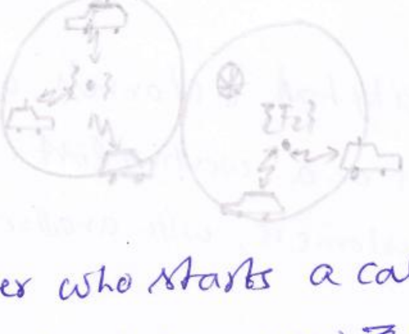
Cellular & Mobile Communications

Reason of using Cellular Mobile Telephone Systems:-

One of many reasons for developing a cellular mobile telephone system & deploying it in many cities is the operational limitations of Conventional mobile telephone systems: limited service Capability, poor service performance, & 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. The Communications Coverage area of each zone is normally planned to be as large as possible, Which means that the transmitted power should be as high as the federal specification allows.



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. This is an undesirable radio telephone system since there is no guarantee that a call can be completed without a handoff capability.

The handoff is a process of automatically Changing frequencies as the mobile unit moves into a different frequency Zone so that the Conversation can be Continued in a new frequency zone without redialing.

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 the past a total of 33 Channels were allocated to three mobile telephone systems:

Mobile Telephone Service (MTS)

Improved Mobile Telephone Service (IMTS) MJ Systems,

" " " " MK Systems.

MTS operates around 40MHZ } both provide 11 channels.
MJ " at 150 MHZ }
MK " " 450MHZ → provides 12 Channels.

These 33 Channels must cover an area 50 mi in diameter.

~~Case Study~~ Example:-

New York city had 6 channels of MJ serving 320 Customers, with 2400 customers on a waiting list. And city also had 6 Channels of MK serving 225 customers, with another 1300 customers on a waiting list.

The large of number of subscribers created a high blocking probability during busy hours. Although service performance was undesirable, the demand was still great. A high capacity system for mobile telephones was needed.

Insufficient frequency spectrum utilization:-

In a Conventional mobile telephone system, the freq. utilization measurement M_o is defined as the maximum number of Customers that Could be served by one Channel at the busy hour.

$$M_o = \frac{\text{no. of Customers}}{\text{Channel}} \text{ (conventional systems).}$$

$$M_o = \begin{cases} 53 \text{ Customers / Channel. (MJ systems).} \\ 37 \quad " \quad " \quad \text{(MK} \quad " \text{).} \end{cases}$$

Spectrum Efficiency Considerations:-

A major problem facing the radio communication industry is the limitation of the available radio frequency spectrum. In setting allocation policy, the Federal Communications Commission (FCC) seeks systems which need minimal bandwidth but provide high usage + Consumer satisfaction.

The ideal mobile telephone System would Operate with in a limited assigned frequency band and would serve an almost unlimited number of users in unlimited areas. Three major approaches to achieve the ideal are:

1. Single side band (SSB), which divides the allocated frequency band into maximum number of Channels.
2. Cellular which reuses the allocated frequency band in different geographic locations.
3. Spread spectrum (or) frequency - hopped, which generates many Codes over a wide frequency band.

Technology, feasibility & Service affordability:-

The computer industry entered a new era microprocessors & mini computers are now used for controlling many complicated features & functions with less power & size. Large scale integrated circuit technology reduced the size of mobile transceivers so that they easily fit into the standard automobile.

Another factor was the price reduction of the mobile telephone unit. LSI technology & mass production contribute to reduced cost so that in the near future an income of family should be able to afford a mobile telephone unit.

Example:-

Assume an average Calling time of 1.76 min & apply the Erlang B model (lost - Calls - cleared Conditions).

Use 6 Channels, with each Channel serving the two different number of Customers. as,

$$M_0 = \frac{\text{No. of Customers}}{\text{No. of Channel}}$$

The offered load Can be, $A = \frac{\text{avg. calling time (mins)} * \text{total customers}}{60 \text{ min.}}$ (Erlangs)

$$A_1 = \frac{1.76 * 53 * 6}{60} = 9.33 \text{ Erlangs (MJ Systems)}$$

$$A_2 = \frac{1.76 * 37 * 6}{60} = 6.51 \text{ " (MK sys.'s)}$$

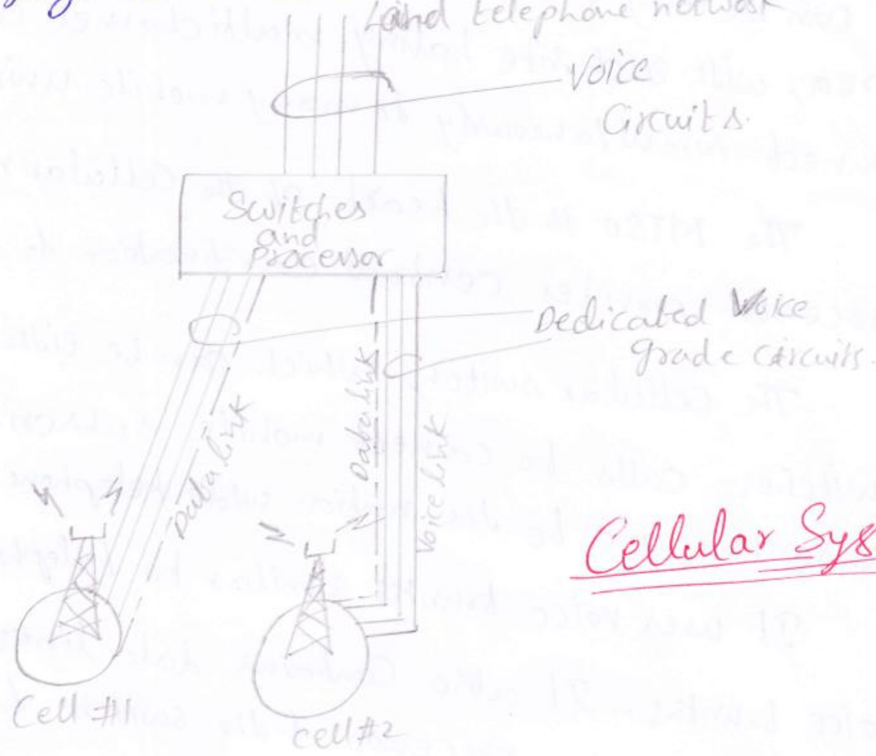
Blocking prob. $B_1 = 50$ for MJ sys.

$B_2 = 30$ " MK sys.

To reduce blocking prob. M_0 Values ↓.

Basic Cellular system:-

A basic Cellular System Consists of three parts: a mobile unit, a cell site, and a mobile telephone switching office (MTSO), shown in fig. with connections to link the three subsystems.



Cellular System

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 & the mobile units. It has a control unit, radio cabinets, antennas, a power plant, & data terminals.

3. MTSO:-

The switching office, the central coordinating element for all cell sites, contains the cellular processor & cellular switch. It interfaces with telephone company zone offices, controls call processing & handles billing activities.

4. Connections:-

The radio & 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.

The MTSO is the heart of the cellular mobile system. Its processor provides central coordination & cellular administration.

The cellular switch, which can be either analog (or) digital, switches calls to connect mobile subscribers to other mobile subscribers and to the nation wide telephone network.

It uses voice trunks similar to telephone Comany interoffice voice trunks. It also Contains data links providing supervision links between the processor & the switch & between the cellsites & the processor.

The radio link Carries the voice & signalling b/n the mobile unit & the cell site. The high speed data links cannot be transmitted over the standard telephone trunks & therefore must use either microwave links or T-carriers (wire lines). Microwave radio links (or) T-Carriers Carry both voice & data b/n the cell site & the MTSO.

Performance Criteria:-

There are three Categories for specifying performance criteria.

Voice quality:-

Voice quality is very hard to judge without subjective tests from users' opinions. In this technical area engineers cannot decide how to build a system without knowing the voice quality that will satisfy the users.

For any given commercial communication system, the voice quality will be based upon the following criterion: a set value x at which y percent of customers rat the system voice quality (from Tx to Rx) as good, or excellent, the top two circuit merits (CM) of the five listed below.

CM	Score	Quality scale
CM5	5	Excellent (speech perfectly understandable)
CM4	4	Good (speech easily understandable, some noise).
CM3	3	Fair (speech understandable with a slight effort, occassional repetitions needed).
CM2	2	Poor (speech understandable only with considerable effort, frequent repetions needed).
CM1	1	unsatisfactory (speech not understandable)

As the percentage of customers choosing CM4 and CM5 increases, the cost of building the system rises.

The average of the CM scores obtained from all the listeners is called mean opinion score (MOS). Usually the toll-quality voice is around MOS ≥ 4.

Service quality:-

Three items are required for service quality.

1. Coverage: The system should serve an area as large as possible. With radio coverage, however, because of irregular terrain configurations, it is usually not practical to cover 100 percent of the area for two reasons:

a) The transmitted power would have to be very high to illuminate weak spots with sufficient reception, a significant added cost factor.

b) The higher the transmitted power, the harder it becomes to control interference.

Therefore, systems usually try to cover 90 percent of an area in flat terrain & 75 percent of an area in hilly terrain. The combined voice quality & coverage criteria in AMPS [Advanced Mobile Phone systems] state that 75 percent of users rate the voice quality between good & excellent in 90 percent of the served area, which is generally flat terrain.

The voice quality & coverage criteria would be adjusted as per decided various terrain conditions. In hilly terrain, 90 percent of users must rate voice quality good or excellent in 75 percent of the served area. A system operator can lower the percentage values stated above for a low-performance & low-cost system.

2. Required grade of service:-

For a normal start-up system the grade of service is specified for a blocking probability of 0.02 for initiating calls at the busy hour. This is an average value.

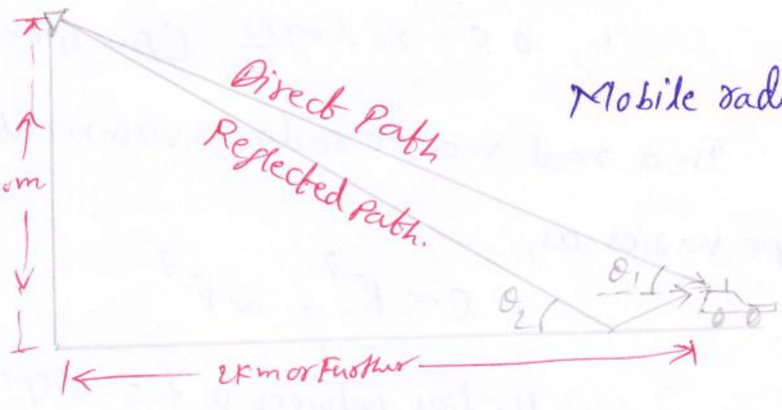
(5)

However, the blocking probability at each cell site will be different. At the busy hour, near free ways, automobile traffic is usually heavy, so the blocking probability at certain cell sites may be higher than 2 percent, especially when car accidents occur. To decrease the blocking probability requires a good system plan & a sufficient number of radio channels.

3) Number of dropped calls:-

During Q calls in an hour, if a call is dropped & Q-1 calls are completed, then the call drop rate is 1/Q. This drop rate must be kept low. A high drop rate could be caused by either coverage problems or handoff problems related to inadequate channel availability.

Uniqueness of Mobile radio Environment:-



Mobile radio transmission model.

The propagation path loss increases not only with frequency but also with distance.

From figure, the propagation path loss would be 40dB/dec, This means that a 40-dB loss at a signal receiver will be observed by the mobile unit as it moves from 1 to 10km.

$$\therefore C \propto \frac{1}{R^4}.$$

where C = received carrier power

R = distance measured from the Tx'ter to the Rx'er

α = Constant.

$$C \propto R^{-4}. = \alpha R^{-4} \quad -(1)$$

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

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

& in decibels

$$\Delta C\ (dB) = C_2 - C_1$$

$$= 10\log\frac{C_2}{C_1} = 40\log\left(\frac{R_1}{R_2}\right)$$

when $R_2 = 2R_1$, $\Delta C = -12dB$.

" $R_2 = 10R_1$, $\Delta C = -40dB$.

40dB/dec is the general rule for the mobile radio environment. It is also easy to compare to the free-space propagation rule of 20 dB/dec. The decibel scale & linear scale expressions,

$$C \propto R^{-2} \ \text{(freespace)}$$

&, $\Delta C = 20\log\frac{R_1}{R_2}$ (free space).

In a real mobile radio environment, the propagation path-loss slope varies as,

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

γ usually lies between 2 & 5 depending on the actual conditions. Of course γ cannot be lower than 2 which is the free-space condition.

$$C = 10\log\alpha - 10\gamma\log R.$$

Trunking Efficiency:-

Trunking:-

To accomodate a large number of users in a limited radio spectrum, generally cellular radio systems relay on truncking. 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 ~~other~~ user, on demand, from a pool of available channels.

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

Trunking efficiency:-

Trunking efficiency is a measure of users, which can be offered a particular GoS (Grade of service) with a particular configuration of fixed channels. GoS is a measure of congestion, which is specified as the probability of call being blocked or the probability of call being delayed beyond a certain amount of time.

The way in which channels are grouped can substantially alter the number of users handled by a trunked system.

When a market is licensing two or more carriers rather than one, the trunking efficiency is degraded.

For example if we Compare the trunking efficiency between one cellular system per market Operating 666 Channels & two cellular systems per market each operating 333 Channels. Consider that, all frequency Channels are evenly divided in to 7 sub areas called as Cells. The blocking probability is assumed to be 0.02 in each Cell & the average time 1.76 min.

Then, the number of Channels per each cell in one cellular System market is given by,

$$N_1 = \frac{666}{7} = 95.$$

Blocking probability $(B) = 0.02$.

Percentage of blocked calls clear for a particular number of Channels per cell, Can be $A_1 = 83.1$.

Similarly the number of Channels for each cell for a two cellular system per market each operating 333 Channels is,

$N_2 = \frac{333}{7} = 47.5$ & $B = 0.02$. then $A_2 = 38$. [From Lee book]. [Apendix 1.1]

∴ two Carriers are considered, the total offered load is $2A_2$.

$$\therefore A_1 \geq 2A_2.$$

By Considering A_1 & A_2 that the number of users who can be served in a busy hour, the number of calls per hour served in a cell can be expressed as,

$Q_1 = \frac{A * 60}{1.76}$ Calls/hr. [For one Carrier market].

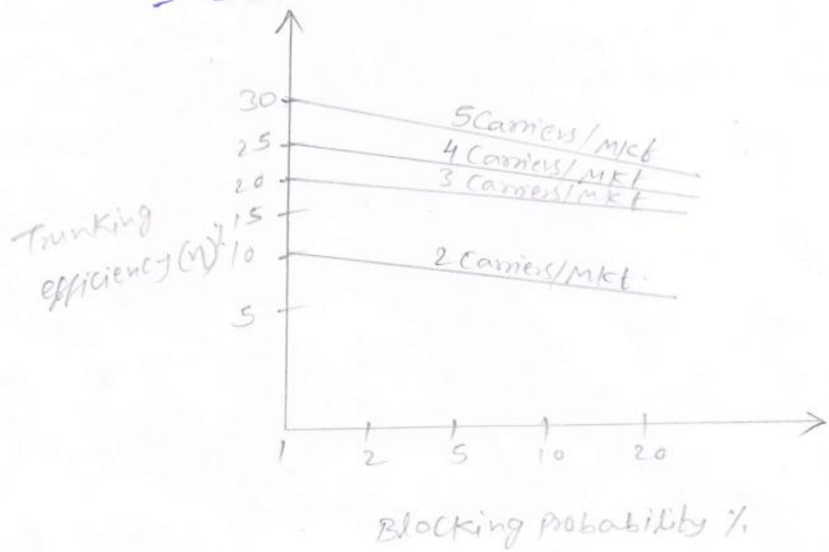
$$Q_1 = \left(\frac{83.1 * 60}{1.76}\right) = 2832.95 \text{ Calls/hr.}$$

$$Q_1 = \left(\frac{38 * 60}{1.76}\right) * 2 = 2590.9 \text{ calls/hr.}$$

For a blocking probability of 2 percent, the trunking efficiency degradation factor (η_c) can be given by,

$$\eta_c = \frac{2832.95 - 2590.9}{2832.95}$$

$$= 8.5\%$$



Trunk definition:-

A trunk is a line or link designed to handle many signals simultaneously, & that connects major switching centres in a communication comm. sys's. The use & management of trunks in a communication sys. is known as trunking.

Erlang:-

An Erlang is a unit of telecommunication & traffic measurement. Erlang represents the continuous use of one voice path. In practice it is used to describe the total traffic volume of one hour.

Operation of cellular systems:-

The operation can be divided into four parts & a handoff procedure.

Mobile unit initialization:-

When a user sitting in a car activates the receiver of the mobile unit, the receiver scans 21 set-up channels which are designed among the 416 channels. It then selects the strongest & locks on for a certain time. Since each site is assigned a different set-up channel, locking on to the strongest set-up channel usually means selecting the nearest cell site. This self-location scheme is used in the idle stage & is user-independent. It has a great advantage because it eliminates the load on the transmission at the cell site for locating the mobile unit. The disadvantage of the self location scheme is that no location information of idle mobile units appears at each cell site.

Therefore, when the call initiates from the landline to a mobile unit, the paging process is longer. Since a large percentage of calls orginates at the mobile unit, the use of self-location schemes is justified. After 60's, the self location procedure is repeated. In future when landline originated calls increase, a feature called "registration" can be used.

Mobile originated call:-

The user places the called number into an originating register in the mobile unit, checks to see that the number is correct, & pushes the "send" button. A request for service is sent on a selected set-up channel obtained from a self-location scheme.

The cell site receives it, & in directional cell sites, selects the best directive antenna for the voice channel to use. At the same time the cell site sends a request to the mobile telephone switching office (MTSO) via a high-speed data link.

The MTSO selects an appropriate voice channel for the call, & the cell site acts on it through the best directive antenna to link the mobile unit. The MTSO also connects the wire-line party through the telephone company zone office.

Network originated Call:-

A land-line party dials a mobile unit number. The telephone company zone office recognizes that the number is mobile & forwards the call to the MTSO. The MTSO sends a paging message to certain cell sites based on the mobile unit number and the search algorithm.

Each cell site transmits the page on its own set-up channel. The mobile unit recognizes its own identification on a strong set-up channel, locks onto it, & responds to the cell site. The mobile unit also follows the instruction to tune to an assigned voice channel & initiate user alert.

Call termination:-

When the mobile user turns off the transmitter, a particular signal (signaling tone) transmits to the cell site, & both sides free the voice channel. The mobile unit resumes monitoring pages through the strongest set-up channel.

Hand off procedure:-

During the call, two parties are on a voice channel. When the mobile unit moves out of the coverage area of a particular cell site, the reception becomes weak. The present cell site requests a handoff. The system switches the call to a new frequency channel in a new cell site without either interrupting the call or altering the user.

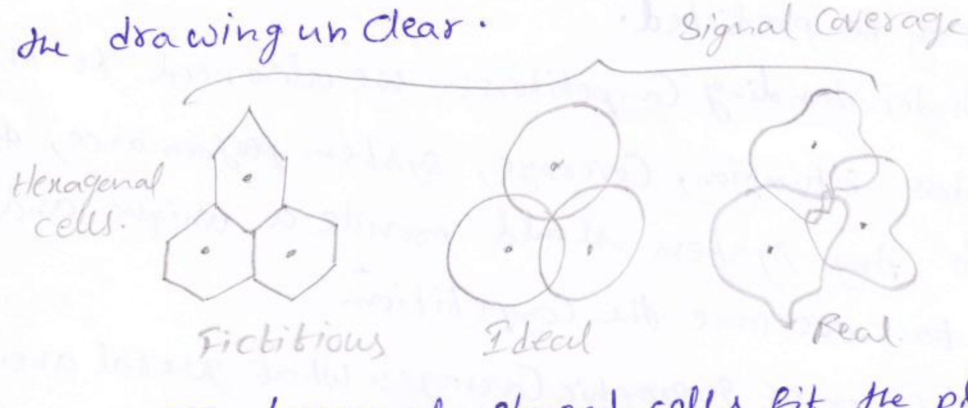
The call continues as long as the user is talking. The user does not notice the handoff occurances. Handoff was first used by the AMPS system, then renamed handover by the European system.

~~Mark~~

Hexagonal - Shaped cells:-

We have to realize the hexagonal-shaped communication cells are artificial & that such a shape cannot be generated in the real world. Engineers draw hexagonal-shaped cells on a layout to simplify the planning & design of a cellular system because it approaches a circular shape that is the ideal power coverage area.

The circular shapes have overlapped areas which make the drawing unclear.



Hexagonal cells & the real shapes of their coverages.

The hexagonal-shaped cells fit the planned area nicely, with no ~~over~~ gap & no overlap b/n the hexagonal cells. The ideal cell shapes as well as the real cell shapes are shown in fig.

The hexagonal-shaped cells have already become a widely promoted symbol for cellular mobile systems.

Planning a cellular System:-

How to start planning:-

Assume that the Construction permit for a cellular system in a particular market area is granted. The planning stage becomes critical. A great deal of money can be spent & yet poor service may be provided if we donot know how to create a good plan.

First, we have to determine two elements: Regulations, Market situation

Regulations:-

The federal regulations administered by the FCC are the same throughout the united states. The state regulations may be different from state to state, & each city & town may have its own building codes & zoning laws.

Market situation:-

1. Prediction of gross income: We have to determine the population average income, business types, & business zones so that the gross income can be predicted.

2. Understanding Competitors:- we also need to know the competitors situation, Coverage, system performance, & no. of customers. Any system should provide a unique and outstanding service to overcome the Competition.

3. Decision of geographic Coverage:- What general area should ultimately be covered? What near-term service can be provided in a limited area? These questions should be answered & the decisions passed on to the Engineering department.

The engineers role:-

The engineers follow the market decisions by,

1. Initiating a cellular mobile service in a given area by creating a plan that uses a minimum number of cell sites to cover the whole area. It is easy for marketing to request but hard for the engineers to fulfill.

2. Checking the areas that marketing indicated were important revenue areas. The no. of voice channels required to handle the traffic load at the busy hours should be determined.

3. Studying the interference problems, such as cochannel & adjacent channel interference, & the intermodulation products generated at the cell sites, & finding way to reduce them.

4. Studying the blocking probability of each call at each cell site, & trying to minimize it.

5. Planning to absorb more new customers. The rate at which new customers subscribe to a system can vary depending on the service changes, system performance, & seasons of the year. Engineering has to try to develop new technologies to utilize fully the limited spectrum assigned to the cellular system. The analysis of spectrum efficiency due to the natural limitations may lead to a request for a larger spectrum.

Uniqueness of Mobile radio Environment :-

Cont..! :-

Fading:-

The rapid fluctuations of the amplitudes, phases or multipath delays of a radio signal over a short period of time or travel distance is known as fading.

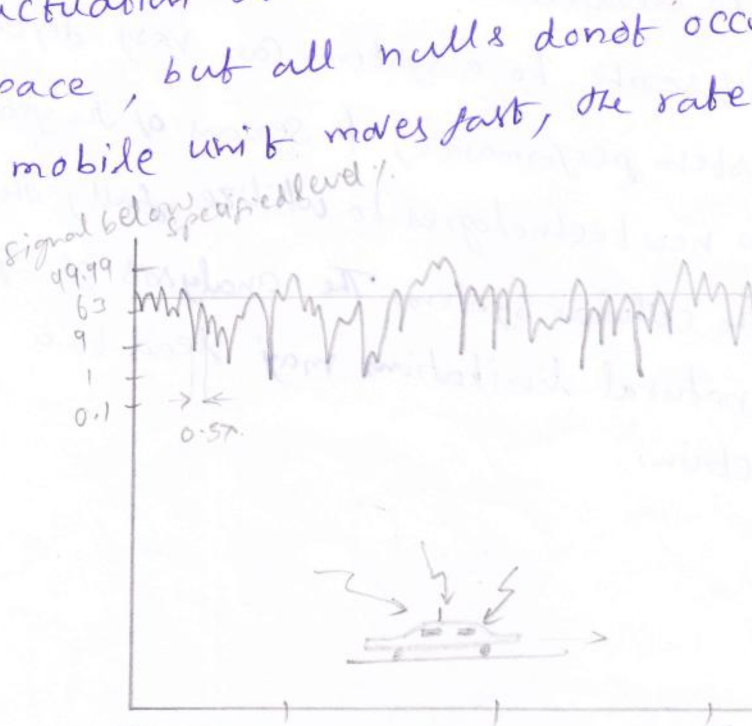
In radio propagation multipath waves are generated due to,

i) Lower antenna height of mobile unit compared to its surroundings.

ii) Much less wavelength of carrier freq. compared its surrounding structures.

This multipath components combine vectorially at the receiver antenna, & causes the signal received to fade.

The signal fluctuates in a range of about 40dB (10 dB above & 30 dB below the average signal). The nulls of the fluctuation at the base band at about every half wavelength in space, but all nulls donot occur at the same level. If the mobile unit moves fast, the rate of fluctuation is fast.

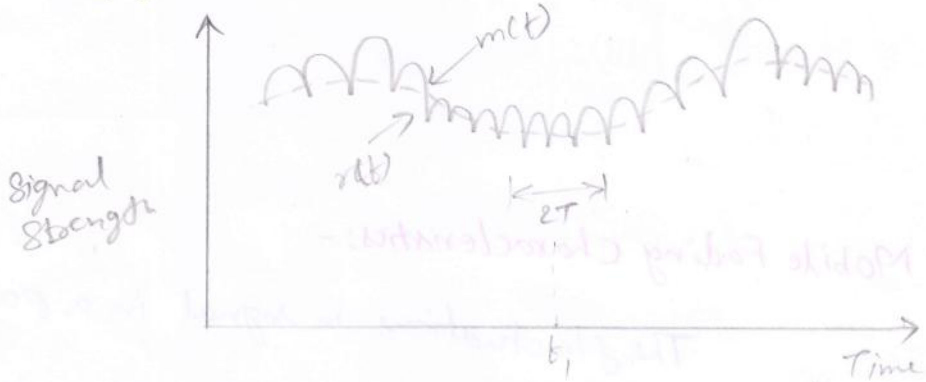


A typical fading signal received while the mobile unit is moving.

Model of Transmission medium:-

A mobile radio signal $r(t)$ can be artificially Characterized by two Components $m(t)$ & $r_0(t)$.

$$r(t) = m(t)\, r_0(t)$$



Where the Component $m(t)$ is known as local mean (or) long term fading (or) lognormal fading, this occurs due to path loss of signal as a function of distance & showding by large objects such as hills. The Component $r_0(t)$ is known as multipath fading (or) short-term fading (or) Rayleigh fading, this occurs due to Constructive & destructive interference of the multiple signal paths b/n Tx'ter & Rx'er.

For long term fading,

$$m(t_1) = \frac{1}{2T}\int_{t_1-T}^{t_1+T} r(t)\, dt. \quad \rightarrow \text{Time domain.}$$

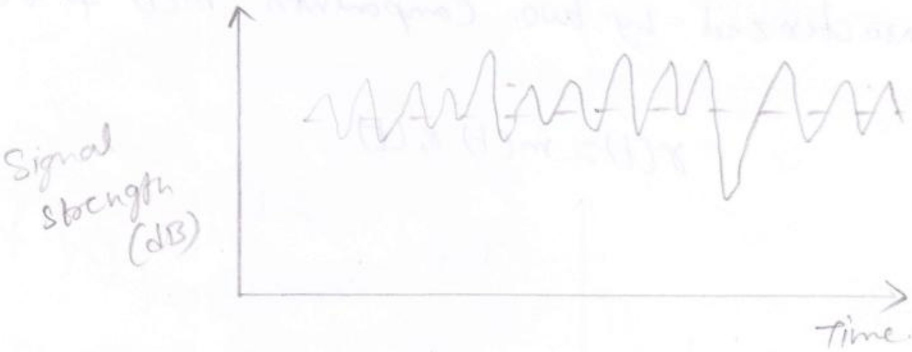
2T, is the timeperiod for averaging $[r(t)]$

$$m(x_1) = \frac{1}{2L}\int_{x_1-L}^{x_1+L} r(x)\, dx. \quad \rightarrow \text{space domain.}$$

Short-term fading $r_0(t)$ is,

$$r_0 \text{ (in dB)} = r(t) - m(t).$$

The short-term fading component $r_0(t)$ exhibits a Rayleigh distribution. It is known as Rayleigh fading.



Mobile Fading Characteristics:-

The fluctuations in signal in a particular range of bandwidth (ie., about 40dB). This is signal fading.

The multipath waves bounce back & forth due to obstacles they form many standing wave pairs in space, which are summed together & become an irregular wave fading structure. If the mobile unit is moving, the fading structure of wave in the space is received. It is known as multipath fading.

Characteristics:-

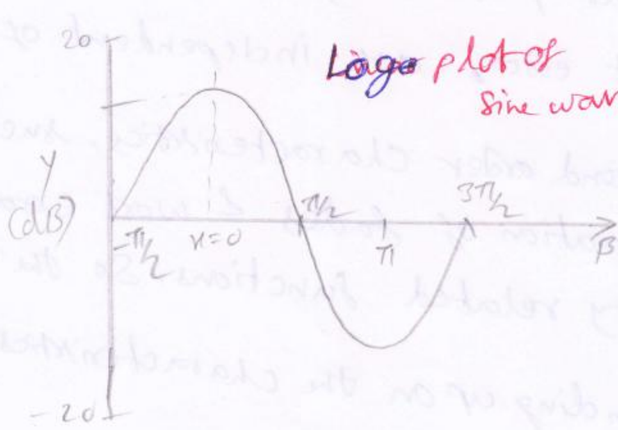
1. Radius of the Active scatter region:-

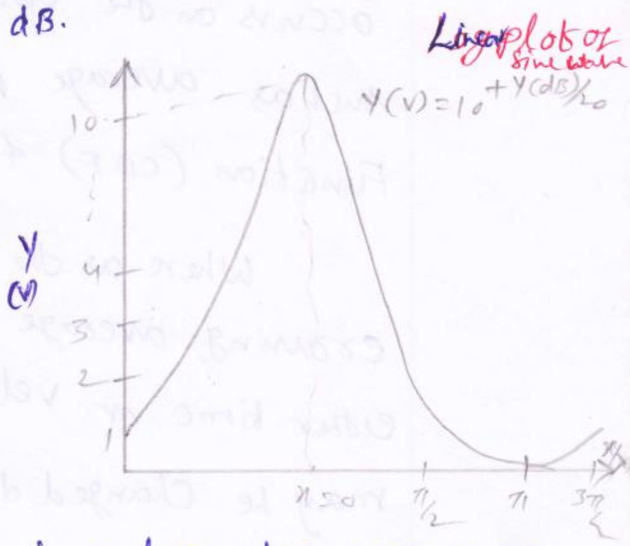
Always the active scatter region moves with the mobile unit as its centre. It means that some houses were inactive scatters & become active as the mobile unit approached them, some houses which are active scatters became inactive as the mobile unit away from them.

2) Standing waves expressed in a linear scale & a log scale:-

First consider a sine wave in a log scale.

$$Y = 10 \cos \beta x \ \ dB.$$





The symmetrical wave form in a log plot becomes an unsymmetrical wave form when plotted in a linear scale.

Two sine waves, the incident wave travelling along the x-axis & the reflected wave in opposite direction,

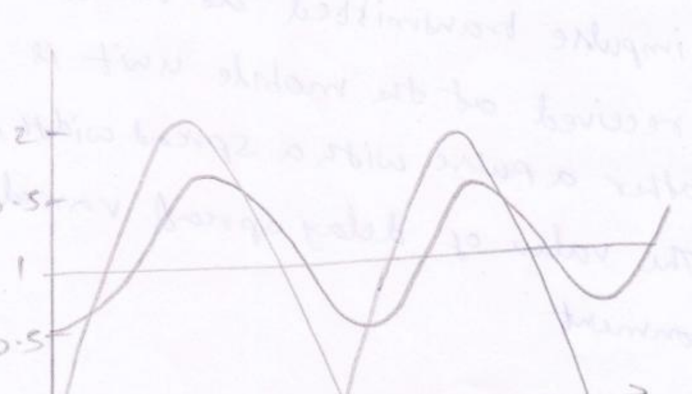
$$e_0 = E_0 e^{j(\omega t + \beta x)}$$

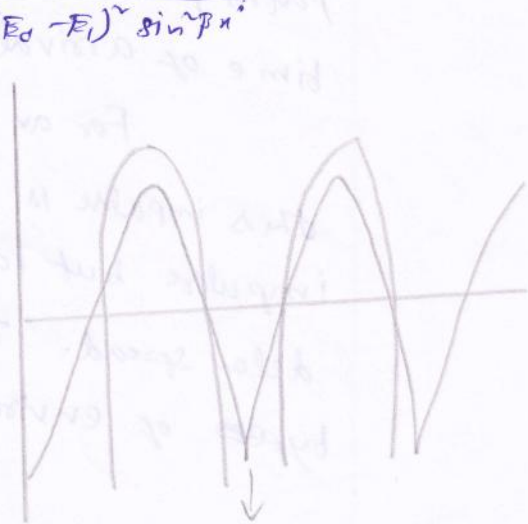
$$\& \quad e_1 = E_1 e^{j(\omega t - \beta x + \delta)}$$

The two waves form a standing wave pattern.

$$e = e_0 + e_1 = R \cos(\omega t - \delta).$$

where, $R = \sqrt{(E_0 + E_1)^2 \cos^2 \beta x + (E_0 - E_1)^2 \sin^2 \beta x}$





real fading signal

3) First order & second order statistics of Fading:-

When the mobile unit is moving, generally the fading occurs on the signal reception. The first order characteristics such as average power probability Cummulative distribution Function (CDF) & bit error, are independent of time.

Where as the second order characteristics, such as level crossing, average duration of fades & word error rate are either time or velocity related functions. So the mobile fading may be changed depending up on the characteristics.

4) Delay spread & Coherence Band width:-

Coherence Band width is defined as the Bandwidth in which either the amplitudes or the phases of two received signals have a high degree of similarity.

In the mobile radio environment, as a result of the multipath reflection phenomenon, the signal transmitted from a cell site & arriving at a mobile unit will be from different paths, & since each path has a different path length, the time of arrival for each path is different.

For an impulse transmitted at the cell site, by the time this impulse is received at the mobile unit is no longer an impulse but rather a pulse with a spread width, it is called delay spread. The value of delay spread varied depending upon the types of environment.

If the multipath time delay spread equal Δ seconds, then the coherence Bandwidth B_c in hertz, is,

$$B_c = \frac{1}{2\pi\Delta} \Rightarrow \text{for, Fading amplitudes.}$$

$$B_c = \frac{1}{4\pi\Delta} \Rightarrow \text{for Two random phases of two Rx'ed signals.}$$

Type of Environment	Delay Spread Δ (μs)
open area	<0.2
Urban area	3
Suburban area	0.5
Inside the building	<0.1

4. Direct wave path, Line-of-sight path & obstructive path:-

A direct wave path is path clear from the terrain Contour. The line of sight is a path clear from buildings. When a line of sight condition occurs, the average received signal at the mobile unit at a 1-mi intercept is higher, although the 40 dB/dec path-loss slope remains the same.

When the terrain Contour blocks the direct wave path, we refer it as obstructive path. In this situation, the shadow loss from the signal reception can be found by using the Knife-edge diffraction curves.

Elements Of Cellular Radio System Design

General Description of the problem:

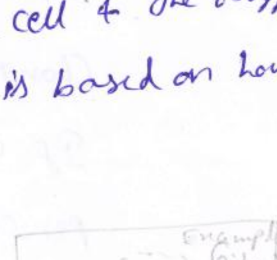
Based on the Concept of efficient spectrum utilization, the Cellular mobile radio system design Can be broken down in to many elements, & each element Can be analysed and related to the others.

The major elements are:

1) The Concept of frequency reuse channels.
2) The Co-channel interference reduction factor.
3) The desired Carrier-to-interference ratio.
4) The handoff mechanism.
5) Cell splitting.

Maximum number of calls per hour per cell:-

To calculate the predicted number of Calls per hour percell Q in each cell, we have to know the size of the cell & the traffic Conditions in the cell. The Calls per hour percell is based on how small the theorical cell size can be.



We assume that the cell can be reduced to a 2-km cell, which means a cell of 2-km radius. A 2-km cell in some areas may cover many highways, & in other areas 2kms cell may only cover a few highways.

Let a busy traffic area of 12km radius fit seven 2-km cells. The heaviest traffic cell may cover 6 freeways & 10 heavy traffic streets, A total length of 64 km of 2 eight-lane freeways, 48 km of 2 six-lane free ways, & 588 km of 43 four-lane roads, including the 10 major roads. Assume that the average spacing between cars is 10 m during busy periods.

We can determine that the total no. of cars is about 70,000. In one-half the cars have car-phones, & among them eight-tenths will ~~have~~ make a call ($\eta_c = 0.8$) during the busy hour, there are 28,000 calls per hour, based on an average of one call per car. The maximum predicted number of calls per hour per a 2-km cell Q is desired.

Maximum number of frequency channels per cell:-

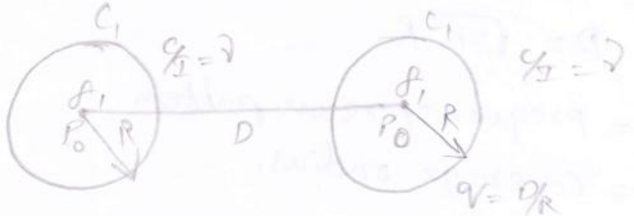
The maximum number of frequency channels per cell N is closely related to an average calling time in the system. The standard user's calling habits may change as a result of the changing rate of the system & the general income profile of the users. If an average calling time T is 1.76 min. & the maximum calls per cell Q_i is obtained, then the offered load can be,

$$A = \frac{Q_i T}{60} \text{ erlangs.}$$

Concepts of frequency reuse channels:-

A radio channel consists of a pair of channels, one for each direction of transmission that is used for full-duplex operation. A particular radio channel, say F_1, used in one geographic zone to call a cell, say C_1 with a coverage R can be used in another cell with the same coverage radius at a distance D away.

Frequency reuse is the core concept of the cellular mobile radio system. In this frequency reuse system, users in different geographic locations (different cells) may simultaneously use the same frequency channel.



The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur. Interference due to the common use of the same channel is called cochannel interference & is our major concern in the concept of frequency reuse.

Frequency reuse Schemes:-

The frequency reuse concept can be used in the time domain & the 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 in to

1. Same frequency assigned in to two different geographic areas, such as AM (or) FM radio stations using the same freq. in different cities.

2. Same freq. 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 freq. spectrum allocation is divided into K freq. reuse patterns.

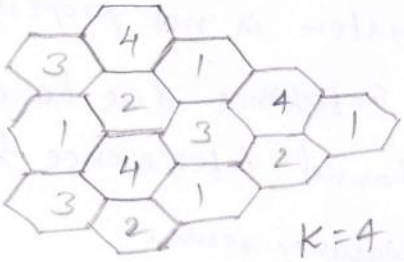
Frequency reuse distance:-

The closest distance between the center of two cells, which allows the same frequency to be reused is known as "frequency reuse distance". It is denoted with 'D'.

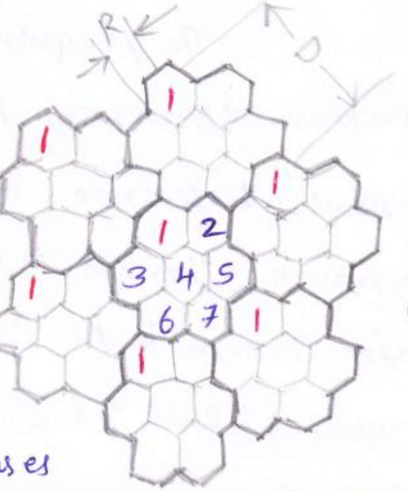
$$D = \sqrt{3K}\, R.$$

K = Frequency reuse pattern

R = coverage radius.



K=4



$q = D/R = 4.6$

$K = 7$

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

When K is too large, the number of channels assigned to each ~~cell~~ of K cells becomes small. It is always true that if the total no. of channels in K cells is divided as K increases, trunking inefficiency results. The same principle applies to spectrum inefficiency: if the total number of channels are divided into two network systems serving in the same area, spectrum inefficiency increases.

Now the Challange is to obtain the smallest number K which can still meet our system performance requirements. This involves estimating co-channel interference & selecting the min. freq. reuse distance D to reduce co channel interference.

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

The main reason for obtaining the above expression is to calculate the smallest number K which can still meet our system performance requirements.

The nearest co-channel cell can be obtained by,

1) Moving i cells along any chain of hexagons.

2) Turn 60° counter clockwise & move j cells.

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 & the number of channels in them.

The max. number of cells per hour per cell is driven by the traffic conditions at each particular cell. After the max. no. of freq. channels per cell has been implemented in each cell, then the max. no. of calls per hour can be taken care of in each cell. Now, take the max. no. of calls per hour in each cell Q_i & sum them over all cells.

Cochannel Interference Reduction Factor:-

Reusing an Identical freq-channel in different cells is limited by Cochannel interference between cells, & the Cochannel interference Can become a major problem. Here we would like to find the minimum freq. reuse distance in order to reduce this Cochannel interference.

Assume that the size of all cells is roughly the same. The cell size is determined by the coverage area of the signal strength in each cell. As long as the cell size is fixed, Cochannel interference is independent of the Tx'ed power of each cell.

Cochannel interference is a function of a parameter q is,

$$q = \frac{D}{R} \quad \longrightarrow (1)$$

The parameter q is the Cochannel interference reduction factor. When the ratio q increases, Cochannel interference decreases. Furthermore, the separation D in eq. (1) is a function of K_I & C/I.

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

$K_I \rightarrow$ No. of Cochannel interfering Cells in the first tier.

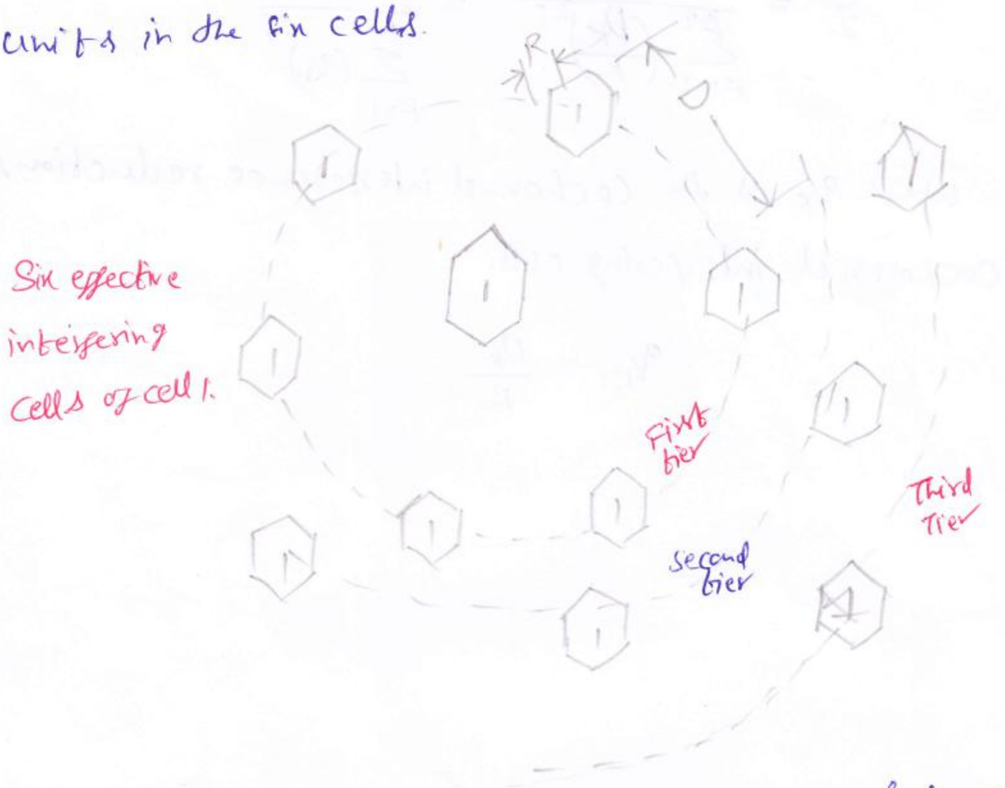
$C/I \rightarrow$ Rx'ed Carrier to interference ratio at the desired mobile receiver.

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

In a fully equipped hexagonal-Shaped cellular system, there are always six cochannel interfering cells in the first tier. ie,

$K_I = 6$.

Cochannel interference can be experienced both at the cell site & at mobile units in the center cell. If the interference is much greater, then the carrier-to-interference ratio C/I at the mobile units caused by the six interfering sites is same as the C/I received at the center cell site caused by interfering mobile units in the six cells.



A/c to both the reciprocity theorem & the statistical summation of radio propagation, the two C/I values can be very close. Assume that the local noise is much less than the interference level & can be neglected.

C/I 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 determined by the actual terrain environment. In mobile radio medium, γ usually is assumed to be 4. K_I is the no. of co-channel interfering cell & is equal to 6 in a fully developed system as shown in fig.

The six co-channel interfering cells in the second tier cause weaker interference than those in the first tier. Therefore, the cochannel 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.

$$q_K = \frac{D_K}{R}.$$

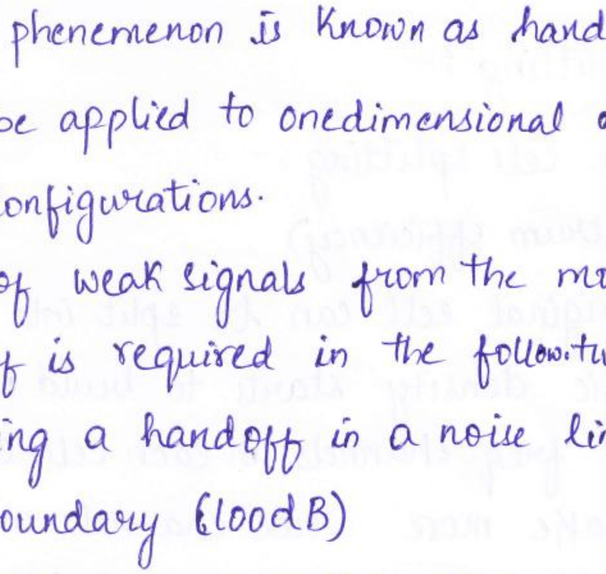
Hand off Mechanism

Hand off is the process of automatically changing the frequencies, when the mobile unit moves out of the coverage areas of a particular cell site, the reception becomes weak. At this instant, the present cell site requests hand off, then system switches the call to a new frequency channel in a new cell site without interrupting either call or user. This phenemenon is known as handoff.

This concept can be applied to onedimensional as well as two-dimensional cellular configurations.

By the reception of weak signals from the mobile unit by the cell site, the handoff is required in the follow. two situations :-

1. The level for requesting a handoff in a noise limited environment is at the cell boundary (100dB)
2. In a particular cell site when the mobile unit is reaching the signal strength holes (gaps).



· The fig. shows the usage of frequency of F_1 in two channel cells which are seperated by a distance D. Now, we have to provide a communication system in the whole area by filling other frequency channels F_2; F_3 & F_4 b/w two co-channel cells.

Depending on the same value of Q, the cells C_2, C_3 & C_4 to which above fill in frequencies F_2, F_3 & F_4 are assigned resp. Initially, a mobile unit is starting a call in cell with fill in frequency F_1 & then moves to a cell freq. F_2. However, the call being dropped & re-initiated in frequency channel from F_1 to F_2. This process of changing freq. can be done automatically by the system without the users intervention.

Cell Splitting :-

Need for cell splitting :-
(For spectrum efficiency)

The original cell can be split into smaller cells when :
(a) traffic density starts to build up
(b) the freq. channels in each cell cannot provide enough mobile calls
(c) to make more voice channels available to accomodate traffic growth in the area covered by the original cell.

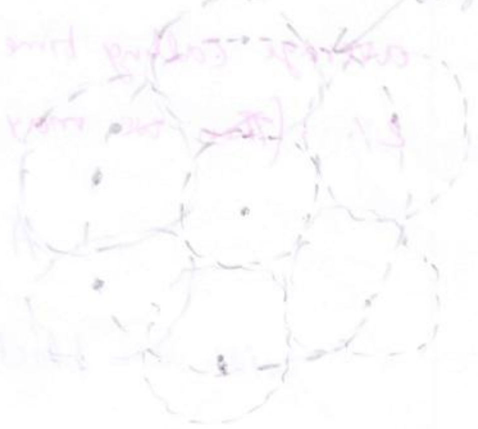
If the radius of a cell is reduced from R to R/2, the area of cell is reduced from area to area/4. The no. of available channels is also increased i.e.,

$$\text{If, radius of new cell} = \frac{\text{Radius of old cell}}{2}$$

$$\text{Area of new cell} = \frac{\text{Area of old cell}}{4}$$

Assume that the max. traffic load carried by the new cell is same as the tough old cell then,

$$\frac{\text{New traffic load}}{\text{Unit Area}} = 4 \times \frac{\text{traffic load}}{\text{Unit Area}}.$$



Permanent Splitting :-

The installation of every new split cell has to be planned a head of time, the no. of channels, that transmitted power, the assigned freq., the choosing of the cell site selection & the traffic load consideration should all be considered. When ready, the actual service cut-over should be set at the lowest traffic point usually at midnight on a week end. Hopefully, only a few calls will be dropped because of this cut-over, assuming that the down time of the system is within two hours. ~~This technique is also~~

Dynamic Splitting :-

This technique is also referred to as Real time splitting. In this technique the splitting is based on utilising the allocated spectrum efficiency in real time. The algorithm for dynamic splitting cell sites is a tedious job. Since, we cannot afford to have one single cell, unused during cell splitting procedure handling made easy by using software algorithm programs.

(a) Cell splitting affects the neighbouring cells.
(b) Particular channels should be used as barriers.

The above 2 considerations are to be made in maintainence of freq. reused distance ratio 'q' by the cell splitting process.

1) Let the maximum calls per hour Q_i in one cell be 3000 & an average calling time T be 1.76 min. The blocking probability B is 2%. (~~Then we may use Q~~) Find offered load. A.

$$A = \frac{3000 * 1.76}{60} = 88$$

with the blocking probability B = 2% the max. no. of channels can be found App. 1.1 as N = 100.

2) Let Q_i = 28,000, calls per cell per hour, based on one scenario, B = 2%, T = 1.76 min, how many radio channels?

$$A = \frac{28,000 * 1.76}{60} = 821$$

N = 820 channels/cell.

3) If there are 50 channels in a cell to handle all the calls & the avg. is 100s per call, how many calls can handled in this cell with a blocking prob. 2%? ∴ N=2, B=2%.

$$A = 40.3$$

The no. of calls/hr in a cell is,

$$Q_i = \frac{40.3 * 3600}{100} = 1451 \text{ calls/hr.}$$

4) If the maximum no. of calls/hr per cell is 1451 & then is seven cell reuse pattern (K=7). & Assume B=2 & T=100s as in above prob. ③, then N = 50 as indicated.

The total no. of required channels for a K=7 reuse system is,

$$N_t = 50 * 7 = 350 \text{ radios.}$$

Differences b/n permanent & Dynamic cell splitting:-

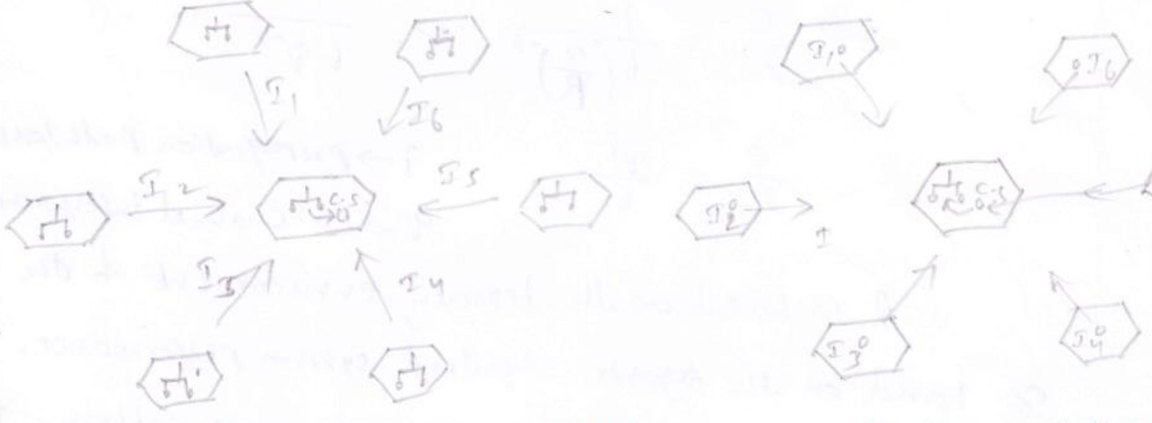
Permanent Splitting	Dynamic splitting
1) In this technique, the installation of every new split cell has to be planned a head to time.	1) In this technique, we need to utilize the allocated spectrum efficiency in real time.
2) These splitting can be easy to handle as long as cut over from large cells to small cells takes place during a low traffic period.	2) These cell splitting procedures should be easy to handle with a software algorithm program.
3) In this type of splitting ~~orgi~~ original cell is not used.	3) In this type of splitting original cell is used.
4) Selecting small cell sites is a tough job.	4) The algorithm for dynamically splitting cell sites is a tedious job since we cannot afford to have a single cell unused during cell splitting at heavy traffic hours.
5) In this technique freq. channel assignment should follow the rule based on the freq. re use distance ratio 'q' with power adjustment.	5) In this technique to maintain service for ongoing calls while doing the cell splitting, we let the channels assigned in the old cell in to two groups.

Desired C/I in Omnidirectional Antenna Systems:-

The two cases which can be considered in the calculation of Carrier to Interference (C/I) ratio in an omni directional antenna are,

1) The mobile unit received signal & Co-Channel interference.
2) The cell site received signal & Co-channel interference.

The local noise at the mobile unit with N_m & at the cell site is N_b. Compared to the interference level, these local noises are very small, thus they can be neglected.



Receiving at the cell site   Receiving at the mobile unit

A system is said to be balanced, if the received Carrier to Interference ratios at both the mobile unit & cell site are same. In a balanced system, the system requirements can be analyzed by using either of the two cases. Consider a 7 cell pattern i.e., K=7, then,

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

$\therefore K_I = 6.$

$$\frac{C}{I} = \frac{1}{\sum_{K=1}^{6}\left[\frac{D_K}{R}\right]^{-\gamma}}$$

$$= \frac{1}{\left(\frac{D_1}{R}\right)^{-\gamma} + \left(\frac{D_2}{R}\right)^{-\gamma} + \cdots \left(\frac{D_6}{R}\right)^{-\gamma}}$$

Assume that all D_K are the same for simplicity i.e, $D_1 = D_2 = \cdots = D$.

$$\therefore \frac{C}{I} = \frac{1}{6\left(\frac{D}{R}\right)^{-\gamma}}$$

$$\Rightarrow \frac{C}{I} = \frac{1}{6\left(\frac{D}{R}\right)^{-\gamma}} \Rightarrow \frac{1}{6\, q^{-\gamma}}$$

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

$\gamma \to$ propagation path loss

$q \to$ Co-channel interference reduction factor.

γ is based on the terrain environment & the specified value of C/I based on the ~~system~~ required system performance. The typical value of $q = 4.6$. i.e., for seven cell reuse pattern. $\gamma = 4$ for mobile radio environment.

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

$$= \frac{(4.6)^4}{6}$$

$$\frac{C}{I} = ~~18~~ 74.624.$$

$$\frac{C}{I} = 10\log(74.624) = 18.73\,dB$$

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

$$q = \left[6\left(\frac{C}{I}\right)\right]^{1/\gamma} \Rightarrow q = \left[6\left(\frac{C}{I}\right)\right]^{(\gamma)^{-1}}$$

$C/I = 18.$

$\gamma = 4.$

$$q = (6 * 63.1)^{1/4}$$

$q = 4.41.$

Large coverage are would be achieved by increasing the transmitted power at each-cell, increasing the same amount of transmitted power in each cell which does not effect the co-channel interference reduction factor (q). The Co-channel interference reduction $q = 4.4$ for practical case.

The co-channel interference reduction factor can also be obtained from simulation. Let, one main cell site & six possible co-channel interference, the distance b/n the main cell site & co-channel interference is 'D',

$$C/I = 18dB.$$

For, C/I values,

$4.6R = D.$ $\left\{ \begin{array}{l} \text{for } K=7, \; D = \sqrt{3K} \cdot R. \\ D = \sqrt{21}\, R \\ D = 4.6R \end{array} \right\}.$

$q = D/R$

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

$q = 4.6.$

Comparing the values of 'q,' obtained from an practical solution & 'q' obtained from a simulation is same.

Consideration of Components of Cellular System:-

General view of Cellular tele-Communications Systems.

MTSO:

- Coordinates all switch functions.
- Performs all internal switching of calls
- Serves features implemented via software

CELL:

- Autonomously locate mobiles
- Manages data Communication with mobile & MTSO.

Cell Coverage for signal & Traffic

→ Cell Coverage (or) Signal Coverage (or) Traffic coverage.

→ Task is to build with min. no. of cell sites.

→ Signal coverage can be predicted by coverage prediction model.

The prediction model:-

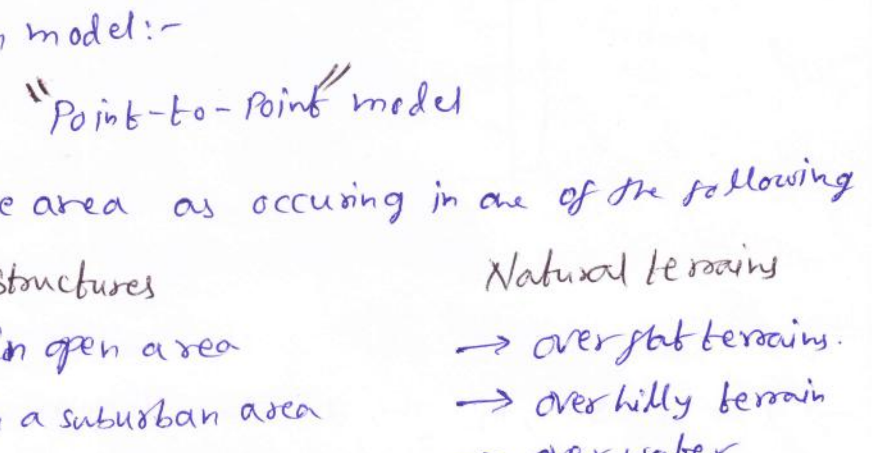
"Point-to-Point" model

The service area as occuring in one of the following environments:-

Human-made Structures
- → In open area
- → In a suburban area
- → In an urban area.

Natural terrains
- → over flat terrains.
- → over hilly terrain
- → over water
- → Through Foliage areas.

Ground incident angle & ground elevation angle:-



ϕ is the elevation angle
θ is the incident angle.

→ In a mobile radio environment, the avg. cell site antenna ht. is 50m, the mobile antenna ht. is about 3m, & comm. path link is 5km. The incident angle is,

$$\theta = \tan^{-1}\left(\frac{50m + 3m}{5km}\right) = 0.61°$$

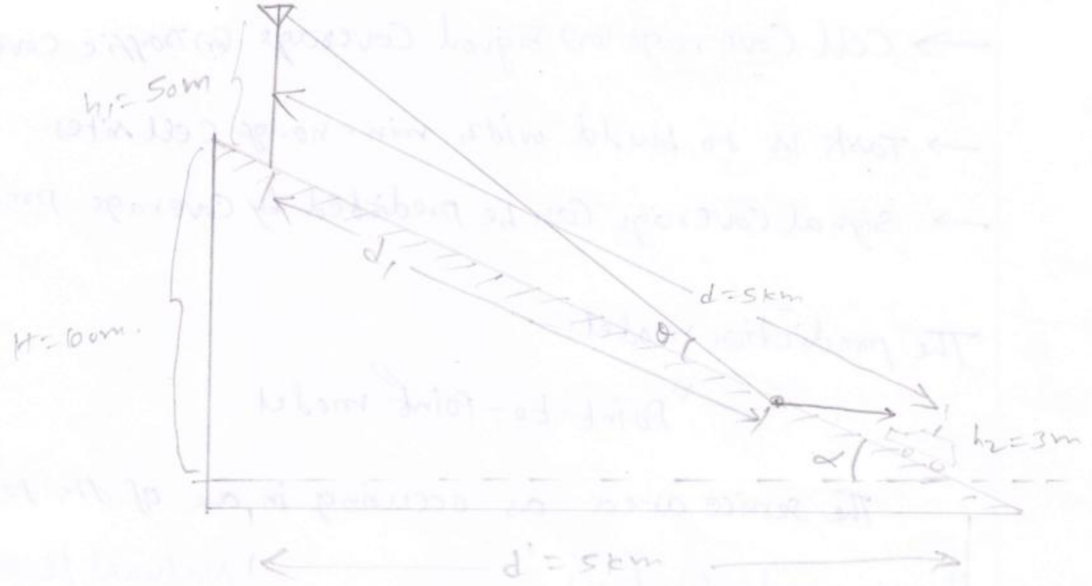
The elevation angle of the antenna of the mobile unit is,

$$\phi = \tan^{-1}\frac{50m - 3m}{5km} = 0.54°$$

The elevation angle at the location of the mobile unit is,

$$\phi = \tan^{-1}\frac{50m}{5km} = 0.57°$$

Ground reflection angle & reflection point:-



→ Let $h_1 = 50m$, $h_2 = 3m$, $d = 5km$, $H = 100\,m$, the slope angle α of the hill is,

$$\alpha = \tan^{-1} \frac{100m}{5Km} = 1.14570^\circ \approx 1.5^\circ$$

The incident angle,

$$\theta = \tan^{-1} \frac{50+3m}{5Km} = 0.61^\circ$$

& the reflect point location from the cell site-antenna,

$$d_1 = 5/\tan\theta = 4.717\,km.$$

Point - to - point prediction model (Lee Model)

The point-to-point model can be obtained in three steps:

1) Generate a standard condition
2) obtain a area to area prediction model
3) obtain a mobile point to point model using area to area model as a base.

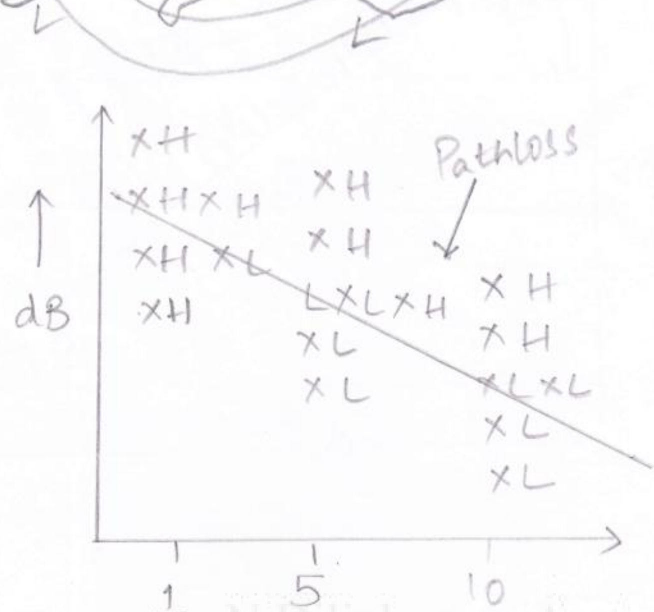
The purpose of developing these models is try to seperate two effects, one caused by Natural terrain contour & the other by Human made structures in the received signal strengths.

Standard Condition:-

To generate the standard condition, transmitted power & antenna ht. at base station and mobile unit should satisfy the following requirements:-

Standard Condition.	Correction factor.
At the Base station.	
Transmitted power $P_t = 10W$ (40dBm)	$\alpha_1 = 10 \log \frac{P_t'}{10}$
Antenna ht. $h_1 = 100ft$ (30m)	$\alpha_2 = 20 \log \frac{h_1'}{h_1}$
Antenna gain $g_t = 6dB$/dipole	$\alpha_3 = g_t' - 6$
At the mobile unit.	
Antenna ht. $h_2 = 10ft$ (3m)	$\alpha_4 = 10 \log \frac{h_2'}{h_2}$
Antenna gain, $g_m = 0dB$/dipole.	$\alpha_5 = g_m'$

Obtain Area to Area prediction Curves for Human made structures:-



The performance of area to area prediction can be represented by two parameters.

(i) 1-mi intercept point.

(ii) The path loss slope.

The 1-mi intercept signifies power received at a distance 1-mi from the transmitter. The 1-mi intercept point depends upon the effective antenna height gain.

Therefore, AG = Effective antenna - Height gain

$$= 20 \log \left(\frac{h_e}{h_1} \right)$$

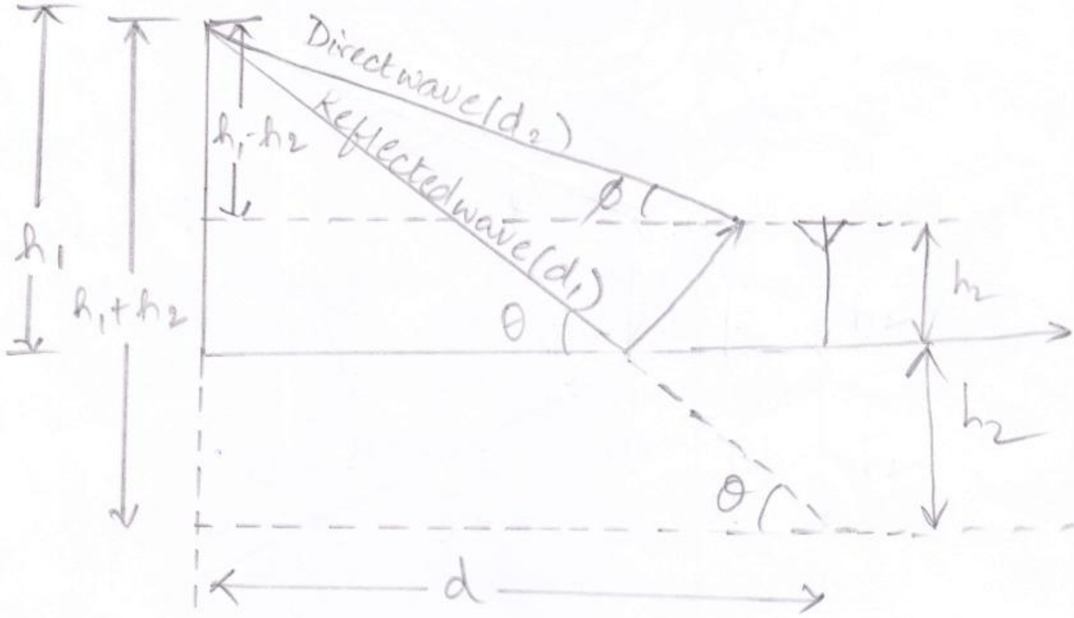
where,

h_e = effective antenna height

h_1 = Actual height.

Phase difference between Direct & Reflected Paths (Two-Ray Ground Model)

The structure of a mobile environment is shown below.



The received power 'P_r' is given by

$$P_r = P_0 \left[\frac{1}{4\pi d/\lambda}\right]^2 |1 + a_v e^{j\Delta\phi}|^2$$

where,

P_0 = Transmitted power

d = Maximum coverage distance.

a_v = Reflection coefficient.

$\Delta\phi$ = The phase difference between direct path and reflected path.

λ = Wave length.

We Know that,

$$e^{j\theta} = \cos\theta + j\sin\theta$$

a = -1 for mobile environment.

Therefore, equation can be rewritten as

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 |1 - \cos\Delta\phi - j\sin\Delta\phi|^2$$

$$P_r = P_0 \frac{1}{(4\pi d/\pi)^2} |(1-\cos\Delta\phi)(j\sin\Delta\phi)|^2$$

We know that from algebra,

$$|a - jb| = |a + jb| = \sqrt{a^2+b^2}$$

$$\therefore |(1-\cos\Delta\phi) - j(\sin\Delta\phi)|^2 = \left(\sqrt{(1-\cos\Delta\phi)^2 + (\sin\Delta\phi)^2}\right)^2$$

$$= \left(\sqrt{1 - 2\cos\Delta\phi + (\cos^2\Delta\phi + \sin^2\Delta\phi)}\right)^2$$

$$= \left(\sqrt{1 - 2\cos\Delta\phi + 1}\right)^2$$

$$= \left(\sqrt{2 - 2\cos\Delta\phi}\right)^2$$

$$= (2 - 2\cos\Delta\phi)$$

$$= 2(1 - \cos\Delta\phi)$$

Therefore, by substituting this value in equation, we get,

$$\therefore P_r = P_0 \cdot \frac{2}{\left(\frac{4\pi d}{\lambda}\right)^2}(1-\cos\Delta\phi)$$

$$= P_0 \cdot \frac{2}{(4\pi d/\lambda^2)}\left[1-\left(1-2\sin^2\frac{\Delta\phi}{2}\right)\right]$$

$$\Rightarrow P_r = P_0 \frac{4}{(4\pi d/\lambda)^2} \sin^2\frac{\Delta\phi}{2}$$

where,

$\Delta\phi = \beta\Delta d$ and 'Δd' is the path difference, i.e.,

$\Delta d = d_1 - d_2$

But from the figure,

$d_1 = \sqrt{(h_1+h_2)^2+d^2}$

$d_2 = \sqrt{(h_1-h_2)^2+d^2}$

and also Δd is much smaller than d_1 and d_2

$$\therefore \Delta\phi = \beta\,\Delta d = \frac{2\pi}{\lambda}\cdot\frac{2h_1h_2}{d}$$

$$\Delta d = d_1 - d_2 \approx \frac{2h_1h_2}{d}$$

Then the received power from equation becomes,

$$P_r = P_0 \frac{4\cdot\lambda^2}{(4\pi^2)d^2} \sin^2\frac{4\pi h_1 h_2}{2\lambda d}$$

If $\Delta\phi$ is very small then, $\sin\left(\frac{\Delta\phi}{2}\right) \approx \left(\frac{\Delta\phi}{2}\right)$

$$\Rightarrow P_r = P_0 \cdot \frac{4}{16\pi^2(d/\lambda)^2}\left(\frac{2\pi h_1 h_2}{2\lambda d}\right)^2$$

$$= P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

$$\therefore P_r = P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

where, 'd' is maximum coverage distance & is given by,

$$d = \sqrt{\frac{h_1 h_2}{(P_r / P_0)^{1/2}}}$$

from equation, we can deduce two relationships,

1) $\Delta P = 40 \log_{10} \frac{d_1}{d_2}$ (a 40 dB/dec path loss).

Where, ΔP is the power difference in decibels between two different path lengths.

2) $\Delta G = 20 \log_{10} \frac{h_e}{h_1}$

where

h_1 = Height of cell site antenna.

h_2 = Effective antenna height.

$\approx (h_1 + h_2)$ and

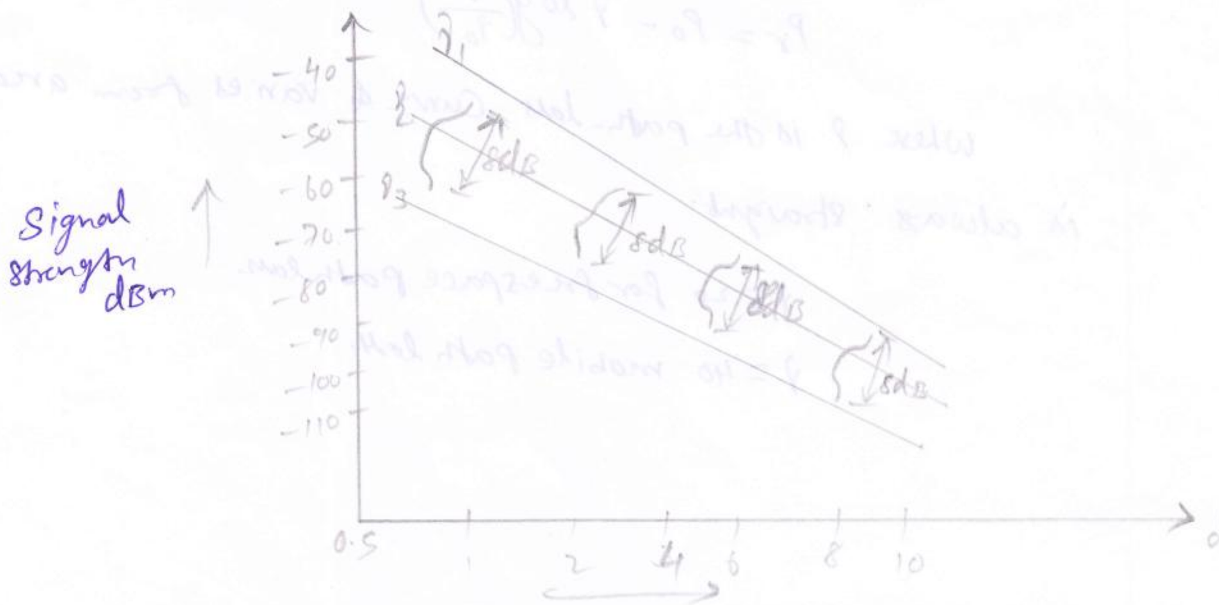
'ΔG' is the gain in decibels obtained from two different antenna heights at the cell site.

Constant Standard Deviation:-

The plot of signal strength at different points in a radio-path distance is 8dB deviated from predicted values & the deviation is true for several areas. This happens due to the following reasons.

The direct wave & the reflected wave are very strong, if there is a line of site path & the two waves are weak, if there is a out of site path.

As considered to theoretical model, there is a 40dB/dec path loss for both the cases. The only difference b/w the two is the 1mi intercept point. The 1-mi intercept has different different values for urban & open area, the value is high for open area & low for urban area. The std. deviation on the other hand is independent of environment & it remains same for different path loss curves.



Distance from Transmitting antenna.

The std. deviation from measured data along the prediction path is 8 dB. It remains Constant at 8 dB, independent of Signal Strength.

Straight line path – Loss Slope:-

The path loss curves can be measured in different areas. But the Complexity in the measurent of path loss depends on the uniformity in distances between the mobile unit & the base station.

If the distances of radio propagation paths from cell sites & the mobile are equal, then the measured signal strength for that distance can be used for calculating the avg. value of path loss.

In a terrain Contour that is not flat, it is observed that the path loss deviation is 8dB for a distance of 1.6 Km to 15 Km. The graph measured is a uniform.

The power received is,

$$P_r = P_0 - \gamma \log\left(\frac{r}{r_0}\right)$$

Where γ is the path-loss curve & varies from area to area, but is always straight.

$\gamma = 20$ for freespace path loss

$\gamma = 40$ mobile path loss.

General Formula for Mobile Radio propagation:-

The general formula for mobile radio propagation path-loss, assuming a suburban area, The 1-mi intercept level in a suburban area is ~~−61.7 dBm~~ −61.7 dBm under standard suburban area conditions:

$$\text{Gain } \Delta G = 20 \log\left(\frac{h_1'}{h_1}\right)$$ {An antenna height gain of 6 dB/oct} {Cell site}

$$\Delta G' = 10 \log\left(\frac{h_2'}{h_2}\right)$$ {An Antenna ht gain of 3 dB/oct} {Effective antenna / Mobile unit}

Received power,

$$P_r = P_0 - \gamma \log\left(\frac{r}{r_0}\right)$$

The received power at the Suburban area is,

$$P_r = (P_t - 40) - 61.7 - 38.4 \log\left(\frac{r}{1mi}\right) + 20 \log\left(\frac{h_1}{100ft}\right) + 10 \log\left(\frac{h_2}{10ft}\right) + (G_t - 6) + G_m$$

$$P_r = P_t - 157.7 - 38.4 \log(r) + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

Where, P_t is in dB above 1mW, r is in miles, h_1 & h_2 are in feet, & G_t & G_m are in dB. The above eq. is used in suburban areas. By using P_r at 10 mi as a reference, which is −100dBm, the eq. can be changed into a general formula.

$$P_r = P_t - 156 - 40 \log r_0 + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

The most general formula is,

$$P_r = P_t - K - \gamma \log r_0 + 20 \log h_1 + 10 \log h_2 + G_t + G_m.$$

Where, $P_r = P_t - K$ at $r = 1$ mile, $h_1 = h_2 = 1ft$ & $G_t = G_m = 0dB$.

The values of K & γ are different & are to be measured in different human made environments.

Propagation over water (or) Flat open area:-

Propagation of mobile signals over water or flat open area leads to interference of cells, if they are not properly arranged. This interference can be avoided if the cause is known. The relative permittivity (ϵ_r) is same for different types of water i.e., it is same for fresh water & sea water but conductivity is different for both water.

The dielectric constant ϵ_c, relative permittivity (ϵ_r) & the conductivity (σ) are related as,

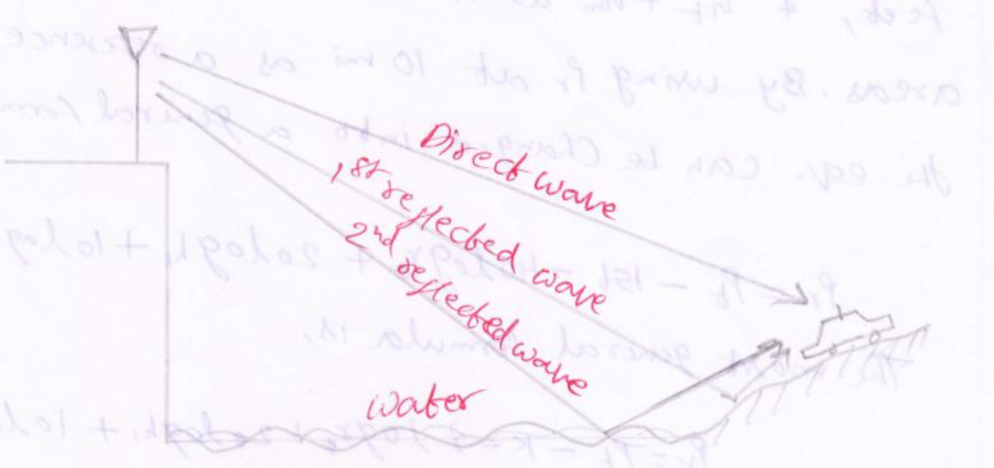
$$\epsilon_c = \epsilon_r - j60\sigma\lambda.$$ where $\lambda \rightarrow$ wavelength,

At 850 MHz 'λ' is 0.35m.

$$\therefore \epsilon_{c\,(seawater)} = 80 - j84.$$

$$\epsilon_{c\,(freshwater)} = 80 - j0.021.$$

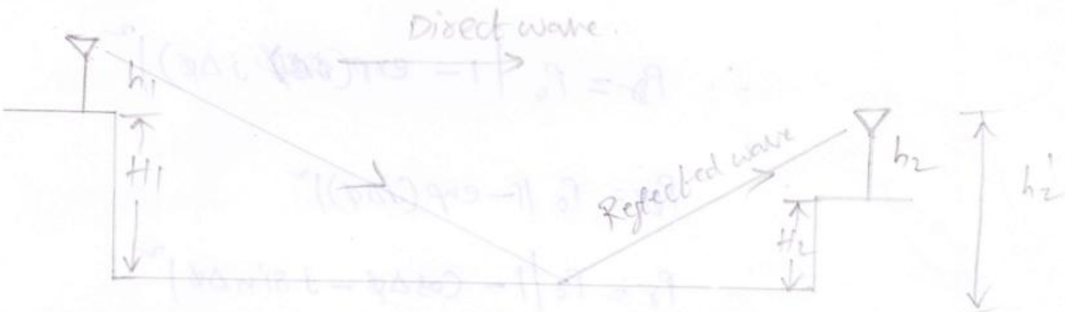
According to the formula of reflection co-efficients, with small incident angles the magnitude of reflection coefficients of both horizontally & vertically polarized waves comes close to '1'. But are opposite in sign due to 180° phase change at the ground reflection point.



A model for propagation over water.

The figure shows, two antenna, one at mobile unit & the other at cell site. These antenna are above the sea level, hence the reflection points are generated. One of the reflected points is close to the mobile unit & the other is reflected from water surface & is a bit away from the mobile unit. The reflection point near to the mobile unit, is the one to be considered always. Now we can calculate the formula to find field strength for point to point transmission & land to mobile transmission over flat open area or water.

Between fixed stations :-



The point to point transmission between two stations over flat area or water as follows, the received power,

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^2 \left|1 + a_v e^{-j\phi_v} \exp(j\Delta\phi)\right|^2 \longrightarrow ①$$

where,

a_v = Amplitude reflection co-efficient

ϕ_v = phase of a complex reflection co-efficient

λ = wave length.

d = distance b/w two stations.

$\Delta\phi$ = phase distance.

$$\Delta\phi = \beta\Delta d = \frac{2\pi}{\lambda} d.$$

In eq. ① the first part represents the free space loss with a 20 dB/dec slope for every 1 to 10 km.

i.e., $P_0 = \frac{P_t}{(4\pi d/\lambda)^2}$

The $a_v e^{-j\phi_v}$ are the Complex reflection coefficients, which can be determined,

$$a_v e^{-j\phi_v} = \frac{\epsilon_c \sin\theta_1 - (\epsilon_c - \cos^2\theta_1)^{1/2}}{\epsilon_c \sin\theta_1 + (\epsilon_c - \cos^2\theta_1)^{1/2}}$$

If the vertical incidence is small then θ is also very small.

This results in,

$$a_v = -1, \quad \phi_v = 0.$$

$$\therefore P_r = P_0 \left| 1 - \exp(j\Delta\phi) \right|^2$$

$$P_r = P_0 \left| 1 - \exp(j\Delta\phi) \right|^2$$

$$P_r = P_0 \left| 1 - \cos\Delta\phi - j\sin\Delta\phi \right|^2$$

$$\vdots$$

$$P_r = P_0 (2 - 2\cos\Delta\phi)$$

To determine $\Delta\phi$, we need to first find out Δd,

$$\Delta d = d_1 - d_2$$

$$d_1 = \sqrt{(h_1' + h_2')^2 + d^2}$$

$$d_2 = \sqrt{(h_1' - h_2')^2 + d^2}$$

$$\Delta d = \frac{2h_1'h_2'}{d} \text{ (Approx. value) when } d \gg h_1' \,\&\, h_2'$$

$h_1' = h_1 + H_1$

$h_2' = h_2 + H_2$

where, h_1 = Actual height of Antenna '1'.

h_2 = " " '2'.

H_1 = Height of hill '1'.

H_2 = " " '2'.

Sub. Δd in $\Delta\phi$,

$$\Delta\phi = \frac{2\pi}{\lambda} * \frac{2h_1'h_2'}{d}$$

$$\Longrightarrow \Delta\phi = \frac{4\pi h_1'h_2'}{\lambda d}$$

$\Delta\phi$ can be determined by considering five different conditions,

Case(i):- If the power received is less than the power received in free space i.e., $P_r < P_o$. $\Rightarrow \frac{P_r}{P_o} < 1$.

$$2 - 2\cos\Delta\phi < 1.$$

$$\cos\Delta\phi < \frac{1}{2}$$

$$\Delta\phi < \pi/3.$$

Case(ii):- If the power received is '0' i.e., $P_r = 0$.

$$2 - 2\cos\Delta\phi = 0.$$

$$\cos\Delta\phi = 1.$$

$$\Delta\phi = 0.$$

Case(iii):- If received power is equal to power received in free space i.e.,

$$P_r = P_o.$$

$$2 - 2\cos\Delta\phi = 1.$$

$$\cos\Delta\phi = \frac{1}{2}$$

$$\Delta\phi = \pm\pi/3.$$

Case(iv):- If the received power is greater than received power in freespace,

$$P_r > P_o,$$

$$2 - 2\cos\Delta\phi > 1$$

$$\cos\Delta\phi < \frac{1}{2}$$

$$\pi/3 < \Delta\phi < \frac{5\pi}{3}.$$

Sub. Δd in $\Delta\phi$,

$$\Delta\phi = \frac{2\pi}{\lambda} * \frac{2h_1'h_2'}{d}$$

$$\Rightarrow \Delta\phi = \frac{4\pi h_1'h_2'}{\lambda d}$$

$\Delta\phi$ Can be determined by Considering five different conditions,

Case(i):- If the power received is less than the power received in free space i.e., $P_r < P_0$. $\Rightarrow \frac{P_r}{P_0} < 1$.

$$2 - 2\cos\Delta\phi < 1.$$

$$\cos\Delta\phi < \tfrac{1}{2}$$

$$\Delta\phi < \pi/3.$$

Case(ii):- If the power received is '0' i.e., $P_r = 0$.

$$2 - 2\cos\Delta\phi = 0$$

$$\cos\Delta\phi = 1.$$

$$\Delta\phi = 0.$$

Case(iii):- If received power is equal to power received in free space i.e.,

$$P_r = P_0.$$

$$2 - 2\cos\Delta\phi = 1.$$

$$\cos\Delta\phi = \tfrac{1}{2}$$

$$\Delta\phi = \pm\pi/3.$$

Case(iv):- If the received power is greater than received power in freespace,

$$P_r > P_0,$$

$$2 - 2\cos\Delta\phi > 1$$

$$\cos\Delta\phi < \tfrac{1}{2}$$

$$\pi/3 < \Delta\phi < \frac{5\pi}{3}.$$

Case (v):-

If the received power is four times the power received in free space. i.e., $(P_r = 4P_d)$

$$\Rightarrow 2 - 2\cos\Delta\phi = \text{max.}$$

$$\Delta\phi = \pi.$$

Land to mobile Transmission over water:-

Received power is taken for both water & land reflection points

$$P_r = \frac{P_t}{\left(\frac{4\pi d}{\lambda}\right)^2} \left|1 - e^{j\Delta\phi_1} - e^{j\Delta\phi_2}\right|^2$$

where,

$\Delta\phi_1$ = path length difference b/n direct wave & first reflected wave.

$\Delta\phi_2$ = path length difference b/n direct wave & second reflected wave

$$P_r = P_t\left(\frac{\lambda}{4\pi d}\right)^2 \left|1 - \cos\Delta\phi_1 - \cos\Delta\phi_2 - j(\sin\Delta\phi_1 + \sin\Delta\phi_2)\right|^2$$

$\because$ $\Delta\phi_1$ & $\Delta\phi_2$ are very small,

$\sin\Delta\phi_1 = \Delta\phi_1$ & $\sin\Delta\phi_2 = \Delta\phi_2$.

$\cos\Delta\phi_1 \approx \cos\Delta\phi_2 = 1$

} for land to mobile Transmission over water.

$$P_r = P_t\left(\frac{\lambda}{4\pi d}\right)^2 \left|-1 - j(\Delta\phi_1 + \Delta\phi_2)\right|^2$$

$$= P_t\left(\frac{\lambda}{4\pi d}\right)^2 \left[\sqrt{1^2 + (\Delta\phi_1 + \Delta\phi_2)^2}\right]^2$$

$$= \frac{P_t}{\left(\frac{4\pi d}{\lambda}\right)^2}\left[1 + (\Delta\phi_1 + \Delta\phi_2)^2\right]$$

In most practical cases, $\Delta\phi_1 + \Delta\phi_2 < 1$;

then $(\Delta\phi_1 + \Delta\phi_2)^2 \ll 1$. & it is neglected.

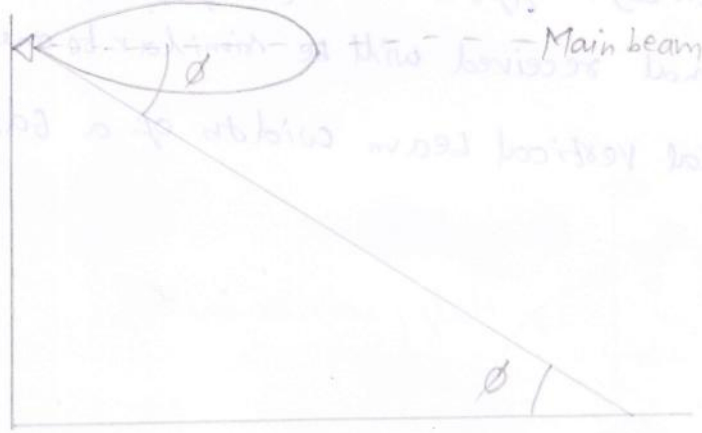
$$\therefore P_r = \frac{P_t}{\left(\frac{4\pi d}{\lambda}\right)^2}$$

Near & Long Distance propagation:-

Propagation in Near-in Distance:-

Why to use a 1-mi intercept?:-

1. With in a 1-mi radius, the antenna beamwidth, especially of a high-gain omni directional antenna, is narrow in the vertical plane. Thus the signal reception at a mobile unit less than 1mi away will be reduced because of large elevation angle which causes the mobile unit to be in shadow region (outside the main beam). The larger the elevation angle, the weaker the reception level due to the antenna's vertical pattern.



Elevation angle of the shadow of the antenna pattern

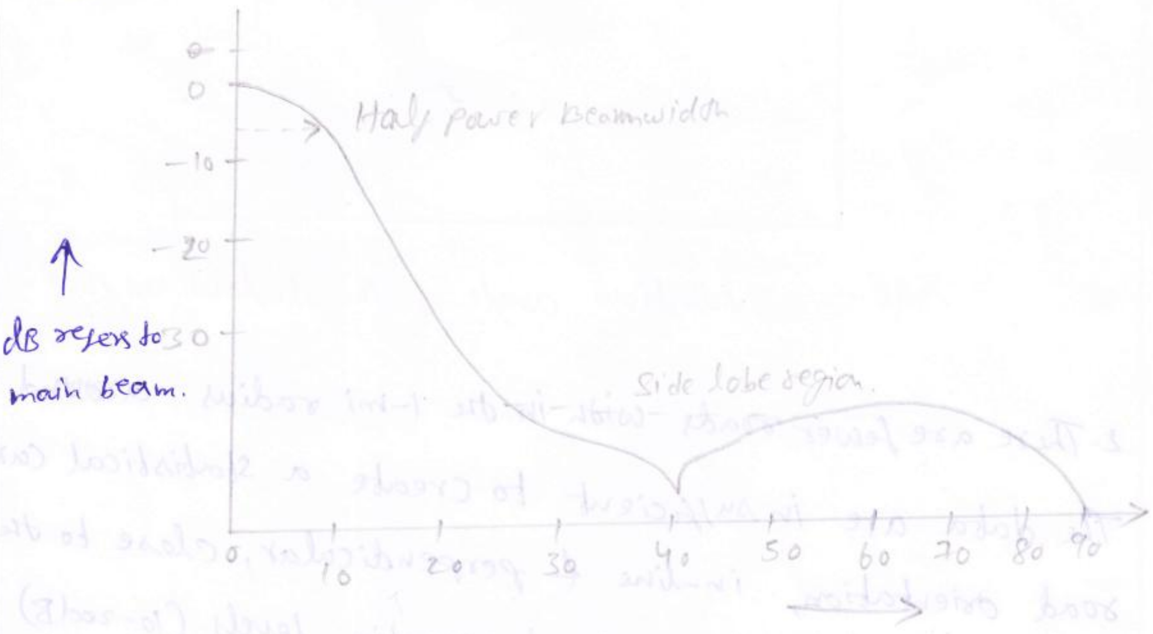
2. There are fewer roads with in the 1-mi radius around the cell site. Also the The data are insufficient to create a statistical curve. Also the road orientation, in-line & perpendicular, close to the cell site can cause a big difference in signal reception levels (10-20dB) on those roads.

3. The near by surroundings of the cell site can bias the reception level either up or down when the mobile unit is with in 1-mi radius. When the mobile unit is 1-mi away from the cell site, the effect due to near-by surroundings of the cell site becomes negligible.

4. For land-to-mobile propagation, the antenna height at the cellsite strongly affects the mobile reception in the field; therefore, mobile reception 1mi away has to refer to a given base station antenna height.

Curves for near-in propagation:-

Let us Consider, the example of a suburban area for investigation of near in distance propagation. If the antenna height is 30m (100ft), the received level at 1mi intercept is 61.7dBm. Further, the antenna ht. increased to 30-60m (100-200ft) & 60m-120m (200-400ft) a 6dB gain is obtained in each instance respectively. After 120m (400ft) if the height is increased then the signal received will be similar to one received in free space. A Typical vertical beam width of a 6dB omnidirectional antenna.



Antenna height h_1, m(ft)	Elevation angle ϕ (degrees)	Incident angle θ (degrees)	Attenuation α(dB)
30	10.72	11.77	6
60	20.75	21.61	16
90	29.6	30.4	21

At a mobile antenna height of 30m (100ft) & distance d' as 100m (328 ft) the elevation angle & the incident angle are 10.72° & 11.77° respectively. Here the incident angle becomes high, hence the 40dB/dec is invalid at this point. If the antenna beam is aimed at mobile unit then we will have following observations,

24 dB/dec slope for an antenna height of 30 mt,

22 dB/dec " 60mt,

20dB/dec " 120mt.

$$\Delta \phi = \frac{4\pi h_1 h_2}{\lambda d}$$

The near field d_N can be obtained by equating the path difference $\Delta\phi = \pi$,

$$\Delta \phi = \frac{4\pi h_1 h_2}{\lambda d} = \pi$$

$$d_N = \frac{4 h_1 h_2}{\lambda}$$

For best approximation, the signal received out side the field i.e., $(d > d_N)$, the mobile radio path loss formula can be used,

$$P_r = P_t - 157.7 - 38.4 \log r + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

If the signal received is with in the field i.e., $(d < d_N)$ then the free space loss formula is used.

$$P_r = \frac{P_t}{\left(\frac{4\pi d}{\lambda}\right)^2}$$

Long distance propagation:-

The high cell site has an advantage that it can cover the signal in large areas. It can even cover the signal in a noise limited system where several frequencies are repeatedly used in different areas. But as the traffic increases the noise limited system tends to be an interference limited system.

With in a 50-mi Radius:-

For a high site the propagation path of a ground wave is not a straight line. This is usually noticed more on sea water since, the situation of atmosphere over the ocean is varied depending on the variations in altitudes. The wave path can bend either upward or downward and can be observed that the signal is strong at one time & weak at another time.

At a distance of 320km:-

For long distance propagation, the tropospheric wave propagation proves more powerful at 800MHz. The signal can even reach 200 mi(320km) away. The reception of wave so far is due to sudden changes in the effective dielectric constant of troposphere. The dielectric constant usually varies with temperature.

The temperature is inversely proportional to height & hence, changes at 6.5°C/km. The temperature at the upper boundary of troposphere is -50°c.

There are three ways in which a tropospheric wave is (11)

divided,

1) Tropospheric reflection.
2) Tropospheric refraction.
3) Moisture.

1) Tropospheric Reflection:-

When the dielectric Constant of the atmosphere changes suddenly then tropospheric reflection takes place. Here the distance of propagation is much greater than line of sight propagation.

2) Tropospheric Refraction:-

The ray gradually bends itself at the point, where the effective dielectric constant changes suddenly. This phenomena is known as tropospheric refraction.

3) Moisture:-

The dielectric Constant of atmosphere is much effected by water Content when Compared to temperature. Similar to temperature the water vapour pressure decreases with increase of height.

Another effect which occurs during propagation is duct propagation or trapping. This occurs due to decrease in refractive index with height. In trapping Condition the ray will be curved ~~towa~~ downwards.

Two types of ducts:- Surface duct & Elevated duct.

Surface ducts are 1.5 m thick and are found over the seas. They are even found on surface of earth due to cooling air. Elevated ducts are due to large air masses. They vary in thickness from few feets to thousand feets & are found at an elevation of 1000 to 5000 fts.

Tropospheric propagation is a common factor those causing interference & can be reduced by employing umbrella antenna beam pattern, low power low antenna most approach or a directional antenna pattern.

Antenna Height gain:-

The different steps involved in finding antenna height gain are,

1) The first step is to find reflection point. It takes two steps to calculate a reflection point.

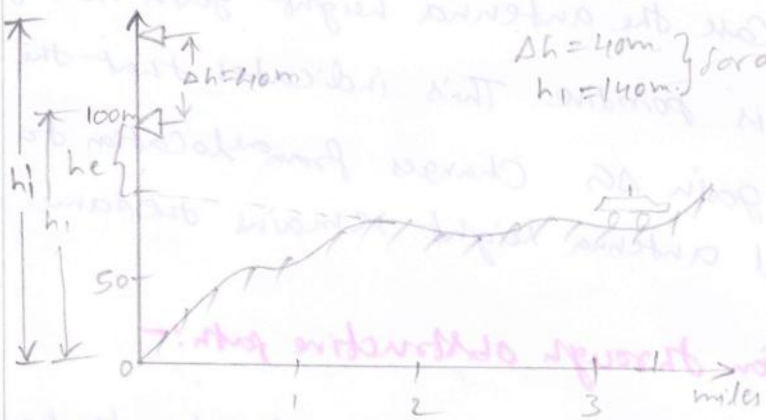
i) By connecting the image antenna of cell site antenna with the mobile antenna, the point of intercept at the ground level is considered as the potential reflection point.

ii) By connecting the image antenna of mobile antenna with the cell site antenna, the point of intercept at the ground level is also considered as the potential reflection point.

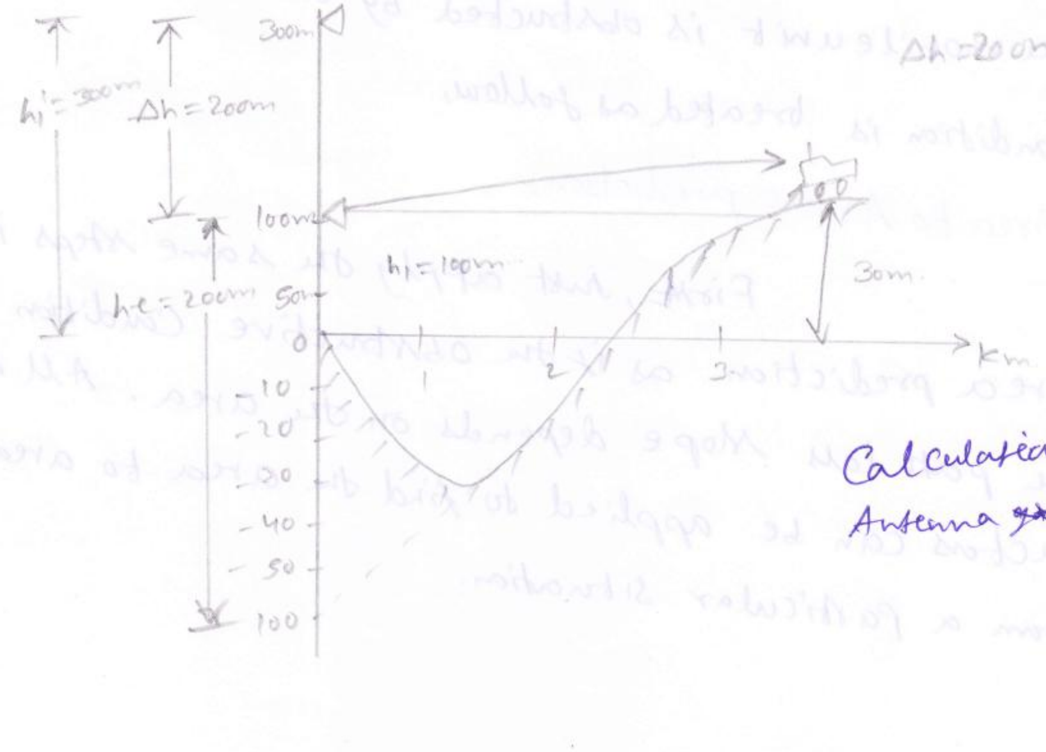
Among the two reflection point calculated above, the one closest to the mobile unit is selected as the real reflection point because it can reflect more signal energy to the mobile unit

2) The second step is to extend the reflected ground plane to the location of cell site antenna. First, the reflected ground plane is determined by drawing a tangent line to the ground curvature point, further extend the reflected ground plane.

3) The third step is to find effective antenna height. It can be calculated at the point where the cell site antenna location & reflected ground plane meet. The calculation of effective antenna heights in two cases.



Calculation of Effective Antenna height in case1.



Calculation of Effective Antenna height in case2.

In the first case, the effective antenna height he is 40cm & in the second case it is 200m

4) The final step is to calculate the antenna height gain. It is represented as ΔG,

$$G = 20 \log \frac{h_e}{h_1}$$

Case(i):- $\Delta G = 20 \log \frac{40}{100}$

$\Delta G = -8 dB.$

Case(ii):- $\Delta G = 20 \log \frac{200}{100}$

$\Delta G = 6 dB.$

In first case the antenna height gain is negative & in the second case it is positive. This indicates that the effective antenna height gain ΔG changes from one location to another, but the physical antenna height remains the same.

Mobile propagation through obstructive path:-

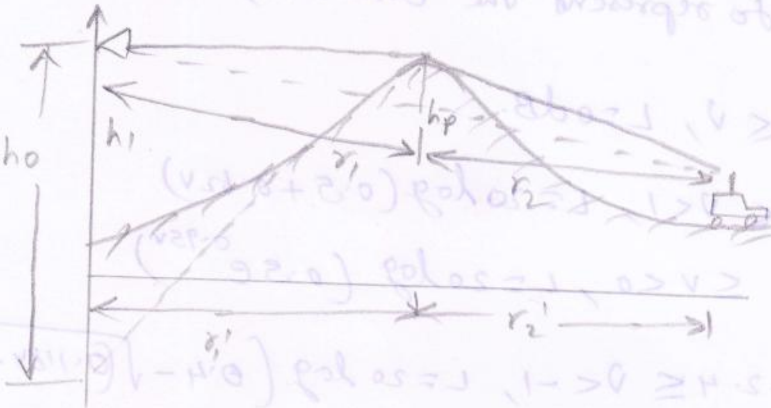
In the obstructive condition the direct path from cell site to the mobile unit is obstructed by the terrain contour. This condition is treated as follows,

i) Area to Area prediction:-

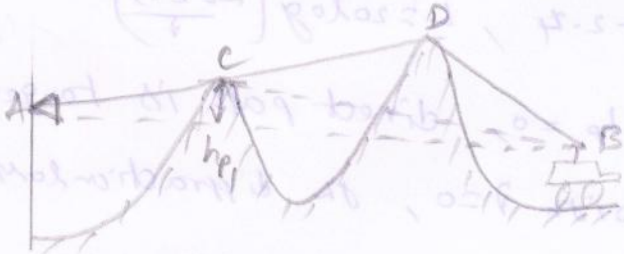
First, just apply the same steps in the area to area prediction as if the obstructive condition does not exist. The path loss slope depends on the area. All the correction factors can be applied to find the area to area prediction from a particular situation.

2) Obtain the Diffraction loss:-

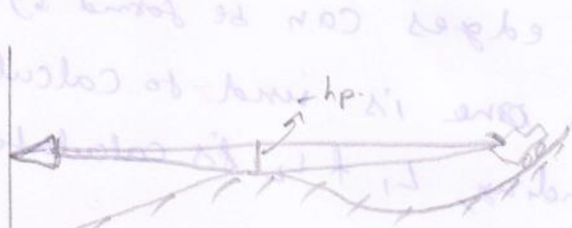
The diffraction loss can be found from a single knife edge or a double knife edge.



hp → is +ve



Diffraction loss due to the obstructive conditions are single knife-edge, double knife-edges & non-clear path.



hp is -ve.

i) Four parameters for a single knife edge case:

r_1 → Distance from knife edge to cell site.

r_2 → " " to mobile unit.

hp → Height of knife edge.

λ → operating wave length.

All are related as,

$$v = -hp\sqrt{\frac{2}{\lambda}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)}$$

As soon as the value of 'v' is obtained, the diffraction loss 'L' can be found from the shadow loss prediction curves. The approximate formula given, with different values of 'v' to represent the curve is,

$1 \leq v, \ L = 0 \, dB.$

$0 \leq v < 1, \ L = 20 \log (0.5 + 0.62 v)$

$-1 \leq v < 0, \ L = 20 \log (0.5 e^{0.95 v})$

$-2.4 \leq v < -1, \ L = 20 \log \left(0.4 - \sqrt{(0.1184 - (0.1 v + 0.38)^2)}\right)$

$v < -2.4, \ L = 20 \log \left(\frac{-0.225}{v}\right)$

when $h_p = 0$, direct path is tangential to the knife edge & $v = 0$. with $v = 0$, the diffraction loss, $L = 6 \, dB$.

ii) Two knife edges can be formed by the two sides ACB & CDM. Each one is used to calculate v & v_1 & v_2. The corresponding, L_1 & L_2 is calculated. & total diffraction loss, is, $L_t = L_1 + L_2$.

Form of a point-to-Point model:-

General Formula of Lee model:-

The formula of the Lee model can be stated simply in three cases:

1. Direct wave case: The effective antenna height is a major factor which varies with the location of the mobile unit while it travels.
2. shadow case:- No effective antenna height exists, the loss is totally due to knife-edge diffraction loss.
3. over the water condition:- The free space path loss is applied.

The model is formed as follows:

a) for non-obstructive path, the received power,

$$P_r = P_0 - \gamma \log \frac{r}{r_0} + 20 \log \frac{h_e'}{h_1} + \alpha.$$

The term $\left[P_0 - \gamma \log \frac{r}{r_0} \right]$ is due to man made structures,

$\left[20 \log \frac{h_e'}{h_1} + \alpha \right]$ is due to terrain contour.

b) For obstructive path the received power,

$$P_r = P_0 - \gamma \log \frac{r}{r_0} + 20 \log \frac{h_e''}{h_1} + L + \alpha.$$

$$= \underbrace{P_0 - \gamma \log \frac{r}{r_0}}_{\text{human made structure}} + \underbrace{L + \alpha}_{\text{By terrain contour}}. \quad [\text{when } h_e'' \simeq h_1]$$

Observations on general formula of Lee model:-

1. The received power P_r cannot be higher than that from the free-space path loss

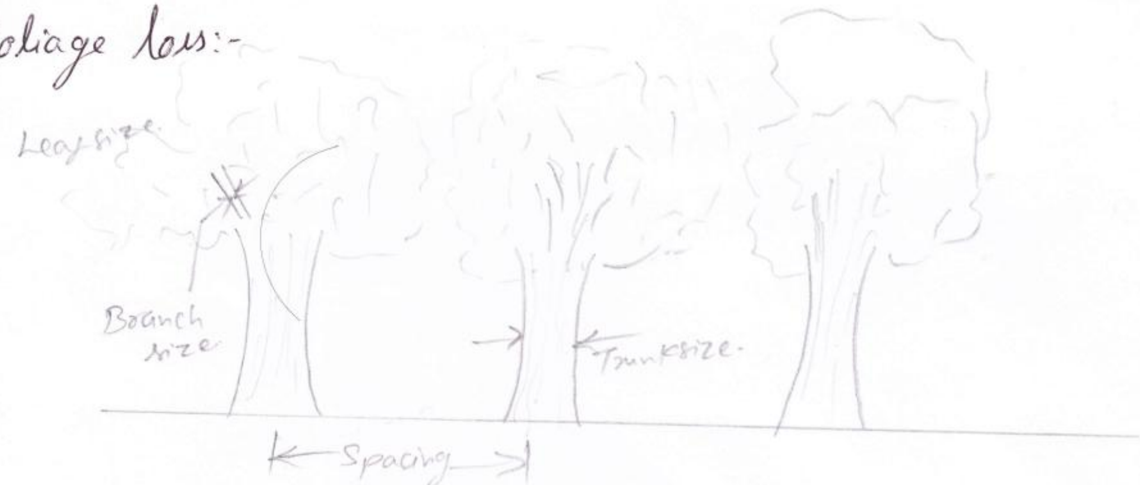
2. The roads orientation, when it is with in 2mi from the cell site, will affect the received power at the mobile unit. The received power at the mobile unit travelling along an in in-line road can be 10 dB higher that along a perpendicular road.

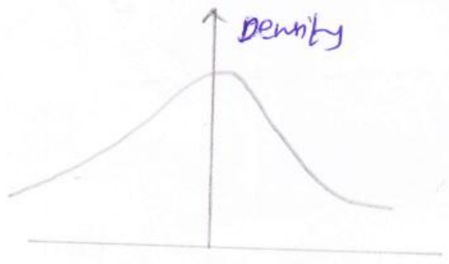
3. α is known as Correction factor it can be obtained from standard Conditions, & it indicates either gain or loss.

4. The foliage loss would be added depending on each individual situation. Avoid choosing a cell site in the forest. Be sure that the antenna height of the cell site is higher than the top of the trees.

5. with in one mile (or one kilometer) in a man-made environment, the received signal is affected by the buildings & street orientations. The macrocell prediction formula [non obstructive path received power equation] cannot be applied in such area.

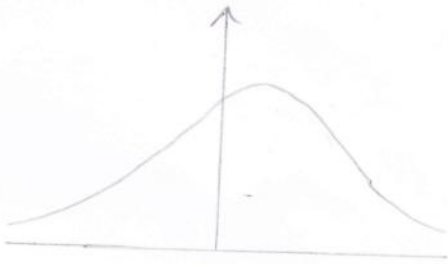
Foliage loss:-





Mean sizes

Distribution of leaves, trunks, or branches



Mean

Distribution of Spacing between adjacent trunks or branches

Oak, maple → fall.

Pine leaves.

A Characteristic of foliage environment