UNIT- I

INTRODUCTION TO CELLULAR MOBILE RADIO SYSTEMS.

SUB: CELLULAR AND MOBILE COMMUNICATIONS

IV - I ECE NOTES.

ECE DEPT

UNIT - I

INTRODUCTION TO CELLULAR MOBILE SYSTEMS.

(1.1) LIMITATIONS OF CONVENTIONAL MOBILE TELEPHONE SYSTEMS.

- Operational limitations of Conventional mobile telephone systems

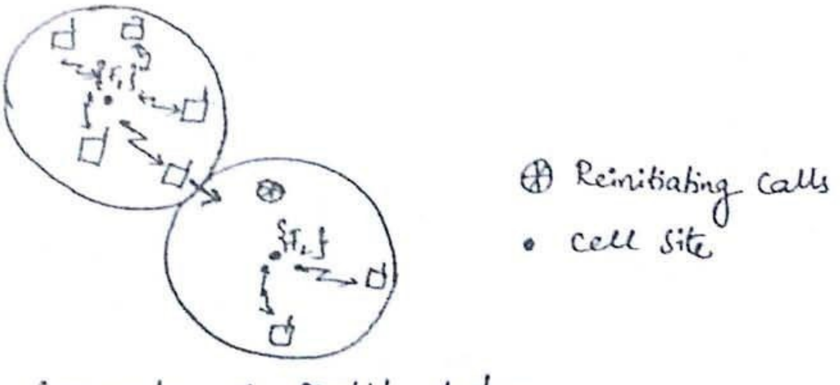
(1) LIMITED SERVICE CAPABILITY.

(2) Poor service performance

(3) Inefficient Frequency spectrum utilization.

LIMITED SERVICE CAPABILITY.

- A conventional mobile telephone system is usually designed by selecting one or more channels from a specific frequency allocation for use in autonomous geographic zones.



Conventional mobile system

- In conventional mobile system uses high power & larger cell. i.e. The communication coverage area of each zone is normally planned to be larger as possible, which means that the transmitted Power should be as high as possible.

- The user who starts a call in one zone has to reinitiate the call when moving into a new zone. because the call will be dropped. There is no gurontee that a call can be completed without a handoff capability.
- Another disadvantage of the conventional system is that the number of active users is limited to the number of channels assigned to a particular frequency zone.

POOR SERVICE PERFORMANCE.

- In past, a total of 33 channels were allocated to three mobile telephone systems.
  (i) mobile Telephone Service (MTS)
  (ii) Improved Mobile Telephone Services (IMTS) MJ systems
  (iii) Improved mobile Telephone Services (IMTS) MK systems.
- MTS operates around 40MHz and MJ operates at 150MHz bothe provide 11 channels.
- IMTS MK operates at 410MHZ and provides 12 channels.
- In 1976, New york city has 6 channel of MJ serving 320 customers, with another 2400 customers on a waiting list.
- Newyork city also has 6 channels of MK serving 225 customers, with another 1300 customers on a waiting list.
- The large number of subscribers created a high blocking probability during busy hours.
- Although service performance was undesirable, the demand was still greate. A high capacity system for mobile telephone are needed.

Inefficient frequency spectrum utilization.

- In a conventional mobile telephone system, the frequency utilization measurement M_0 is defined as the maximum number of customers that could be served by one channel at the busy hour.

$$M_0 = \frac{\text{no. of customers}}{\text{Channel}} \quad \text{(Conventional systems)}$$

- As far as frequency spectrum utilization is concerned, the conventional system doesnot utilize the spectrum efficiently since each channel can only serve one customer at a time in a whole area.

Spectrum Efficiency Considerations.

- A major problem facing the radio communication industry is the limitation of the available radio frequency spectrum.
- In fact, in setting frequency allocation, the FCC (Federal Comm. Commission) seeks systems which require minimal Bandwidth but provide high usage and consumer satisfaction.
- Basically three major approaches, to achieve the ideal mobile telephone system are as under.

(i) Single side band (SSB), which divides the allocated frequency band into maximum number of channels.

(ii) cellular, which reuse the allocated frequency band in different geographic locations.

(iii) Spread spectrum or frequency hopped, which generates many codes over a wide frequency ~~band~~ band.

Technology, Feasibility and Service Affordability.

- In 1971, the computer industry ~~enter~~ entered a new era, microprocessors and minicomputers were used for controlling many complicated features and functions with less power and size than was possible earlier.

- Also large scale integration (LSI) technology reduce the size of mobile transceivers so that they easily fit into the standard automobile.

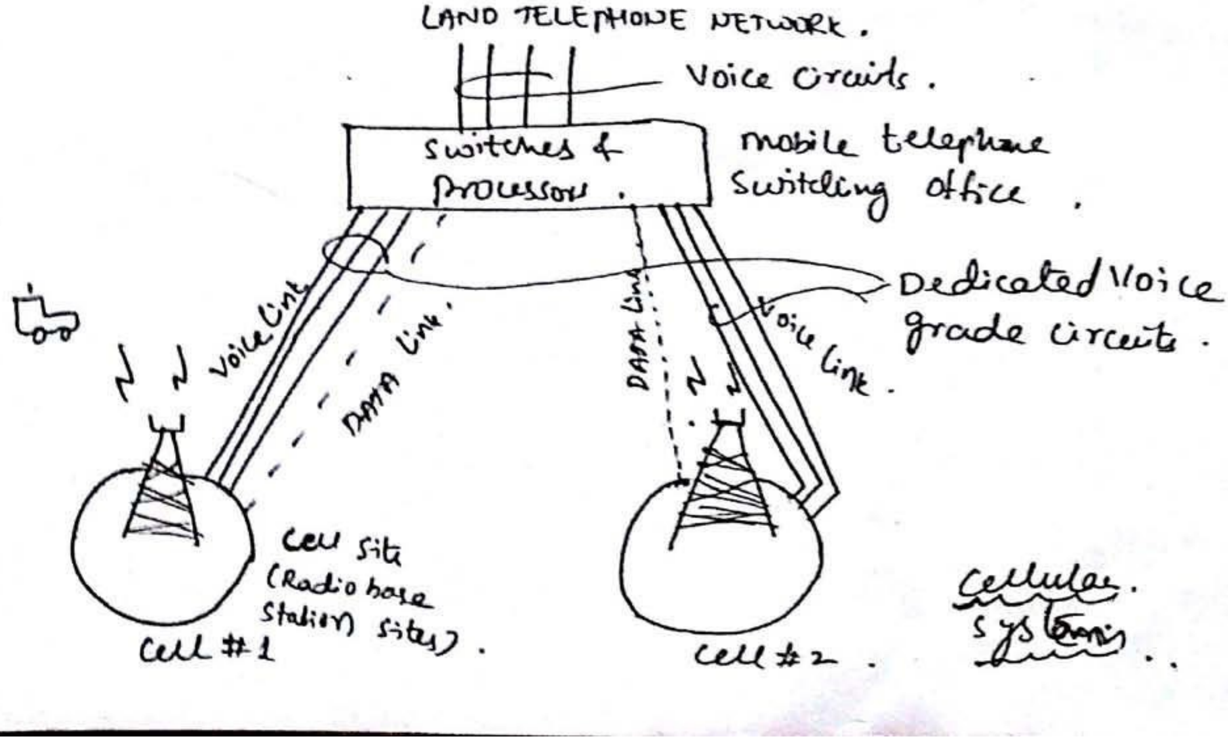
BASIC CELLULAR MOBILE SYSTEM.

- A Basic cellular system consists of following three parts

(i) a mobile unit

(ii) a cell site

(iii) a mobile telephone switching office (MTSO) and with connections to link the three subsystems.



1. mobile units : A mobile telephone unit contains a control unit, a transceiver and an antenna system.
2. cell site : The cell site provides interface between the MTSO and the mobile units. It has a control unit, radio cabinents, antennas, a power plant and data terminals.
3. MTSO :- The switching office, the central coordinating element for all cell sites, contains the cellular processor and cellular switch. It interfaces with telephone company zone offices, controls call processing, and handles billing activities.
4. connections : The radio and high speed data links connect the three subsystems. Each mobile unit can only use one channel at a time for its communication link. But the channel is not fixed; it can be any one in the entire band assigned by the serving area, with each site having multichannel capabilities that can connect simultaneously to many mobile units.

- Few additional points about a basic cellular system.
(i) The MTSO is the heart of the cellular mobile system. Its processor provides central coordination and cellular administration.
(ii) The cellular switch, which can be either analog or digital switches calls to connect mobile subscribers to.

to other mobile subscribers and to the nationalwide telephone network. It uses voice trunks similar to telephone company interoffice voice trunks. It also contains data links providing supervision links between the processor and the switch and between the cell sites and the processor.

(iii) The radio link carries the voice and signalling between the mobile unit and the cell site.

(iv) The high-speed data links cannot be transmitted over the standard telephone trunks and therefore must use either microwave links or T-carriers (wire lines).

(v) Microwave radiolinks or T-carriers carry both voice and data between the cell site and the MTSO.

(1.4)

First generation cellular systems.

- The 1G cellular systems make use of analog FM scheme for speech transmission.
- The individual calls use different frequencies and share the available spectrum through a particular multiple access technique known as frequency-division multiplexing access (FDMA)

AMPS in America & Australia.

- America & Australia make use of the Advanced Mobile Phone System (AMPS) with a 25 MHz band in each uplink transmission, from 824 to 849 MHz and a 25 MHz band in each downlink transmission, from 869 to 894 MHz.
- AMPS uses a channel spacing of 30 KHz with a total capacity of 832 channels and supports a data transmission rate of 10 kilobyte per second (kbps)

ETACS in Europe

- Europe uses the European Total Access Communication System (ETACS) with a 25 MHz band in the uplink transmission from 890 to 915 MHz and a 25 MHz band in the downlink, transmission from 935 to 960 MHz
- ETACS uses a channel spacing of 25 kHz, with a total capacity of 1000 channels & supports data transmission rate of 8kbps.

NTT in Japan.

- The first generation cellular system is the Nippon Telephone and Telegraph (NTT) system which employs a 15MHz band in the uplink transmission from 925 to 940 MHz & a 15MHz downlink transmission from 870 to 885MHz, with a channel spacing of 25kHz.

- NTT system has a total capacity of 600 channels & supports a data transmission rate of 0.3kbps.

- NTT System was modified to enhance its capacity from 600 to 2400 channels. This enhancement was achieved by decreasing the channel spacing from 25KHz to 6.25 KHz & data transmission rate of each channel was increased from 0.3 kbps to 2.40kbps.

First generation Analog cellular systems

Region	America	Europe	Japan.
parameter	AMPS	ETACS	NTT
multiple Access	FDMA	FDMA	FDMA
Duplexing	FDD	FDD	FDD
Forward Channel	869-894 MHz	935-960 MHz	870-885 MHz
Reverse channel	824-849 MHz	890-915 MHz	925-940 MHz
channel spacing	30kHz	25KHz	25 KHz
Data Rate	10kbps	8kbps	0.3 kbps
spectral efficiency	0.33 bps/Hz	0.33 bps/Hz	0.012 bps/Hz
capacity	832 channels	1000 channels	600 channels.

- The modulation scheme used is "Gaussian filtered minimum shift keying (GMSK)".

SECOND GENERATION CELLULAR SYSTEMS:

② IS-54 in North America.

- The modulation scheme is π/4 shifted "Differential Quadrature phase shift keying (DQPSK)" with a channel rate of 48.6 kbps.
- In frequency domain, channel spacing is 30kHz.

③ PDC in Japan.

- The system is TDMA Based with three slots multiplexed onto each carrier.
- In frequency domain, channel spacing is 25 kHz
- The modulation scheme is π/4-shifted DQPSK with a transmission rate of 42kbps.

④ IS-95 in North America.

- IS-95 is a CDMA-Based standard.
- Users share a common channel for transmission within a cell.
- Users in adjacent cells also use the same radio channel. In other words, the frequency spectrum is reused from cell to cell.
- The system is designed to be compatible with the existing analog system Amps.
- The allocated frequency band is 824-849 MHz for the uplink using offset quadrature phase shift keying (OQPSK)

Second generation cellular systems.

- The second generation cellular systems are completely digital.
- These cellular systems employ either TDMA or CDMA as the multiple access technology.
- The digital technology allows greater sharing of the radio hardware in the base station among the multiple users, and provides a large capacity to support more users per base station per MHz of spectrum as compared to analog system.
- Digital system offer a number of advantages over analog systems as under.

(i) digital systems provides natural integration with the evolving digital wireline network

(ii) digital systems provides flexibility for supporting multimedia services

(iii) digital systems provides flexibility for capacity expansion.

(iv) digital systems provides reduction in RF (Radio frequency) transmit power

(v) digital systems provides encryption for communication privacy

(vi) digital systems provides reduction in system complexity.

① GSM in Europe

- The channel time in TDMA is partitioned into frames. Each frame consists of eight time-slots.
- Each time slot is of 0.57 ms duration.
- Each user transmits periodically in every eighth slot and receives in corresponding slot.

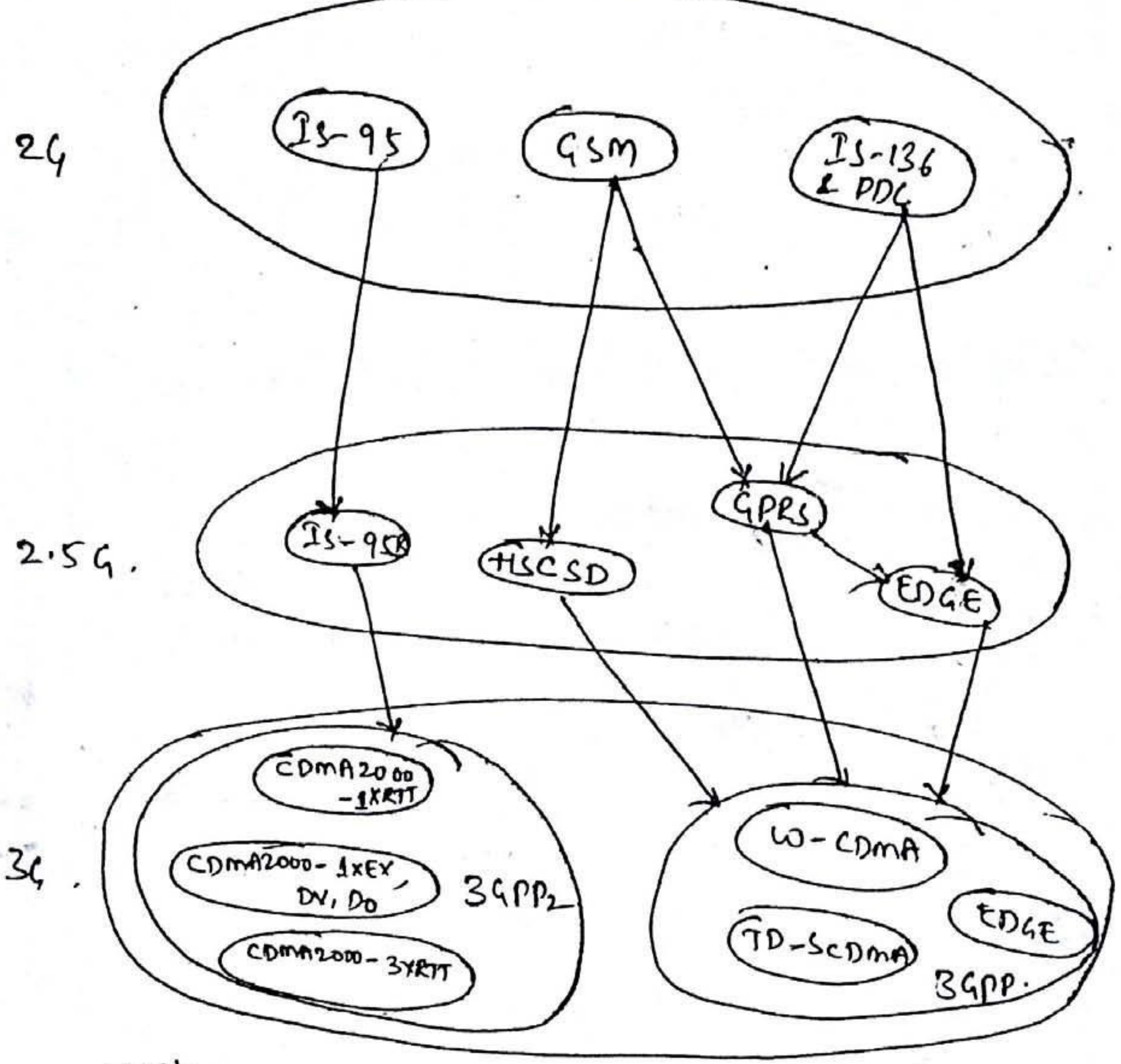
- 869-894 MHz for downlink using QPSK.

Second generation Digital cellular systems

Region Parameter.	US IS-54	Europe GSM	Japan PDC	US IS-95
multiple access	TDMA / FDD	TDMA / FDD	TDMA / FDD	CDMA
modulation	π/4 DQPSK	GMSK	π/4 D QPSK	QPSK / OQPSK
Forward channel	869-894 MHz	935-960 MHz	810-826 MHz	869-894 MHz
Reverse Channel	824-849 MHz	890-915 MHz	940-956 MHz	824-849 MHz
Channel spacing	30KHZ	200KHZ	25 KHZ	1.250 KHZ
Data clip Rate	48.6 kbps	270.833 kbps	42kbps	1.2288 kbps
Speech codec Rate	7.95 kbps	13.4 kbps	6.7kbps	1.2/2.4/4.8/ 9.6 kbps

Third generation wireless Communication Networks

- 3G equipment envision users having the ability to receive live music, conduct interactive web sessions, and have simultaneous voice & data access with multiple parties at the same time using a single mobile handsets.
- Third generation standardization activities were initiated in Europe and in North america under the respective names IMT-2000 & cdma-2000.
- IMT-2000 is wideband direct-sequence code division multiple access (DS-CDMA), while cdma-2000 is multicarrier code division multiple access (MC-CDMA)



Various upgrade paths for 2G to 3G Technologies.

3G W-CDMA (UMTS)

- Universal Mobile Telecommunication System (UMTS) was submitted by ETSI (European Telecommunication Standards Institute) to ITU's (International telecommunication union) IMT (International Mobile Telephone) - 2000 body in 1998 for consideration as a world standard.

At that time, UMTS was known as UMTS Terrestrial Radio Access (UTRA) was designed to provide a high.

capacity upgrade path for GSM.

- UMTS or W-CDMA, assures backward compatibility with the second generation GSM, IS-136 & PDC TDMA Technologies as well as 2.5G TDMA Technologies.

- W-CDMA will support packet data rate upto 2.048 Mbps

- It is likely that the third generation cellular systems will be equipped with the infrastructure to support personal communication systems (PCS). The network infrastructure support will likely include the following.

(i) public Land mobile networks (PLMNs)
(ii) Mobile Internet protocol (mobile IP)
(iii) wireless asynchronous transfer mode (WATM) networks
(iv) low earth orbit (LEO) satellite networks.

- The most attractive feature of 3G, compared with 2G

(i) higher transmission
(ii) Support of multimedia services.
(iii) capacity & Impact of user mobility

FOURTH GENERATION (4G) System

- Future systems will be based on user's demands as the fourth-generation (4G) cellular system applications need high-speed data rates to achieve them.
- ITU made a requirement for 4G system as under
(i) At a standstill condition, the transmission data rate should be 1 Gbps
(ii) At a moving condition, the transmission data rate should be 100 mbps.
- with this high-speed data system, many advanced application for the users can be realized.
- A potential 4G system could be used in the family of OFDM (orthogonal Frequency Division multiplexing) because the WMAN using OFDM can have a transmission data rate of 54-70 Mbps which is much higher than the CDMA system can provide.

- ~~The cellular concept - system Deg design issues.~~

Introduction to 3G to 4G wireless mob.

- 3G stands for 3rd generation
  4G " " 4th "

- 2G wireless systems:

	standard.	Digital voice.
2G	GSM (Global system for mobile comms.)	10kbps
2G	CDMA (Code division multiple Access)	10kbps.
2.5G	GPRS (general packet Radio Serv)	~50kbps.
2.5G (2.75)	EDGE (enhanced	~200kbps.

GSM - Global system for mobile communications

CDMA - code division ~~multiplexing Access~~ for multiple Access.

GPRS - General Packet Radio service.

EDGE - Enhanced data for ~~general~~ gsm Evolution.

- 3G wireless standards.

3G	WCDMA/UMTS	~384 kbps.
3G	CDMA 2000	384 kbps.
3.5G	HSDPA/HSUPA	5 - 30 mbps.
3.5G	1XEVDO Rev A,B,C	5 - 30mbps

Family of 3G/3.5G wireless standards

WCDMA - Wide band CDMA

UMTS - Universal mobile Telecommunications Standard

HSDPA - High speed Downlink packet access

HSUPA " Uplink " "

B - M - Down Link

M - B → up. Link

1XEVDO - Evolution Data Optimized

4G wireless systems

4G	LTE	100-200 Mbps
4G	WiMax	100 - 200 Mbps

LTE - Long term Evolution.

WiMax - Worldwide Interoperability for Microwave access.

2G 2.5G	10-100 kbps	Voice + Data
3G 3.5G	380kbps - 30Mbps	Voice + Data + Video calls
4G	100 Mbps - 200 Mbps	Voice + Data + Video + online gaming + HDTV

Uniqueness of mobile Radio environment.

(i) mobile Radio transmission medium

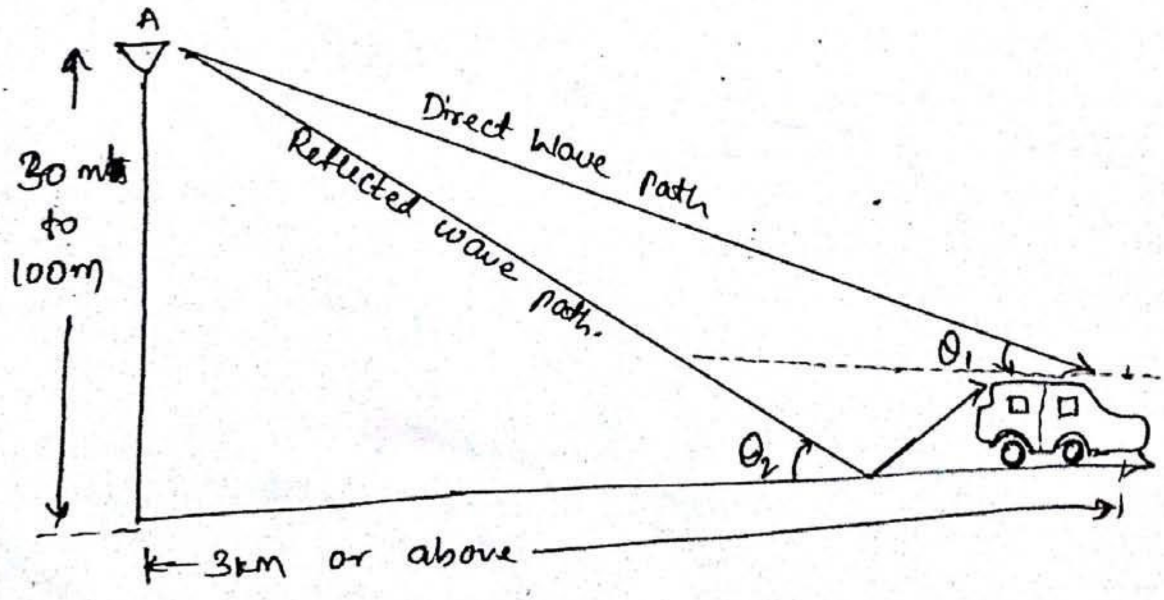
- In signal propogation their exits path loss and the path lo[ss] represents signal attenuation measured in dB
- The path loss in dB is defined as the difference between effecti[ve] transmitted power and effective received power.

$$\text{Path loss (dB)} = 10 \log \frac{P_T}{P_R}.$$

where $P_T = G_T G_R \lambda^2$, $P_R = 16\pi^2 d^2$

G_T - Transmitting antenna gain
G_R - Receiving antenna gain
d - distance between transmitting & receiving antenna
λ = wavelength of the carrier signal $= c/f$

- It is important to note the mobile radio transmission medium. The value of propogation path loss increases with frequency & distance.



mobile Radio transmission model.

- The incident angle of the direct wave is θ_1 w.r.t the mobile unit & incident angle of the wave reflected is θ_2.
- The angle θ_1 measured w.r.t direct wave path is also known as elevation angle.
- The propagation path loss would be 40dB/decade i.e. period of 10. This mean that a 40dB loss at a signal receiver will be observed by the mobile unit as it moves from 1 to 10km.

$C_1 = \alpha R_1^{-4}$

$C_2 = \alpha R_2^{-4}$

$\therefore$ Carrier power $= C = \alpha R^{-4}$

R - distance from transmitter to Receiver unit

α - constant of proportionality.

- The difference in power reception at two different distances R_1 & R_2 will result in

$$\frac{C_2}{C_1} = \left(\frac{R_1}{R_2}\right)^{+4}.$$

The decibel expression.

$$\Delta C \text{ (in dB)} = C_2 - C_1 \text{ (in dB)}.$$

$$= 10 \log \frac{C_2}{C_1} = 40 \log \frac{R_1}{R_2}$$

a) For the free space propagation model ΔC will be

$$\Delta C = C_2 - C_1 \text{ (dB)} \quad (\because C = \alpha R^{-2})$$

where -2 : 20db/decade loss).

$$= 20 \log \frac{R_1}{R_2}$$

b) For Real time mobile environment the C will be

$C = \alpha R^{-\gamma}$

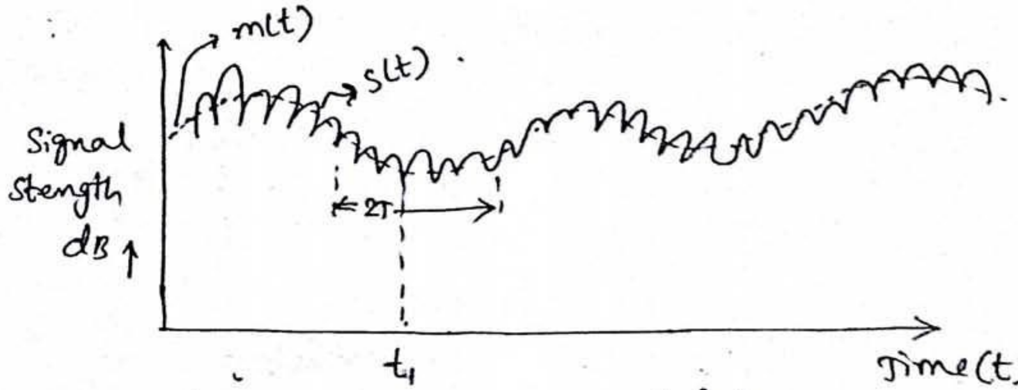
γ - lies between 2 & 5

(c) If γ takes the value $\gamma < 2$ then it would be free space condition.

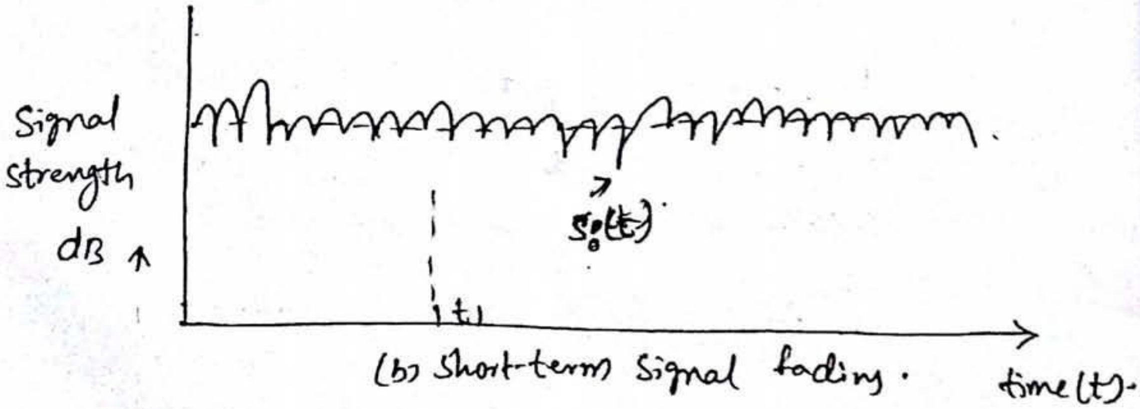
Model of Transmission Medium

A simple mobile radio signal S(t) is shown below. The signal is characterized by the two components namely m(t) & $S_0(t)$ w.r.t their physical properties.

$$S(t) = m(t)\, S_0(t)$$



(a) mobile Signal fading.



(b) Short-term Signal fading.

FIG: MOBILE RADIO SIGNAL FADING.

- The first component m(t) in the equation is known as local mean, lognormal fading [long-term fading]

It varies due to the contour of the terrian available between mobile unit & Base station.

- The second term of the equation is known as short-term fading (i.e. Rayleigh fading).

- The long-term fading m(t) can be obtained

$$m(t_1) = \frac{1}{2T} \int_{t_1-T}^{t_1+T} s(t)\,dt \qquad (1)$$

where 2T is the time interval for averaging s(t). T can be determined based on the fading rate of s(t), usually 40 to 80 fades. Therefore m(t) is the envelope of s(t) as shown in fig(a).

- Equation (1) also can be expressed in spatial scale as

$$m(x_1) = \frac{1}{2L} \int_{x_1-L}^{x_1+L} s(x)\,dx .$$

- The factor m(t) or m(x) is also found to be a log-normal distribution based on its characteristics caused by the terrian contour.

- The short-term fading s_0 is obtained by.

$$S_0(\text{in dB}) = S(t) - m(t) \text{ dB}$$

The factor $S_0(t)$ follows a Rayleigh distribution.

- The carrier frequency wavelength (λ) is lesser than the sizes of the surroundings and there is a sum of multipath waves arriving at the mobile unit that causes signal fading.
- Due to fading the signal has to suffer a fluctuation above 10dB & below 30dB of the average signal level.
- Thus fading effects has to be minimized with more care in mobile environment since it has to face multipath signalling that affects the fading.
- There are also some other factors that influences small-scale fading are

The factors that influences small-scale fading are

(a) multipath propagation
(b) speed of mobile
(c) speed of surrounding objects
(d) Transmission bandwidth of the signal

(ii) Fading.

Fading is a term that describe fluctuations that take place often in amplitudes, multipath delays or phases of a radio signal for a short time period. This is due to the interference of signals being transmitted, i.e. if more than one transmitted signal is received at the receiver end at slightly different time periods the chance of occurance of fading is more.

- These multipath (different transmitted signals) signals causes fading effect in the resultant received signal and the important effects are.

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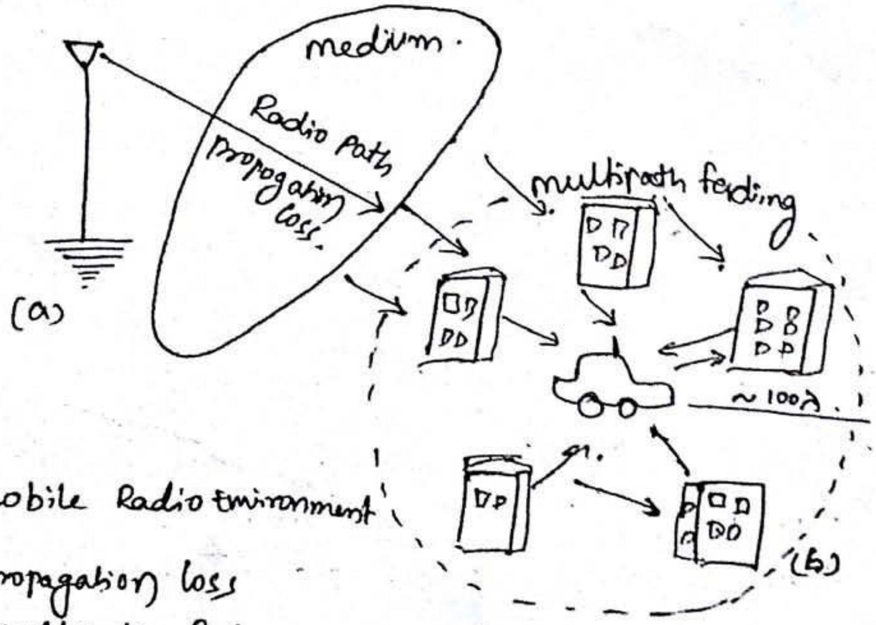
(a) Random frequency modulation
(b) faster changes in Signal strength in a small time period.
(c) multipath propogation delays cause time dispersion/echoes

mobile fading characteristics.

- The multipath fading is also known as Rayleigh fading
- when these multipath waves bounces back & forth due to the buildings & houses, they form many standing wave pairs in space.



A mobile Radio Environment
(1) propagation loss
(2) multipath fading.

- when These wave pairs are summed and form a fading wave structure. In case if the mobile unit is in Standing still position then the receiver would receive only a stronger signal at one spot alone.

- The problem, fading is more if the mobile unit starts to roam. According to the speed increases fading also increases in proportion to it.

The Radius of the active Scatterer Region

- The Radius of the active Scatterer Region at 850 MHz is roughly 100 wave lengths.
- The active scatterer region always move with the mobile unit as its center.

Delay spread & Coherence Bandwidth

- In multipath environment each path has its unique path and it may not resemble the path of other wave.
- The path lengths, time of arrival also will differ. If an impulse is being sent it may be received as a pulse and not an impulse & such a spread width observed is termed as delay spread.
- The mean delay spread values will differ w.r.t the operating environment

Environment	Delay spread (μsec)
Inside the Building	< 0.1
Open area	< 0.2
Suburban Area	0.5
Urban area	3.

Coherence Bandwidth

- If the two received signals have high degree of similarity either with their phases or amplitudes it represents the coherence bandwidth B_c.
- The coherence bandwidth is created as an effect of the natural phenomenon delay spread.
- For two received signals if the similarity is observed with their two amplitudes, then

$$B_c = \frac{1}{2\pi\Delta}$$

- For two received signals if the similarity is observed with their two phases then we have

$$B'_c = \frac{1}{4\pi\Delta}$$

- Coherence Bandwidth,

B_c is suitable for AM systems

B'_c is suitable for PM or FM systems.

(iv) Direct wave path, Line of sight path, & Obstructive path.

(a) Direct wave path:
The direct path is related to the terrain contour related measurements, The path is very clear w.r.t terrion contour.

(b) Line-of-sight wave path (LOS)
It is the wave path that is very clear from all buildings. The wave is not reflected & lost. A clear propogation is observed in LOS wave path.

(b) Obstructive wave path

The direct wave path mentioned above if blocked by the terrian contour then the resulting wave path is called as obstructive wave path.

(v) Noise level in cellular frequency Band

- In mobile environment the two types of dominant noises are
  (a) man made noise
    (i) Ignition noise generated by the vehicles and
    (ii) noise generated by 800 MHz emissions.
  (b) Thermal noise.

(vi) Amplifier noise level:

- A mobile radio signal is amplified at the receiving end. The signal may be from base station (cell site) or from a mobile unit which will be amplified at the amplifier.

- Assume that the amplifier has an available power gain g and the available noise power at the output is N_o.

- The input signal-to-noise (S/N) ratio is P_s/N_i, the output signal-to-noise ratio is P_o/N_o and the internal amplifier noise is N_a. Then the output P_o/N_o become.

$$\frac{P_o}{N_o} = \frac{gP_s}{g(N_i)+N_a} = \frac{P_s}{N_i+(N_a/g)} \quad \text{—— (1)}.$$

The noise figure F is defined as

$$F = \frac{\text{maximum possible S/N ratio}}{\text{actual S/N ratio at output}}.$$

where the maximum possible S/N ratio is measured when the load is an open circuit.

$$F = \frac{P_s / KTB}{P_o / N_o} = \frac{N_o}{(P_o/P_s) KTB} = \frac{N_o}{g (KTB)} \quad \text{--- (2)}$$

Substitute (1) in (2).

$$F = \frac{N_i + (N_a/g)}{KTB}.$$

- The term KTB is thermal noise.
- The noise figure is a reference measurement b/w the a minimum noise level due to thermal noise and the noise level generated by both the external & internal noise of an amplifier.

Pras

Parameters of mobile multipath channels.

~~(ii) Time Dispersion Parameters.~~

- many multipath channel parameters are derived from the power delay profile

$$|r(t_0)|^2 = \frac{1}{\tau_{max}} \int_0^{\tau_{max}} \frac{1}{4} \left[\sum_{k=0}^{N-1} a_k^2(t_0)\, p^2(t-\tau_k)\right] dt$$

$$= \frac{1}{\tau_{max}} \sum_{k=0}^{N-1} a_k^2(t_0) \int_0^{\tau_{max}} \left\{\sqrt{\frac{\tau_{max}}{T_{bb}}}\, rect\left[t - \frac{T_{bb}}{2} - \tau_k\right]\right\}^2 dt$$

$$= \sum_{k=0}^{N-1} a_k^2(t_0).$$

- Power delay profiles are found by averaging instantaneous power delay profile measurements over a local area in order to determine an average small-scale power delay profile

(i) Time Dispersion Parameter

- In order to compare different multipath channels and to develop some general design guidelines for wireless system, parameters which grossly quantify the multipath channel are used.

- The mean excess delay, rms delay spread, excess delay spread (X dB) are multipath channel parameters that can be determined from a power delay profile.

- The time dispersion properties of wide band multipath channels are most commonly quantified by their mean excess delay ($\bar{\tau}$) & rms delay spread (σ_τ).
- The mean excess delay is the first moment of the power delay profile & is defined to be

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum P(\tau_k)}$$

- The rms delay spread is the square root of the second central moment of the power delay profile and is defined to be

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

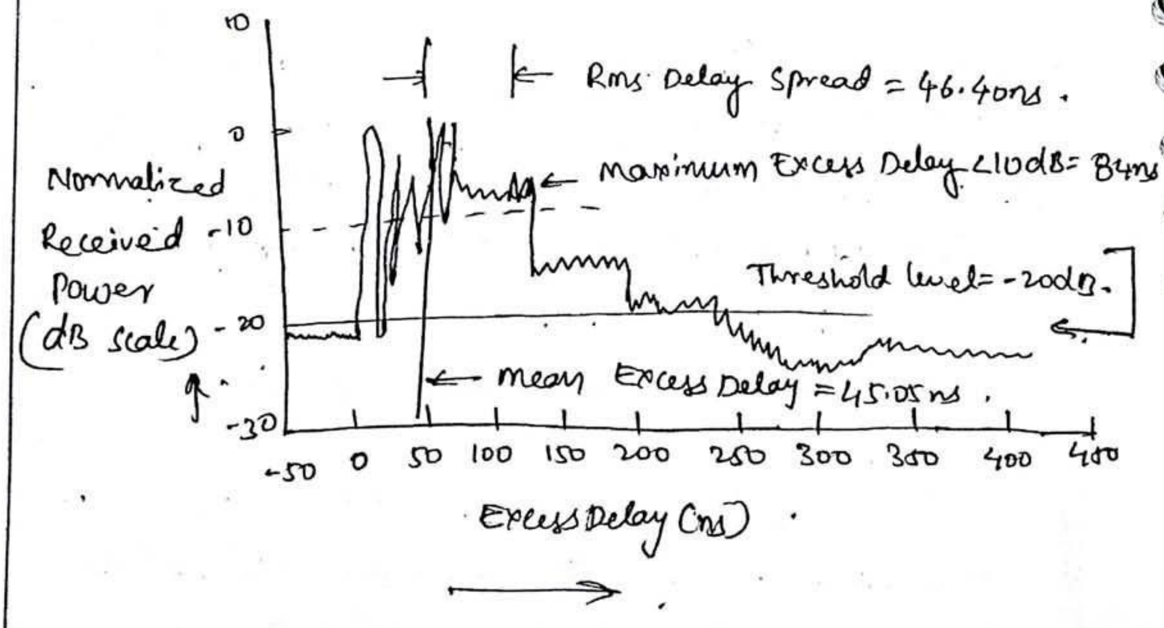
- These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$
- Typical values of rms delay spread are on the order of microseconds in outdoor mobile radio channels and on the order of nanoseconds in indoor radio channels.
- It is important to note that rms delay spread & mean excess delay are defined from a single power delay profile which is the temporal or spatial average

of consecutive impulse response measurement collected and averaged over a local area.

- The maximum excess delay (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum.

In other words, the maximum excess delay is defined as $\tau_x - \tau_0$, where τ_0 is the first arriving signal and τ_x is the maximum delay at which a multipath components is within X dB of the strongest arriving multipath signal

- The value of τ_x is sometimes called the excess delay spread of a power delay profile, but in all cases must be specified with a threshold that relates the multipath noise floor to the maximum received multipath component.



- In practice, values for $\bar{\tau}$, $\overline{\tau^2}$ & σ_τ depends on the choice of noise threshold used to process $P(\tau)$. The noise threshold is used to differentiate between received multipath components and thermal noise.
- If the noise threshold is set too low, then noise will be processed as multipath, thus giving rise to values of $\bar{\tau}$, $\overline{\tau^2}$ and σ_τ that are artificially high.

(ii) Coherence Bandwidth.

- while the delay spread is a natural phenomenon caused by reflected and scattered propagation paths in the radio channel, the coherence Bandwidth B_c, is a defined relation derived from the rms delay spread.
- Coherence Bandwidth is the range of frequencies over which two frequency ~~separation greater than B_c are affected quite d~~ components have a strong potential for amplitude correlation.
- Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel.
- If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, then the coherence bandwidth is approximately

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

- If the definition is relaxed so that the frequency correlation function is above 0.5, then the coherence bandwidth is approximately

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

- The rms delay spread and coherence bandwidth are inversely proportional to one another. ~~although~~ ~~their~~
- It is important to note that an exact relationship between coherence bandwidth and rms delay spread is a function of specific channel impulse responses and applied signals.

(iii) Doppler Spread & Coherence Time.

- Doppler spread and coherence time are parameters which describe the time varying nature of the channel in a small-scale region.
- Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero.
- When a pure sinusoidal tone of frequency f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components in the range $f_c - f_d$ to $f_c + f_d$ where f_d is the Doppler shift.
- If the baseband signal bandwidth is much greater than B_D, the effects of Doppler spread are negligible at the receiver. This is a slow fading channel.

- Coherence time T_c is the time domain dual of Doppler spread and is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain.
- The Doppler spread and coherence time are inversely proportional to one another. That is

$$T_c \simeq \frac{1}{f_m}$$

- Coherence time is actually a statistical measure of the time duration over which the channel impulse response is essentially invariant, and quantifies the similarity of the channel response at different times.
- In other words Coherence time is the time duration over which two received signals have a strong potential for amplitude correlation.
- If the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, then the channel will change during the transmission of the baseband message, thus causing distortion at the receiver.
- If the coherence time is defined as the time over which the time correlation function is above 0.5 the coherence time is approximately

$$T_c = \frac{9}{16\pi f_m}$$

f_m = max. Doppler shift $= v/\lambda$

Type of Small-Scale fading..

- Multipath delay spread leads to time dispersion and frequency selective fading.
- Doppler spread leads to frequency dispersion and time selective fading.
- Four different types of fading..

Small-scale fading.
(Based on multipath time delay spread)

Flat fading	Frequency selective fading.
1. BW of signal < Bw of channel	1. Bw of signal > Bw of channel
2. Delay spread < symbol period	2. Delay spread > symbol period

Small-scale Fading.
(Based on Doppler Spread).

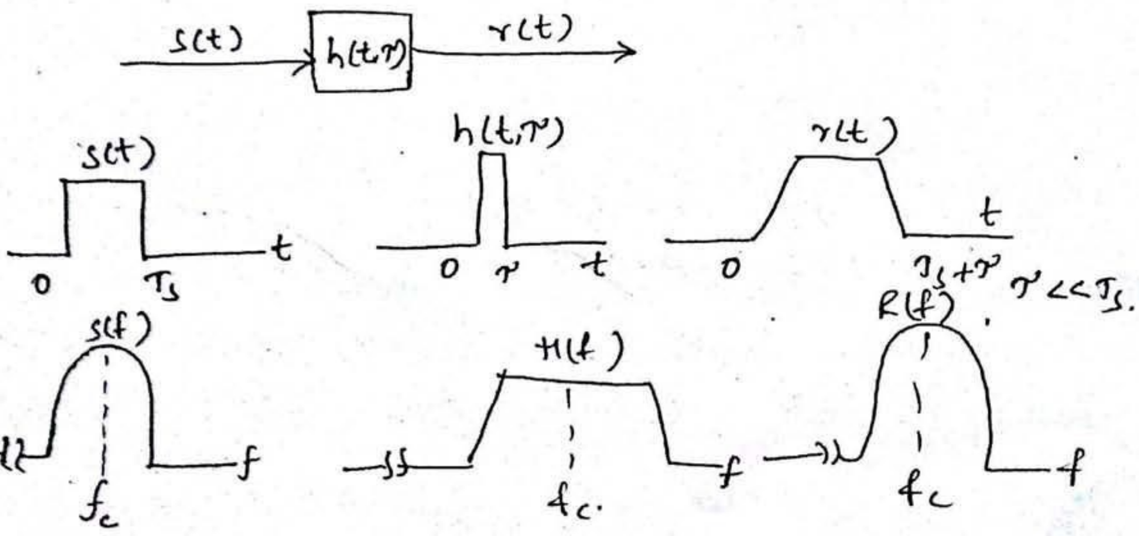
Fast fading	Slow fading.
1. High Doppler spread	1. Low Doppler spread
2. Coherence time < symbol period	2. Coherence time > symbol period
3. Channel variations faster than baseband signal variations.	3. Channel variations slower than baseband signal variations.

Fading Effects Due to multipath Time delay spread.

- Time dispersion due to multipath causes the transmitted signal to undergo either flat or frequency selective fading.

1) Flat fading

- If the mobile radio channel has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will undergo flat fading.
- In flat fading, the multipath structure of the channel is such that the spectral characteristics of the ~~tran~~ transmitted signal are preserved at the receiver. However, the strength of the received signal changes with time, due to fluctuations in the gain of the channel caused by multipath.



Flat fading channel characteristics.

- Flat fading channels are also known as "amplitude varying channels" and are sometimes referred to as "narrowband channels", since the bandwidth of the applied signal is narrow as compared to the channel flat fading bandwidth.
- Typical flat fading channels cause deep fades, and thus may requires 20 or 30dB more transmitter power to achieve low bit error rates during times of deep fades as compared to systems operating over non-fading channels.
- A signal undergoes flat fading if

$$B_s << B_C.$$

& $$T_s << \sigma_T$$

where T_s is the reciprocal bandwidth &

B_s is the bandwidth

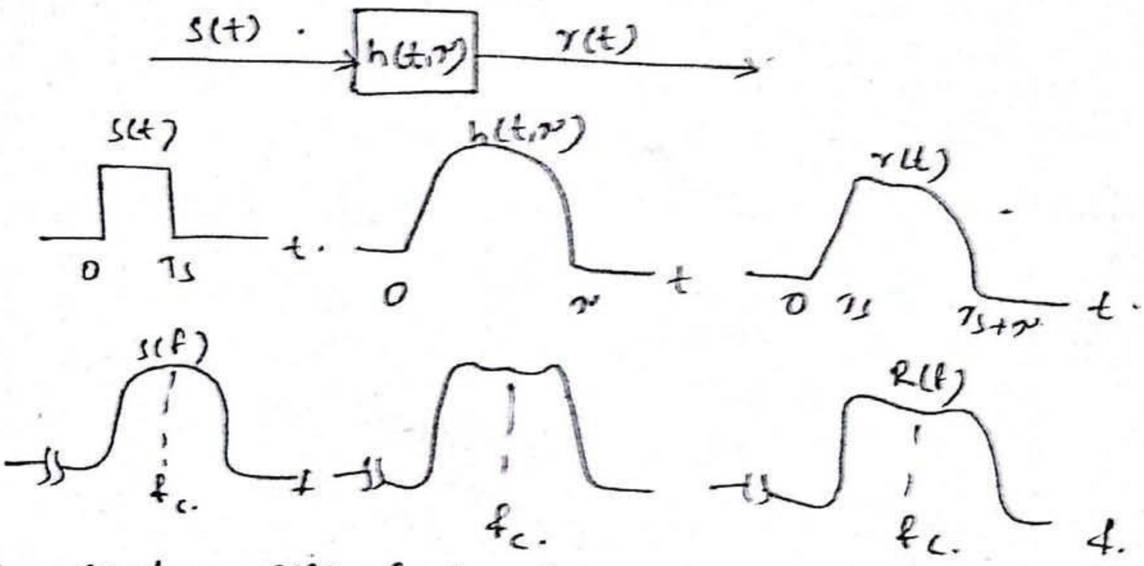
σ_T is rms delay spread

B_C Coherence Bandwidth.

(ii) Frequency Selective fading.

- If the channel possesses a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates "frequency selective fading" on the received signal.

- When this occurs, the received signal includes multiple versions of the transmitted waveform which are attenuated (faded) and delayed in time, and hence the received signal is distorted.
- Frequency selective fading is due to time dispersion of the transmitted symbols within the channel. Thus the channel induces intersymbol interference (ISI)



- The spectrum S(f) of the transmitted signal has a bandwidth which is greater than the coherence bandwidth B_c of the channel.
- Frequency selective fading channels are also known as wideband channel since the bandwidth of the signal s(t) is wider than the bandwidth of the channel impulse response.
- As the time varies, the channel varies in gain and phase across the spectrum of s(t), resulting in time varying ~~distortion in the received signal~~).

distorting in the received signal $r(t)$.

- A signal undergoes frequency selective fading if

$$B_S > B_C$$
&
$$T_S < \sigma_\tau$$

Fading Effects Due to Doppler Spread.

(i) Fast fading.

- In a fast fading channel, the channel impulse response changes rapidly within the symbol duration. i.e. the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion.
- In frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal.
- A signal undergoes fast fading if

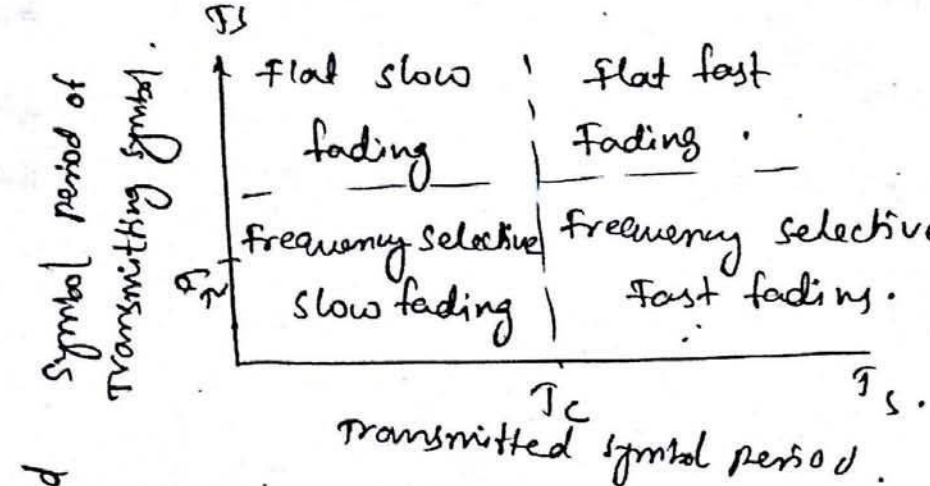
$$T_S > T_C \quad \& \quad B_S < B_D$$

(ii) Slow fading.

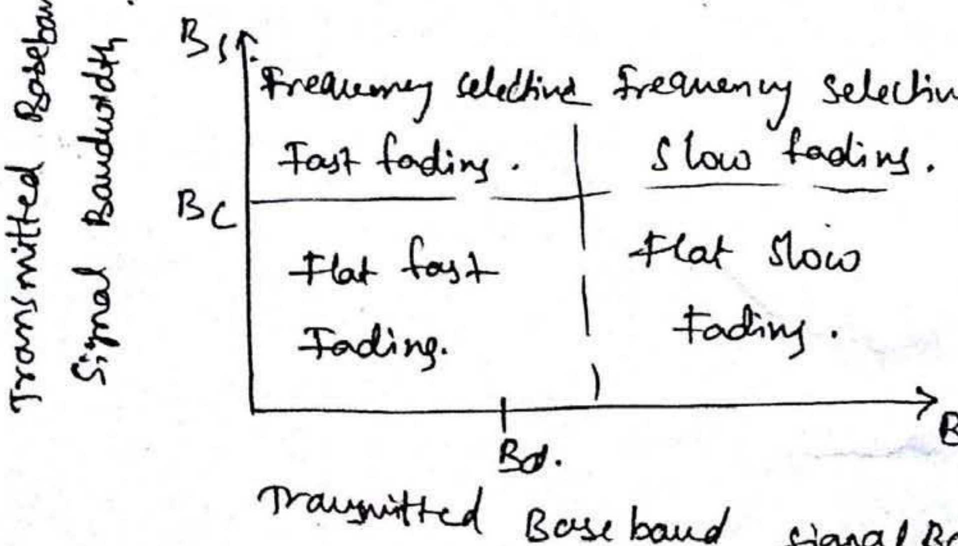
- In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal s(t).

$$T_S << T_C \ \& \ B_S >> B_D.$$

- It should be emphasized that fast & slow fading deal with the relationship between the time rate of change in the channel and the transmitted signal and not with propogation path loss models.



a) symbol period



(b) Baseband signal Bandwidth.

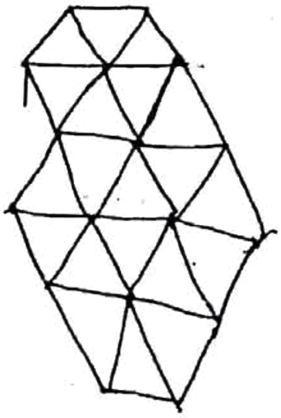
FUNDAMENTALS OF CELLULAR RADIO SYSTEM DESIGN

Introduction

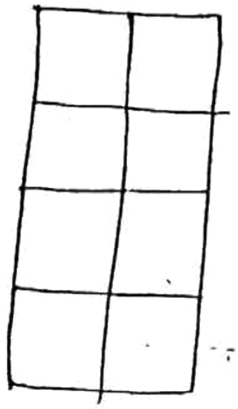
- As a matter of fact, with the limitation in spectral width, the maximum number of users (i.e. capacity) that can be supported in a wireless mobile system is an important performance measure
- The system capacity (i.e. no. of users) can be enlarged by arranging small cells, each requiring only a low power transmitter, in a cellular array.
- The increase in system capacity comes from the use of smaller cells, reuse of frequencies and antenna sectoring.

Cell Fundamentals

- The cellular topology and the concept of employing a cellular architecture to increase the communication capacity and to cater to a large subscriber demand in hot spot, consider quantitative means to characterize the interference in a cellular topology.
- In practice cells are of arbitrary shape (close to a circle) because of the randomness inherent in radio propagation for it is easier to obtain insight and understanding for system design by visualizing all cells as having the same shape.
- For cells of the same shape to form a tessellation so that there are no ambiguous areas that belong to multiple cells or to no cell, the cell shape can be only three types of regular polygons equilateral triangle, square or regular hexagon.

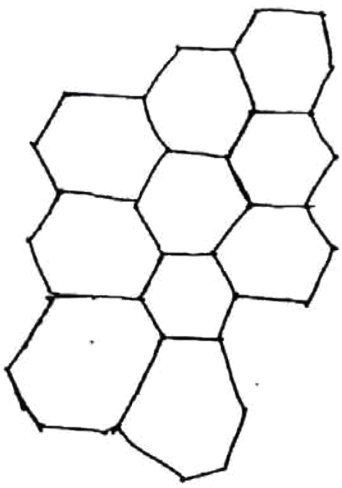


Triangular cells



Rectangular cells.

- A hexagonal cell is the closest approximation to a circle and been used traditionally for system design.
- Hexagonal shape, for a given radius, the hexagon has the largest area.



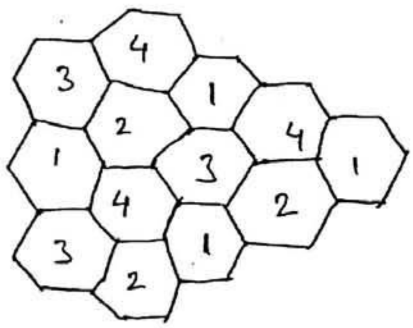
Regular Hexagon.

- By using the hexagon geometry, the fewest number of cells can cover a geographic region and the hexagon closely approximates a circular radiation.
- In practical, the Omni directional antennas are used in centre-excited cells and sectored directional antennas are used in corner-excited cells.

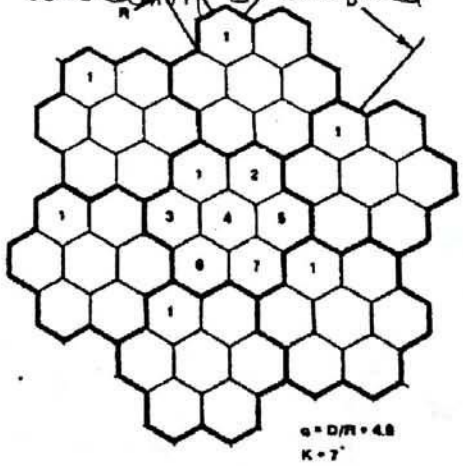
(i) Frequency reuse schemes.

- The frequency reuse concept can be used in the time domain and space domain.
- Frequency reuse in the time domain results in the occupation of the same frequency in different time slots. It is called time division multiplexing (TDM).
- Frequency reuse in the space domain can be divided into two categories
  (1) Same frequency assigned in two different geographic areas such as AM or FM radio stations using the same frequency in different cities.
  (2) Same frequency repeatedly used in a same general area in one system - the scheme is used in cellular systems. There are many cochannel cells in the system.

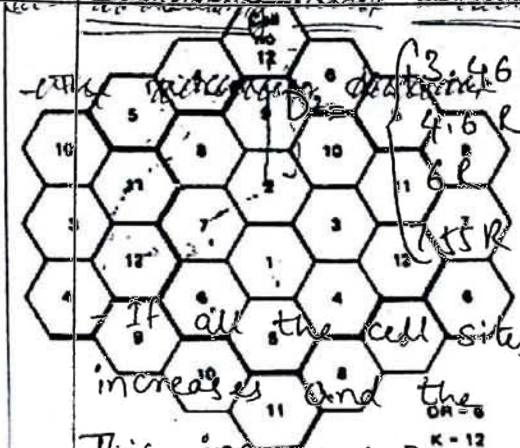
The total frequency spectrum allocation is divided into 'K' frequency reuse patterns.

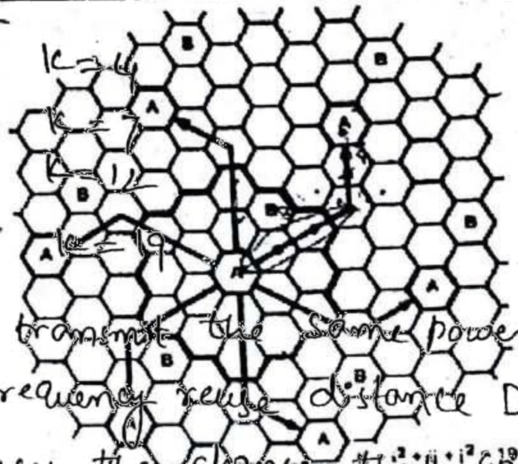


K=4.



(iii) Frequency reuse distance.





- The frequency reuse distance

$$D = \begin{cases} 3.46R & K=4 \\ 4.6R & K=7 \\ 6R & K=12 \\ 7.55R & K=19 \end{cases}$$

- If all the cell sites transmit the same power, then K increases and the frequency reuse distance D increases. This increased D reduces the chance that cochannel interference may occur.

- The co-channel cells that must be separated by a distance such that the co-channel interference is below a prescribed QoS threshold.

- The parameter i & j measure the number of nearest neighbours between co-channel cells, the cluster size K is related to i & j by

(iii) frequency reuse distance

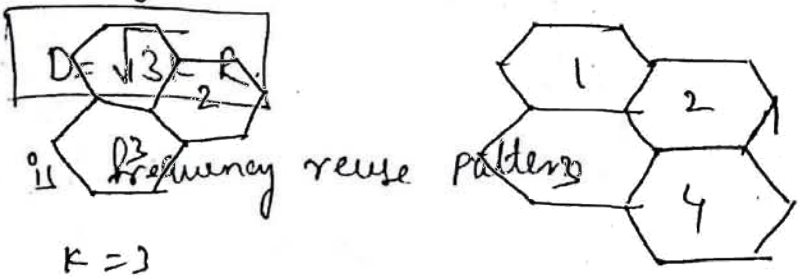
- The minimum distance which allows the same frequency to be reused will $K = i^2 + ij + j^2$ factors such as the number of cochannel cells in the vicinity of the center cell, the type of geographic contour, the antenna height and the transmitted power at each cell site.

Step 1: Move i cells along any chain of hexagons

Step 2: Turn 60 degrees counterclockwise and move j cells.

- The smallest value of distance is D can be determined from

$$D = \sqrt{3K}\, R$$



Where K is frequency reuse pattern

K = 3

K = 4.

(iii) Number of customers in the system

- when we design a system, the traffic conditions in the area during a busy hour are some of the parameters that will help determine both the sizes of different cells and the number of channels in them.
- The maximum number of calls per cell is driven by the traffic conditions at each particular cell. After the maximum number of frequency channel per cell has been implemented in each cell, then the maximum number of calls per hour can be taken care of in each cell.

Co-channel Interference & system capacity

- Frequency reuse implies that in a given coverage area there are several cells that use the same set of frequencies. These cells are called "co-channel cells", and the interference between signals from these cells is called "co-channel interference".
- To redue co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propogation.
- when the size of each cell is approximately the same and the base stations transmit the same power, the co-channel interference ratio is indepedent of the transmitted power and becomes a function of the radius of the cell (R) and distance between centers

of the nearest co-channel cell (D).

- By increasing the ratio of D/R, the spatial separation b/w Co-channel cells relative to the coverage distance of a cell is increased. Thus, interference is reduced from improved isolation of RF energy from the co-channel cells.

- The parameter Q, called the co-channel reuse ratio is related to the cluster size.

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

	Cluster Size (k)	Co-channel Reuse Ratio (Q).
i=1 , j=1	3	3
i=1 , j=2	7	4.58
i=0 , j=3	9	5.20
i=2 , j=2	12	6.

Co-channel Reuse Ration for some values of N.

Cochannel Interference Reduction Factor:

- Assume that the size of cells is roughly the same. The cell size is determined by the coverage area of the signal strength in each cell.

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

- parameter Q is the cochannel interference reduction factor. when the ratio Q increases, cochannel interference decreases. Furthermore the separation D is a function of K_I & C/I

$$D = f(K_I, C/I)$$

K_I – no. of cochannel interfering cells in the first tier

C/I – Received carrier-to-interference ratio

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^{K_I} I_k}.$$

- In a fully equipped hexagonal-shaped cellular system, there are always six cochannel interfering cells in the first tier i.e $K_I = 6$

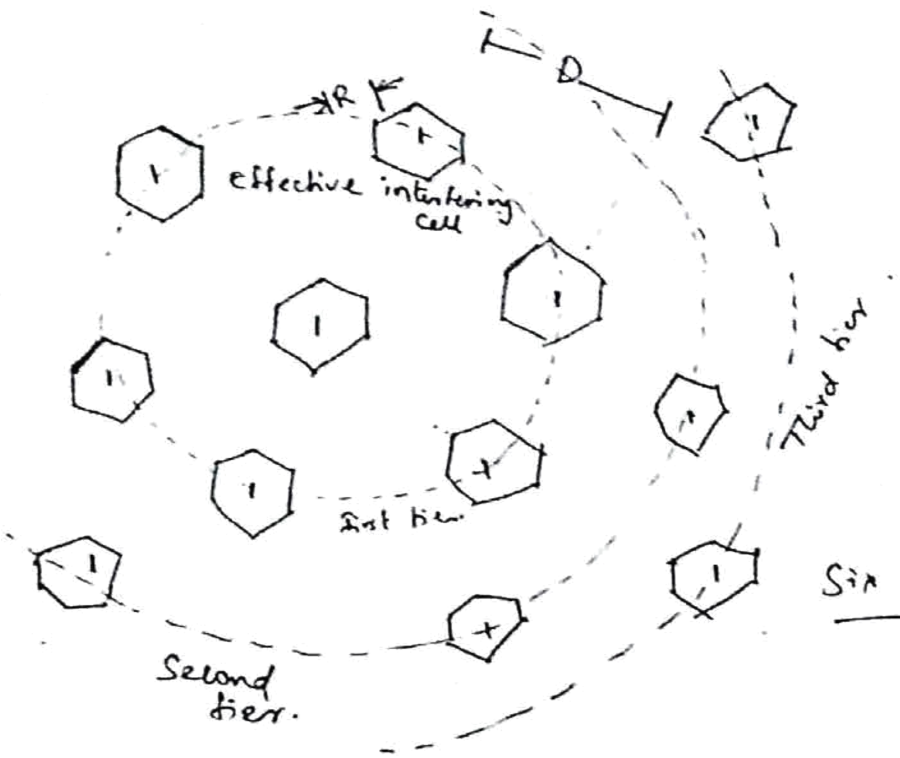
- The maximum number of K_I in the first tier can be shown as six (i.e $2\pi D/D \simeq 6$).

- cochannel interference can be experienced both at the cell site and at mobile units in the center cell.

- Assume that the local noise is much less than the interference level and can be neglected. C/I then can be expressed as

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}}$$

- where γ is a propagation path-loss slope.
- γ usually is assumed to be 4



Six effective cell of cell 1.

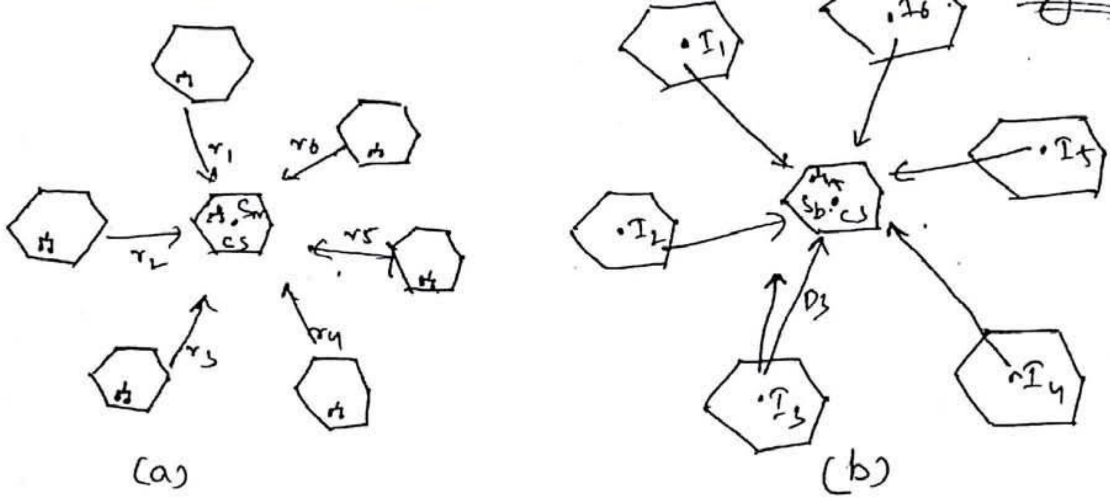
- K_I is the number of cochannel interfering cells and is equal to 6 in a fully developed system.
- The six cochannel interfering cells in the second tier cause weaker interference than those in the first tier.
- The co-channel interference from the second tier of interfering cells is negligible.

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{K_I} \left(\frac{D_k}{R}\right)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K_I} (q_k)^{-\gamma}}$$

where q_k is the cochannel interference reduction factor with k^{th} cochannel interfering cell

$$q_k = \frac{D_k}{R}$$

Desired C/I from a normal case in a omni directional Antenna system



Co-channel interference for six interface.

(a) Receiving at the cell site

(b) Receiving at the mobile unit.

Analytic solution

There are two cases to be considered

(1) the signal & cochannel interference received by the mobile unit

(2) the signal & cochannel interference received by the cell site.

- N_m & N_b are the local noises at the mobile unit & the cell site respectively.
- As long as the received carrier-to-interference ratios at both the mobile unit & the cell site are the same, the system is called a balanced system
- Assume that all D_k are same for simplicity, then $D = D_k$, & $q = q_k$ for k

$$\frac{C}{I} = \frac{R^{-\gamma}}{6D^{-\gamma}} = \frac{q^{\gamma}}{6}.$$

Thus

$$q^{\gamma} = 6\frac{C}{I}$$

$$\therefore q = \left(6\frac{C}{I}\right)^{1/\gamma}$$

γ - propagation path loss slope.

- In the above equation, the value of γ is based the terrain environment and the specified value of $\frac{C}{I}$ based on the required system performance.
- The typical value of $q = 4.6$ i.e for seven cell reuse pattern. In mobile radio environment, the path loss slope $\gamma = 4$. Then the respective typical value of carrier to interference ratio is given by

$$\frac{C}{I} = \frac{q^{\gamma}}{6} = \frac{(4.6)^4}{6}$$

$$= 74.624$$

$$= 18.73 \text{ dB}.$$

$$\therefore \frac{C}{I} = 18.73 \text{ dB}.$$

(2.7)

- Large coverage area would be acheived by increasing the transmitted power at each cell, increasing the same amount of transmitted power in each cell which doesnot effect the co-channel interference reduction factor (q). The co-channel interference reduction factor $q = 4.4$ for practical case.

Solution Obtained from simulation

- The co-channel interference reduction factor can also be obtained from simulation. Let, one main cell site & all six possible co-channel interference. The distance between the main cell site & co-channel interference is 'D'
- The data from six simulated interferences is

$$I = \sum_{k=1}^{k_I=6} I_k .$$

Here

$$\frac{C}{I} = 18\,dB.$$

For $\frac{C}{I}$ value

$$4.6R = D$$

$$q = \frac{D}{R} = \frac{4.6R}{R}$$

$$\boxed{q = 4.6}$$

- comparing the value of 'q' in both cases, which are same

∴ The values of 'q' obtained from an practical solution & 'q' obtained from a simulation is same.

TRUNKING AND GRADE OF SERVICE

- cellular radio systems rely on trunking to accomodate a large number of user in a limited radio spectrum.
- The concept of trunking allows a large number of users to share the relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channel.
- In a 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.
- The telephone company uses trunking theory to determine the number of telephone circuits that need to be allocated for office buildings with hundreds of telephones, and this same principle is used in designing cellular radio systems.
- As the number of phone lines decreases, it becomes more likely that all circuits will be busy for a particular user.
- In a trunked mobile radio system, when a particular user request service & all of the radio channels are already in use, the user is blocked. In some systems a queue may be used to hold the requesting user until a channel becomes available.

Improving coverage and capacity in cellular systems.

- Techniques such as cell splitting, Sectoring and microzone cell concepts are used in practice to expand the capacity of cellular system.
- cell splitting increases number of Base stations deployed and allows an orderly growth of the cellular system.
- Sectoring uses directional antennas to further control interference and frequency reuse.
- macrocell zoning distributes the coverage of a cell & extends the cell boundary to hard-to-reach places.

cell splitting.

- Cell splitting is a process of subdividing a congested cell into smaller cells with
  - i) their own Base station
  - ii) A corresponding reduction in the antenna height
  - iii) A corresponding reduction in the transmitter power.
- Splitting the cell reduces the cell size & thus more number of cells have to be used.
- more no. of cells ⇒ more no. of clusters ⇒ more no. of channels ⇒ higher capacity
- cell splitting allows system to grow by replacing large cells by small cells, without upsetting the channel allocation
- cells are split to add channels with no new spectrum usage.
- Depending on traffic patterns the smaller cells may be activated/deactivated in order to efficiently use cell resources.

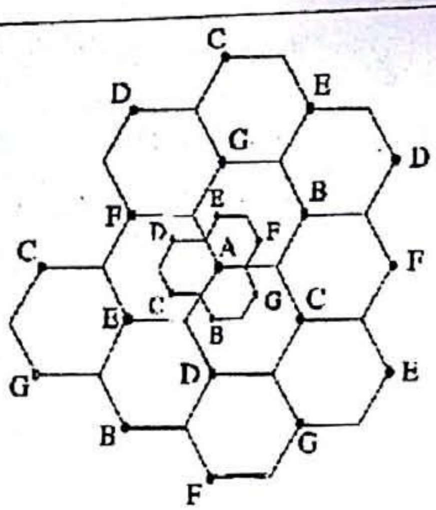


Illustration of cell splitting.

- suppose the cell radius of the new cells are reduced by half, then Required transmitted power for these new cells is

$$P_r(\text{old cell boundary}) = P_{T0} R^{-\gamma}$$

$$P_r(\text{New cell boundary}) = P_{Tn}(R/2)^{-\gamma}$$

$$\therefore \; P_{Tnew} = \frac{P_{T0}}{2^{\gamma}}$$

- For $\gamma = 3$ (normal suburban)

$$P_{Tnew} = \frac{P_{Told}}{8}.$$

- Thus, the transmitting power of new cell should be 9dB lower than original transmitting power.

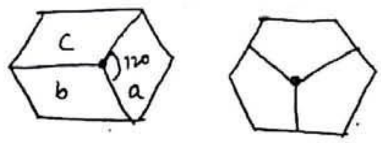
- Basically, the cell splitting technique are of two types,

1) permanent splitting: In this technique we need to plan the installation of every new split cell ahead of time.

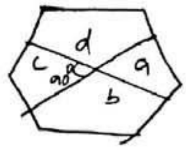
2) Dynamic splitting or Real time splitting: The spliting is based on utilization the allocated spectrum efficiency in real time.

Sectoring.

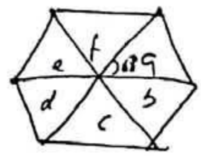
- As opposed to cell splitting, where D/R is kept constant while decreasing R, sectoring keeps 'R' untouched and reduce the D/R.
- capacity improvement is achieved by reducing the no. of cells per cluster, thus increasing frequency reuse.
- D/R increases ⇒ interference increases.
- In order to do this, it is necessary to reduce the relative interference without decreasing the transmitter power.
- The co-channel interference in a cellular system may be decreased by replacing a single omnidirectional antenna at the Base station by several directional antennas, each radiating within a specified sector. This reduce the interference.
- A directional antennas transmits to and receives from only a fraction of the total no. of co-channel cells. Thus co-channel interference is reduced.
- A cell is normally partitioned into three 120°, four 90° or six 60° sectors.



a) 120° sector

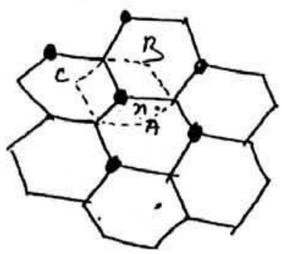


b) 90° Sector



c) 60° sector.

- placing directional transmitters at corners where three adjacent cells meet.



- Sectoring improve C/I.

- Problems with sectoring .

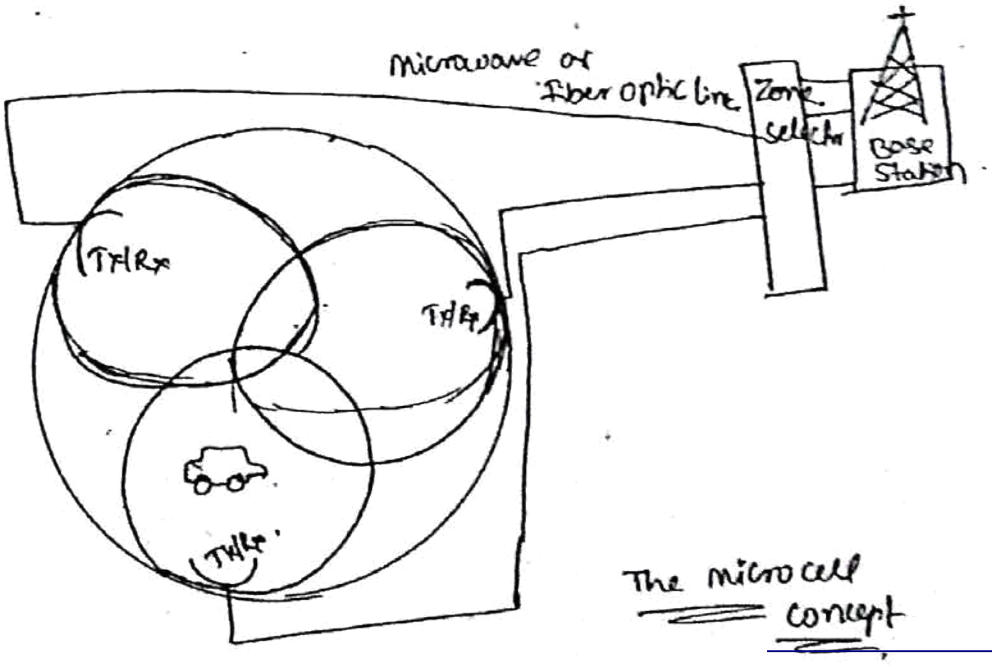
(i) Increased no. of antennas at each Base station .

(ii) Decreasing in trunking efficiency due to sectoring

(iii) Increase no. of hand off.

Microcell zone concept

- A cell is divided into microcells or zones.
- Each microcell zone is connected to the same Base station
- Each zone uses a directional antenna.
- As a mobile travel from one zone to another, it retains the same channel i.e. no hand off.
- Base station simply switches the channel to next zone site
- The advantage of the zone cell technique is that while the cell maintains a particular coverage radius, the co-channel interference in the cellular system is reduced since a large central Base station is replaced by several lower powered transmitters (zone transmitters) on the edge of the cell.



The microcell concept

- Antennas are placed at the outer edges of the cell
- Any channel may be assigned to any zone by the Base station
- Mobile is served by the zone with the strongest signal.
- Handoff within a cell
  - No channel reassignment
  - Switch the channel to a different zone site.
- Reduce interference
  - Low power transmitters are employed.

Definitions of common Terms

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

Blocked call: call which can't be completed at time of request, due to congestion. Also Referred to as a lost call.

Holding Time: Average duration of a typical call.

Traffic Intensity: measure of channel time utilization, which is the average channel occupancy measured in Erlangs.

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

Request Rate: The average number of call requests per unit time. (Denoted by λ).

Grade of Service (GOS)

A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).

- For a lost call system, (GOS) can be measured using

$$GOS = \frac{\text{no. of lost calls}}{\text{no. of offered calls.}}$$

- To determine the GOS of a network when the traffic load and number of circuits are known, telecommunications network operators make use of following eq.

$$GOS = \frac{\left(\frac{A^N}{N!}\right)}{\left(\sum_{k=0}^{N} \frac{A^k}{k!}\right)}$$

which is Erlang B equation.

Grade of Service (GOS)

A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).

- For a lost call system, (GOS) can be measured using

$$GOS = \frac{\text{no. of lost calls}}{\text{no. of offered calls.}}$$

- To determine the GOS of a network when the traffic load and number of circuits are known, telecommuni-cations network operators make use of following eq.

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