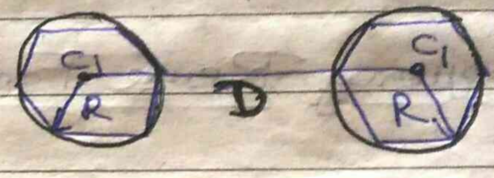
(iii) The antenna height.
(iv) The transmitted power at each cell-site

The cell size is usually determined by the coverage area of the signal strength in each cell. As long as the cell size is fixed, co-channel interference is independent of transmitted power of each cell.

Co-channel interference is a fn. of a parameter known as freq. reuse ratio, q.

$$\boxed{q = D/R}$$

D → distance b/w two nearest co-channel cells.



R → radius of the cells under consideration.

Note → This ratio is applicable for any value of cluster size K.

Example. Determine the distance from the nearest co-channel cell for a cell having a radius of 0.64 km and a co-channel reuse factor of 12.

Solution → $R = 0.64$

$q = 12$

$q = \frac{D}{R}$

$D = qR = 0.64 \times 12 \text{ km} = 7.68 \text{ km}$

Hence, distance of nearest co-channel cell, $D = 7.68$ km

The MSC only allocate a given freq. if that freq isn't presently in use by cell or any other cell which falls within the min. restricted distance of freq. reuse to avoid co-channel interference

↳ Channel Assignment Strategies :-

Objectives of freq reuse schemes are :-

(i) Efficient utilization of radio spectrum.

(ii) Increasing capacity.

(iii) Minimizing interference.

Classification → Fixed assignment Strategy / Dynamic assignment Strategy

① Fixed Assignment Strategy →

- Each cell is allocated a predetermined set of voice channels
- Call attempt within that particular cell is served by unused channels within that cell.
- If all channels are occupied then call is blocked.
- However there are a few variation in this strategy too.
- It utilizes borrowing strategy in which channels can be borrowed from neighbouring cell if it own channels are occupied under the supervision of MSC ensuring that call in progress may not be disrupted.

② Dynamic Channel Assignment Strategy →

- In this voice channels are not allocated permanently to different cells.
- Each time call is made, BS requests a channel from MSC
- Then a channel is allocated to the particular requesting cell following an algorithm that takes into account the likelihood of the future blocking within the cell, the freq of use of the candidate channel the reuse distance of the channel & cost function

- It reduces the likelihood of blocking. Increases trunking capacity of ~~channel~~ the system.

↳ <u>Handoff Strategy</u> → When a mobile moves into a different cell while a conversation in progress, MSC automatically transfers the call to a new channel belonging to a new base station.

Handoff must be performed successfully and as infrequently as possible. To meet this requirement there must be an optimum signal level at which handoff is initiated. This signal level is specified as the minimum usable signal (normally taken between −90 dB to −100 dB). For handoff to be made a slightly stronger signal level is taken so that there may not be call drop.

$$\Delta = P_{r\,handoff} - P_{r\,minimum\ usable}$$

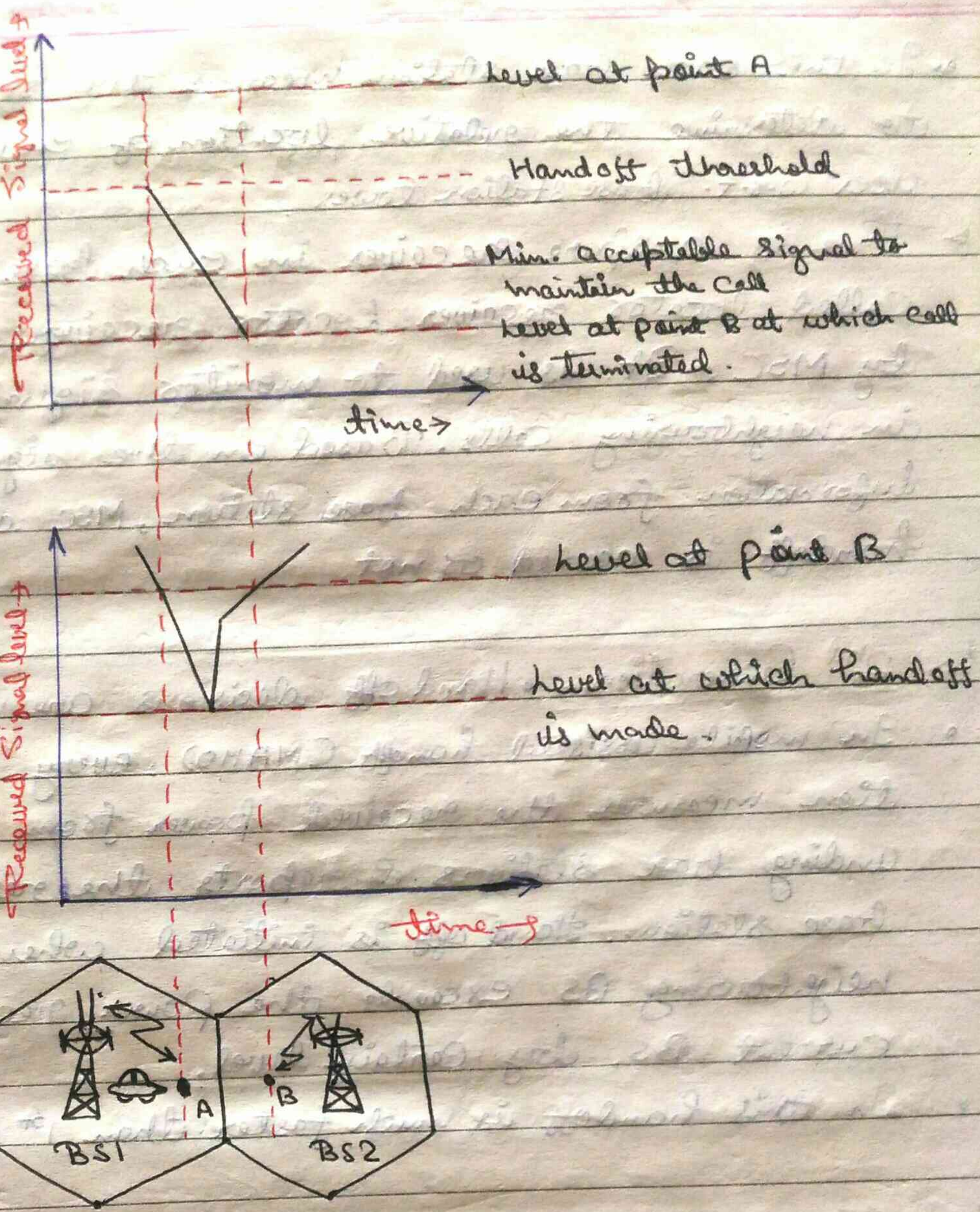
(i)→ If Δ is too small, there may be insufficient time to complete handoff before a call is lost due to a weak signal condition.

(ii)→ If Δ is too large, unnecessary handoffs which burden the MSC

- Excessive delay occurs during high traffic condition or due to unavailability of channels in the nearby base station.

- It should also be ensured by the base station that the drop in the measured signal level is not due to momentary fading; but due to movement of mobile station away from base station

(a) Improper Handoff Situation



↳ Dwell Time → Time over which a call may be maintained within a cell without handoff.

It is governed by following factors.

① Propagation ② Interference ③ distance b/w the subscriber and base station.

↳ I Generation Analog Cellular Systems → Signal strength is measured by base station and supervised by MSC.

↳ Interference and System Capacity →

- Major limiting factor in the performance of cellular system.
- Sources → (i) → Another mobile in the same cell.
  - (ii) Call in progress in a neighbouring cell.
  - (iii) → BS operating in same freq. band.
  - (iv) → Non-cellular system which leaks energy into the cellular freq. band.

- Interference on voice channel causes cross talk.
- Interference on control channel leads to missed and blocked calls due to errors in the digital signalling.

* • Types of system Generated Cellular Interference.

① Co-channel Interference.

②→ Adjacent Channel Interference.

①→ Co-channel Interference → ~~In a given coverage area~~ there are several cells within given coverage area ~~that~~ uses same set of frequencies. These cells are called Cochannels. Interference b/w signals from these cells is called co-channel interference.

- Co-channel interference can't be combated by simply increasing the carrier power of a transmitter. An increase in carrier power increases interference to neighbouring co-channel cells.

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

↳ **Co-Channel Reuse Ratio** → When size of each cell is same & the B.S. transmit the same power :- The co-channel interference ratio is independent of transmitted power and becomes a fn. R and D.

R → radius of the cell.

D → distance b/w centres of the nearest co-channel cells.

- As 'Q' increases, the spatial distance b/w co-channel cells increases relative to coverage distance of the cell.

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

(i). Small Q → Large capacity → Smaller N

(ii). Larger Q → Improved transmission quality → Smaller level of co-channel interference.

Signal-to-interference ratio is :-

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

i_0 → no. of co-channel interfering cells.

S → desired signal power from desired B.S.
I_i → interference caused by i^{th} interfering co-channel cell base station.

- The avg. power P_r at a distance d from the transmitting antenna is given by power law.

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n}$$

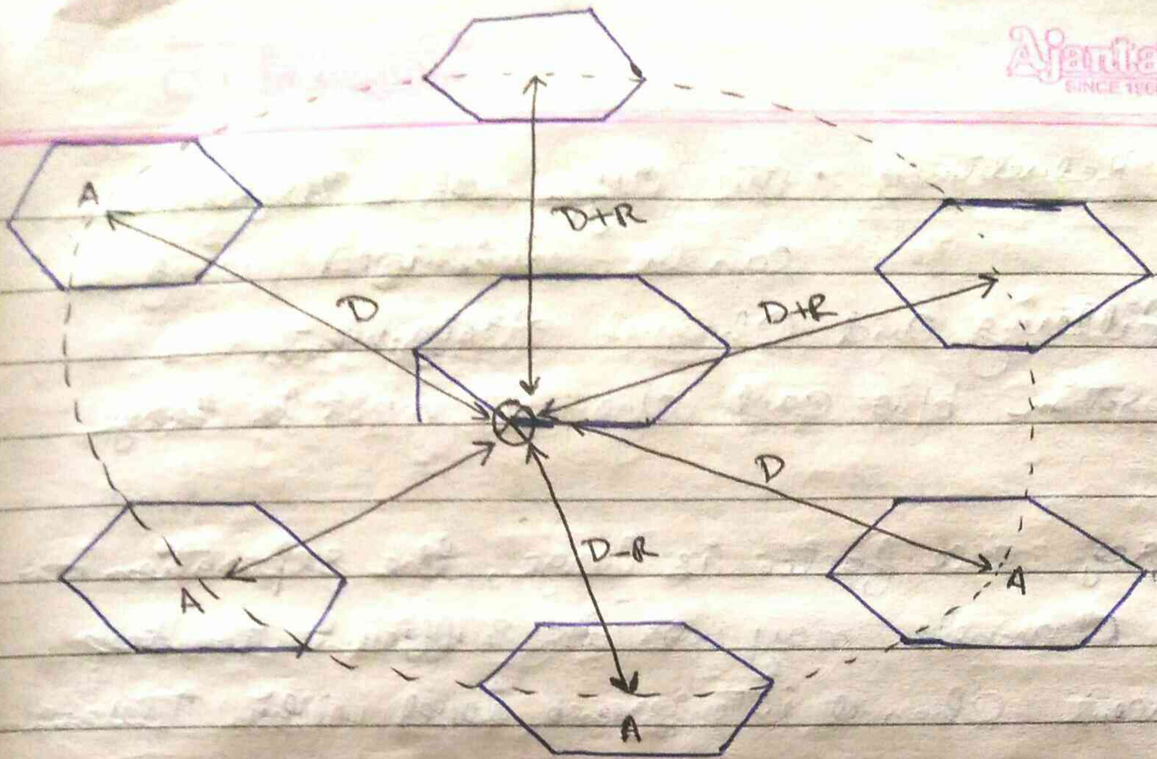
- Power at a given mobile due to i^{th} interferer from mobile is proportional to $(D_i)^{-n}$
  D_i = the distance of the i^{th} interferer from the mobile.

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

- If all the B.S. are equidistance from the desired B.S. and this distance is equal to D between cell centers, then eqn simplifies to :-

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

- Using the exact cell geometry layout, it can be shown for a seven-cell cluster, with the mobile unit at the cell boundary. Assuming $n=4$.



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

*. Co-channel interference determines link performance, which in turn dictates the frequency reuse plan & overall capacity of cellular systems.

↳ Adjacent Channel Interference →

- Due to signals which are adjacent in freq. to the desired signal.
- This type of interference results from imperfect receiver filter. This allows the nearby frequencies to leak into passband.
- This problem becomes serious if an adjacent channel user is transmitting in very close range to a subscriber's receiver, while receiver attempts to receive a base station on the desired channel.
  This is called near far effect.

• Methods of Reduction → • This type of interference can be minimized using :-

(i) Careful filtering and Channel Assignment.

(ii) Freq. separation b/w each channels must be large.

• If the freq. reuse factor is large, the separation b/w adjacent channels may not be sufficient to keep the adjacent channel interference level within tolerance.

• The signal to interference ratio at the base station for a weak mobile is :-

$$\frac{S}{I} = (2a)^{-n}$$

$n \rightarrow$ path loss exponent.

Mobile Radio Propagation: Small Scale Fading & Multipath

↳ Small Scale fading is used to describe rapid fluctuation of the amplitude, phases or multipath delays of a radio signal over a short period of time or travel distance.

↳ It is caused due to interference b/w 2 or more versions of transmitted signal.

*. Small Scale Multipath Propagation →

Multipath in radio channels creates small-scale fading effects. 3 most important effects are :→

(i) → Rapid change in signal strength over small distance or time.

(ii) → Random freq. modulation due to ~~Doppler~~ varying doppler shift on different multipath signals.

(iii) → Time dispersion caused by multipath propagation delay.

* Factors Influencing Small-Scale Fading →

(1) → Multipath Propagation → Presence of reflecting objects and scatterers results in multiple versions of the transmitted signal that arrive at the receiving antenna, displaced w.r.t one another in time and spatial orientation.

Multipath propagation induces small scale fading, distortion and lengthens the time duration for baseband portion to reach the receiver

② Speed of Mobile → Relative motion b/w the base station and mobile results in random frequency modulation due to different Doppler shifts on each of the multipath components.

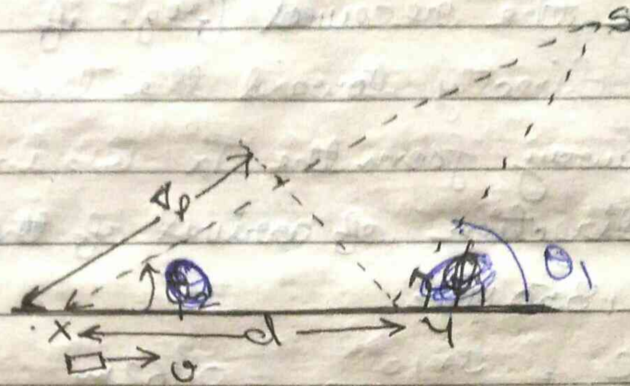
③ Speed of Surrounding Objects → If objects in the radio channel are in motion, they induce a time varying doppler shift on multipath components. If surrounding objects move at greater rate than the mobile, then this effect dominates the small scale fading.

④ The transmission B.W. of signal → If the transmitted radio signal BW > B.W of multipath ~~signal~~ channel, then :-

- Received signal will be distorted.
- Signal strength will not fade much over a local area. (No significant fading)

- Coherent B.W. → It is the measure of the max. frequency difference for which signals are strongly correlated in amplitude.

↳ Doppler Shift →



Here the mobile user moving with a velocity 'v'. B/w X and Y points distance is 'd' and it receives signal from source S.

path diff. : $\Delta l = d\cos\theta = v\Delta t\cos\theta$

$\Delta t \rightarrow$ time required for mobile to travel from X to Y.

Phase change due to difference in path length

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

Doppler Shift → apparent change in freq.

$$f_d = \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

- f_d is +ve → If the mobile is moving towards the direction of arrival of the wave. ($\theta = 0°$)
- f_d is −ve → If the mobile is moving away from direction of arrival of the wave. ($\theta = 180°$)

↳ Coherence Bandwidth →

* Delay spread is caused by reflected and scattered relation propagation paths in the radio channel.
* Coherence bandwidth B_c is defined relation derived from rms delay spread.

* Coherence BW is statistical measure of the range of frequencies over which channel be considered flat.

* Flat channel is one which passes all spectral components with approx. equal gain and linear phase.

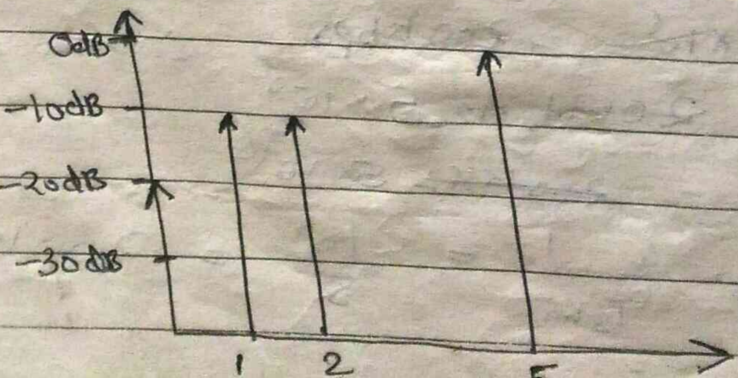
(i) If the coherence BW is defined as the BW over which the freq. correlation fn. is above 0.9, then

$$B_c = \frac{1}{50\sigma_\tau}$$

(ii) If the freq. Correlation fn. is above 0.5.

$$B_c = \frac{1}{5\sigma_\tau}$$

<u>Example</u> → Calculate mean excess delay, rms delay spread maximum excess delay for multipath given below along with 50% Coherence B.W.



Sol → $\bar{\tau} = \frac{(1)(5)+(0.1)(1)+(0.1)(2)+(0.01)0}{[0.01+0.1+0.1+1]} = 4.38\,\mu s$

Second moment can be calculated as

$\overline{\tau^2} = \frac{(1)(5)^2+(0.1)(1)^2+(0.1)(2)^2+(0.01)0}{1.21} = 21.07\,\mu s^2$

Rms delay spread, $\sigma_\tau = \sqrt{21.07-(4.38)^2} = 1.37\,\mu s$

Coherence BW, $B_C = \frac{1}{5\sigma_\tau} = \frac{1}{5 \times 1.37\,\mu s} = 146\,kHz$

↳ Doppler Spread and Coherence Time →

* These are parameters which describe time varying nature of the channel in a small-scale region.
* Doppler Spread → It is defined as the range of freq. over which the received ~~radio~~ Doppler spectrum is non-zero.

Doppler Spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel.

* If the baseband signal B.W. is much greater than B_D the effects of Doppler spread are negligible at the receiver.

T_c time domain dual of B_D.

$T_c \propto \frac{1}{f_m}$ ← max. doppler shift. --- (1)

(i) For time correlation fn. 0.5, T_c is given by:

$$\boxed{T_c = \frac{9}{16\pi f_m}} \quad --- (2)$$

f_m is max. doppler shift given by $\boxed{f_m = \frac{v}{\lambda}}$

↳ Types of Small-Scale Fading →

(1) → Signal parameters are bandwidth, symbol period etc.

(2) → Channel parameters are rms delay spread & Doppler spread

Time dispersion and freq. dispersion mechanism lead to 4 possible effects.

① → Multipath delay Spread
- → flat fading
  - BW signal < BW channel
  - Delay spread < Symbol spread
- → Freq. Selective fading
  - B W signal > BW channel
  - Delay spread > Symbol period

② Doppler Spread
- → fast fading
- → Slow fading.

D) Fading Effects due to Multipath Time Delay Spread →

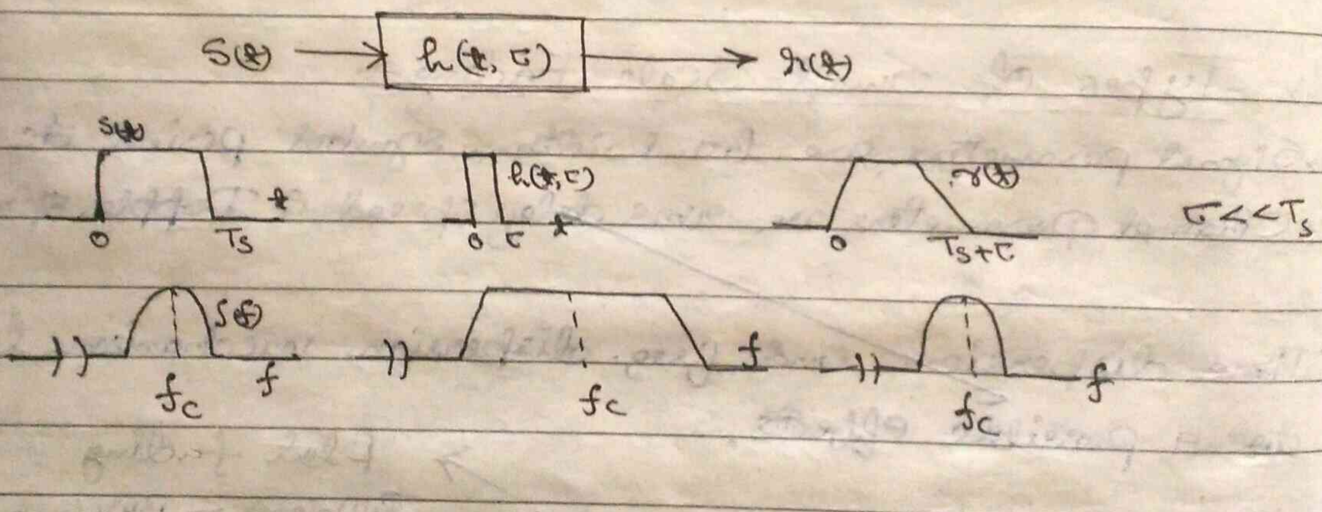
Multipath delay leads to time dispersion or freq. selective fading.

(a) Flat fading →

BW of signal < BW of the channel

Delay spread < Symbol period

- Characteristic of transmitted signal is preserved at receiver while strength at receiver changes due to fluctuation in gain caused by multipath.



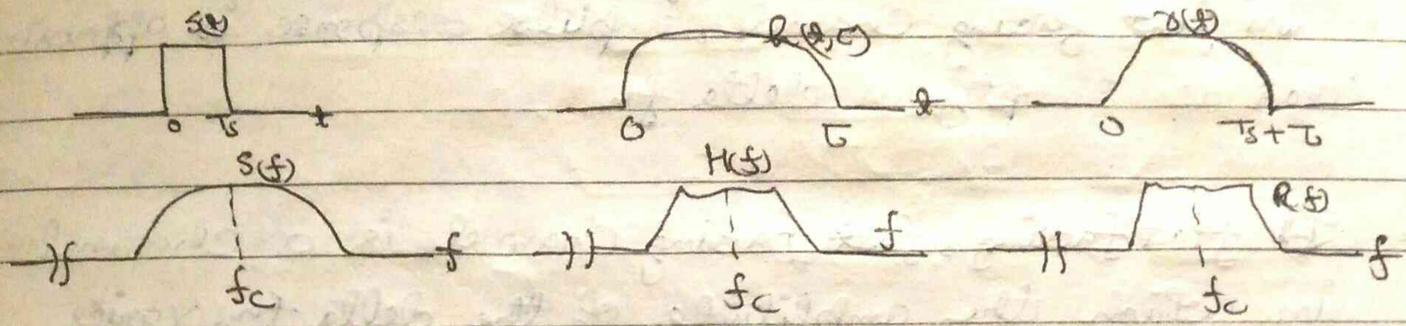
(b) Freq. Selective fading →

BW signal > BW of channel

Delay Spread > Symbol Period

- The received signal consists of various versions of the transmitted waveform which are attenuated or faded and delayed in time.
- In other words received signal is distorted.

- Intersymbol interference (ISI) is induced into the received signal by the channel.
- In this different freq. components have different gains.



*· A channel is flat fading if :- $T_s \geq 10\sigma_\tau$

*· A channel is freq. selective if : $T_s < 10\sigma_\tau$

2)→ <u>Fading Effects due to Doppler Spread</u> →

- Doppler spread leads to freq. dispersion & time selective fading.
- Depends on how rapidly transmitted signal changes as compared to rate of change of the channel it is classified as :→ fast or slow fading.

· ~~In fast~~

(a)→ <u>fast fading</u> → (i)→ High doppler spread.

(ii)→ Coherence time < Symbol period

(iii)→ Channel variations are faster th[an] baseband signal variations.

$T_s > T_c$

$B_s < B_D$

- Fast fading deals only with rate of change of channel due to motion.

- In flat fading channel, impulse response is approximated as simply a delta fn.

- A flat fading, fast fading channel is a channel in which the amplitude of the delta fn. varies faster than the rate of change of transmitted signal (baseband).

- In freq. selective, fast fading channel, the amplitude, phases and time delays of any one of the multipath components vary faster than the rate of change of the transmitted signal.

(b) <u>Slow fading</u> → (i) Low Doppler spread.
(ii) Coherence time > Symbol period.
(iii) Channel variation ~~faster~~ slower than baseband signal variation

- Channel impulse response changes at a rate much slower than the transmitted signal S(t).
- Signal undergoes slow fading if :→
- ~~Channel is static over reciprocal BW intervals.~~

$$T_S << T_C$$
$$B_S >> B_D$$

↳ Improving Coverage and Capacity in Cellular System→

Various techniques are used in order to expand the cellular capacity of the systems:-

(1)→ Cell Spliting.

(2)→ Sectoring.

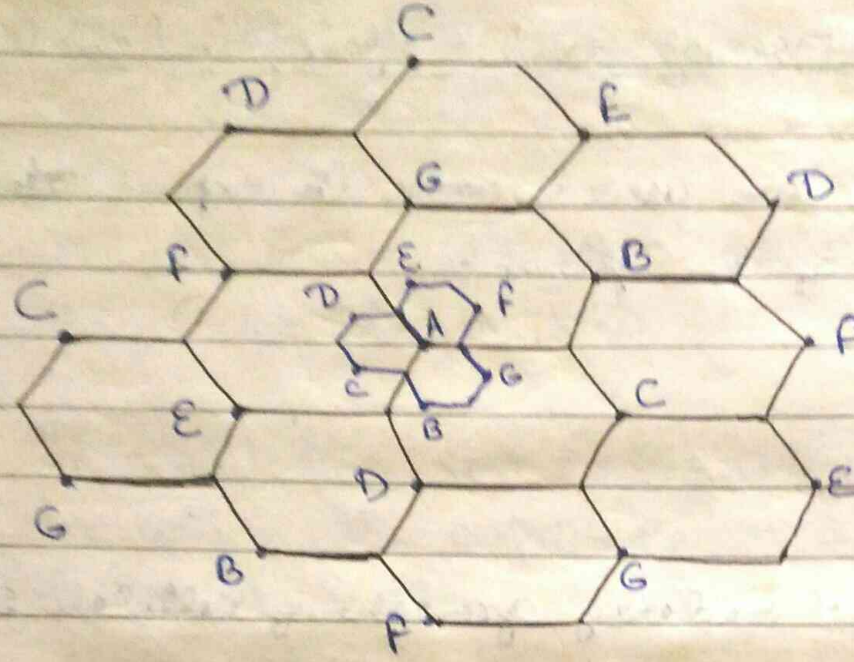
(3)→ Microcell Zone.

- Cell splitting allows orderly growth of cellular system.
- Sectoring uses directional antennas to further control the interference & freq. reuse of channels.
- Zone microcell concept distributes the coverage of a cell and extends the cell boundary to hard to reach places.
- Cell splitting increases the number of base stations in order to increase the capacity.
- Sectoring and zone microcells rely on base station antenna placement to improve capacity by reducing co-channel interference.

(1)→ **Cell Splitting**→ The process of subdividing a congested cell into a smaller cell, each having its own base station.

- In this there is reduction in antenna height & transmitter power.
- Capacity of cellular system increases the no. of times freq. is reused.

• New cells which have a smaller radius than the original cell & by installing these small cell (called microcell), b/w the existing cell ⇒ capacity increases due to additional no. of channels per unit area.



• The capacity increases by subdividing each cell into new cells called "microcells" having smaller radius.

• Transmit power decreases or is reduced as cell size is reduced. The transmitted power is given as ⇒

$$P_r[\text{old cell boundary}] \propto P_{t_1} R^{-n}$$

Radius of new cell is halved, then power is given as

$$P_r[\text{new cell boundary}] \propto P_{t_2} \left(\frac{R}{2}\right)^{-n}$$

for $n=4$ where n is path loss component.

$$\boxed{P_{t_2} = \frac{P_{t_1}}{16}}$$

Problems in Cell Splitting :-

• Different cell sizes will be existing simultaneously in a cell.

• Channel ~~alignment~~ assignments become more complicated as the distance b/w co-channels cells should be kept min.

• Accomodation of high speed and low speed simultaneously to address their handoff issues.

• If larger power is used for all cells which are having different sizes, then Co-channel interference may happen.
~~due to co~~

• If smaller power is used for all the cells, then some parts of larger cells will remain unserved.

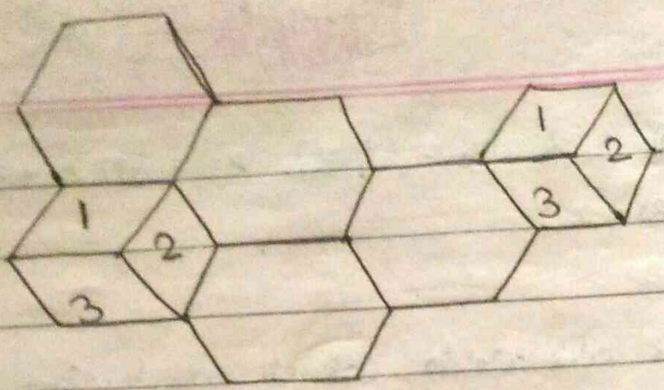
* Advantages → Capacity is improved by a large amount by scaling the cell.

*· Channels in the old cell are broken into two groups
1. Smaller Cell → Dedicated to low speed traffic.
2. Larger Cell → Dedicated to high speed traffic so that hand off occur less frequently.

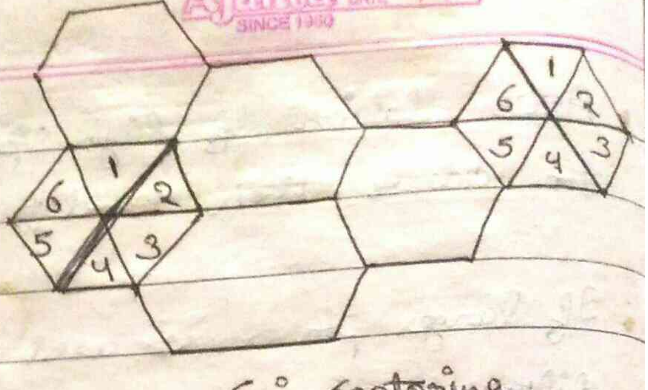
Imp.* In Cell splitting $\frac{D}{R}$ is unchanged & R (cell radius) decreases, hence "no. of channels increases per unit area."

2. Sectoring → In this method the capacity of the cell is increased to keep the cell radius unchanged & seek methods to decrease the D/R ratio.

• Sectoring increases the S/R so that cluster size is reduced
• S/R is improved by:-
• Using directional antennas.
• Capacity is improved by:
Reducing the number of cells in a cluster.



(a) 120° sectoring



(b) - 60° sectoring

<u>Definition</u> → It is a technique for reducing Co-channel interference and increasing system performance by using directional antennas.

- By using directional antennas, if a cell receive an interference, then a fraction of it is transmitted to the co-channel cells.
- The factor by which co-channel interference is reduced depends on sectoring used.
- A cell is normally partitioned into ~~three~~ 120° sectors or six 60° sectors.

- In seven-cell ~~cluster~~ reuse, using 120° sectoring, no. of interferer in the first tier are reduced from 6 to 2 Because only 2 receive interference in 120° sectoring out of 6 Co-Channels.

- The reduction in interference due to sectoring enables planners to reduce the cluster size 'N'.

*. As a result of sectoring :-

① → No of antennas increases.

② → Capacity of the system is improved

by reducing cluster size.

③ Handoff increases as the coverage area of group of channels is reduced.

④ More than one antenna is used per base station, so available channels are subdivided ~~into~~ to a specific antenna. This decreases the trunking efficiency.

* Drawbacks of Sectoring :

Increased number of handoffs results in an increased load on switching & control link elements in a mobile system.

Its solution was microcell zone concept.

↳ Repeaters for Range Extension :

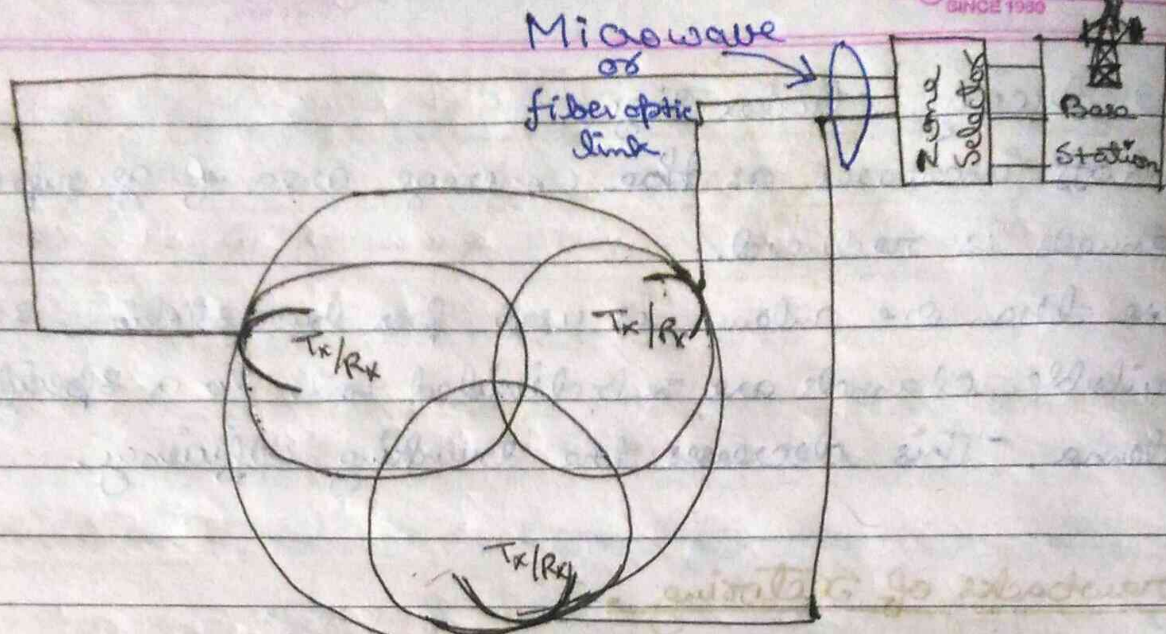
(1) Repeaters are used for range extension to provide coverage to hard to reach areas as within buildings, tunnels, valleys etc.

(2) Bidirectional in nature. Can simultaneously send and receive signals from base station.

(3) Noise & interference is also reradiated by repeaters.

(4) It amplifies & reradiate the base station signal to the specific region.

3. Microcell Zone Concept → In this scheme of seven cell reuse, each of 3 zone sites are connected to a single base station and share the same radio equipment.



- The zones are connected by coaxial, fiber optic cable or microwave link to base station.
- As the mobile travels within cells, it is served by zone with strongest signal.
- This approach is superior to sectoring as the antennas are placed at the outer edge of the cell & base station may assign any channel to any zone.
- The mobile retains same channel while moving from one zone to another within the cell.
- Base station monitors switching from one zone to another, MSC is not involved in handoff b/w zones.
- The channels are used in time and space by all 3 zones and are reused in normal fashion in co-channels too.

↳ <u>Advantages</u>:- ①. Co-channel interference is reduced since the large central base station is replaced by low power transmitters at the edges of the cell.