UNIT – I   Cellular & Mobile Communications

Press & Publications

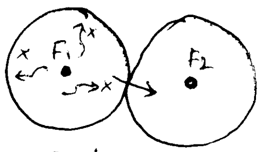
Notice Boards

Introduction to Cellular Mobile Systems :

→ The main reasons for developing a CMC System over a Conventional telephone System has Some of the operational limitations. That they are

a) Limited Service Capability
b) Poor Service performance
c) Inefficient frequency Spectrum utilization

Limited Service Capability :



(i) A Conventional mobile telephone System is usually designed by Selecting one or more channels from a Specific frequency allocation for use in Some ~~Cell zones~~ autonomous geographic zones.

(ii) The Communication 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 ~~possible~~ the FCC allows.

(iii) 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.

Handoff Problem: It 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.

iv) Disadvantage of Conventional Telephone 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 a three mobile Systems.

Mobile Telephone ~~System~~ (MTS) → operates at 40 MHz → Provide 11 Chan

Improved Mobile Telephone ...

IMTS MK System → operates at 450 MHz → provide 12 channels.

In 1976, Newyork City had 6 channels of MJ Serving 320 Customers & 2400 Customers waiting

" " MK Serving 225 Customers & 1300 Customers waiting

∴ So the large number of Subscribers Created a high blocking probability during busy hours. So a high Capacity System for mobile telephones ~~System~~ was needed.

Inefficient frequency Spectrum utilization:

i, In a Conventional mobile telephone System, the frequency utilization measurement M_o is defined as the max number of Customers that Could be Served by one channel at the busyhour.

In 1976, the N.Y City: $M_o = \frac{\text{no. of Customers}}{\text{channel}}$

$$M_o = \begin{cases} 53 \text{ Customers/channel} & (\text{MJ Systems}) \\ 37 \text{ customers / channel} & (\text{MK Systems}) \end{cases}$$

Assume an average Calling time of 1.76 min

The offered load $A = \frac{\text{average Calling time (minuits)} \times \text{Total Customers}}{60 \text{ min}}$ Erlan

$$A_1 = \frac{1.76 \times 53 \times 6}{60} = 9.33 \text{ Erlangs} \quad (\text{MJ System})$$

$$A_2 = \frac{1.76 \times 37 \times 6}{60} = 6.51 \text{ Erlangs} \quad (\text{MK System})$$

Given that the no. of channels is 6 & offered loads are have Blocking Probabil

$A_1 \to 9.33 \to 50\%$ (m

$A_2 \to 6.51 \to 30\%$ (m

→ If the actual average Calling time is greater than 1.76 min the blocking probability Can be higher. To reduce the Blocking probability we must decrease the Value of frequency Spectrum utilization measuremen

→ As far as frequency Spectrum utilization is Concerned, the Conventional System does not utilize the Spectrum Efficiently. Since Each channel

→ Generally Federal Communication Commission (FCC) Seeks Systems which need minimal Bandwidth but provide high usage & Consumer Satisfaction To provide above factors, three major approches be be achieved as

1) SSB, which divides the allocated frequency band into max no. of channels
2) Cellular, which reuses the allocated frequency band in different geographic locations
3) Spread Spectrum, which generates many codes over a wide freq band

→ Microprocessors & MiniComputers are now used for Controlling many Complicated features & functions with less power & Size, reduced Cost showed the technological feasability & affordbabity of Cellular Service.

<u>why 800 MHz for CMC:</u>

→ Federal Communication Commission decision to choose 800 MHz was made because of Severe Spectrum limitations at lower frequency bands.

(i) FM broadcasting is operated at 88 – 108 MHz
(ii) The TV broadcasting is operated between 40 MHz – 960 MHz
(iii) Air to ground Systems use 118 to 136 MHz
(iv) Military aircraft use 225 to 400 MHz.
(v) The maritime mobile Service is located in the vicinity of 160 MHz.

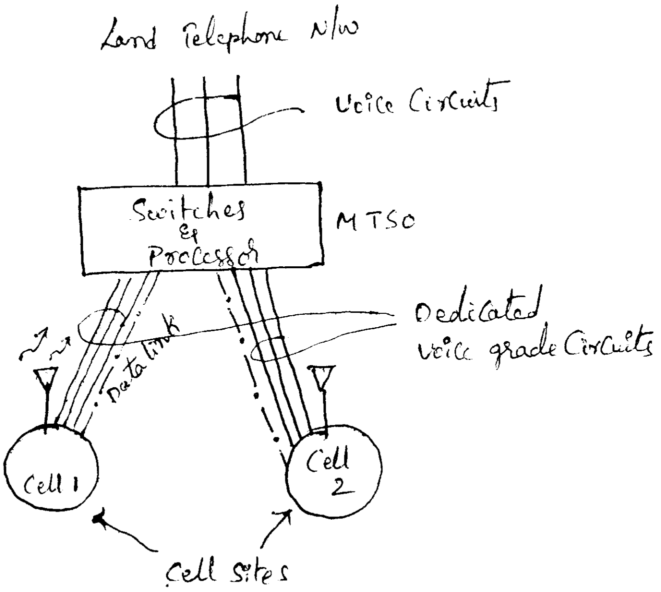
on the other hand mobile radio Communications Cannot be applied at 10 GHz & above because Severe propagation path losses, multipath fading, & rain activity make the medium improper for mobile Communications.

Originally 800 MHz is assigned to Educational TV Channels. when Cable TV became a big factor in the mid 70's and shared the burden of Providing TV channels. and This Situation opened up the 800 MHz System to mobile radio Cellular Systems.

→ A Basic Cellular System :

A basic Cellular System Consists of three parts

a) a mobile unit
b) a Cell site
c) a mobile Telephone Switching office (MTSO)



Mobile units : A mobile telephone unit Contains a Control unit, a transceiver and an antenna System

Cell site : The Cell site provides interface between MTSO & the mobile unit. It has a Control unit, radio Cabinets, antennas, Power plant and data terminals.

MTSO : The Switching office, It is the Central Co-ordinating Element for all Cell sites, Contains the Cellular processor & Cellular Switch. It interfaces with telephone Company zone offices, Controls Call Processing & handles billing activities. It is the heart of cellular mobile System. MTSO processor provides Central Co-ordination & Cellular administration.

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.

→ The Cellular Switch, which Can be Either analog or digital, Switches Calls to Connect mobile Subscribers to other mobile Subscribers & to the nationwide telephone network.

→ Cellular Switch uses Voice trunks Similar to telephone Company interoffice voice trunks. It also Contains datalinks providing Supervision links between the processor & the Switch and between the Cell Sites & the processor.

The radio link Carries the voice and Signalling between the mobile unit and the Cell site.

Performance Criteria: There are 3 Catagories for Specifying Performance Criteria

a) Voice quality
b) Service quality
c) Special features

Voice quality: In this technical area Engineers we Can't 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 Some following Criteria

→ A set value 'x' at which 'y' percent of Customers rate the System Voice quality (from Tx'er to Rx'er) as good or Excellent, the top two Circuits merits (cm) of the five listed below.

cm	Score	Quality Scale
cm5	5	Excellent (Perfectly speech understandable)
cm4	4	Good (Some noise)
cm3	3	Fair (occasional repetions needed)
cm2	2	Poor
cm1	1	Unsatisfactory

→ As the percentage of Customers choosing cm5, cm4 increases the Cost of the building 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:

i) Coverage: The System Should Serve an area as large as possi with radio Coverage, however because of irregular terrain Configurat it is usally not practical to Cover 100% of the area for two reaso

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 transmitted power, the harder it becomes to control interference.

→ Therefore the system usually to cover 90 % of an area in flat terrain & 75% in hilly terrain

→ The combined voice quality & coverage criteria in a cellular system states that 75% of users rate the voice quality b/w good & excellent in 90 % of served area i,e flat terrain

→ In hilly terrain 90% of customers users must rate voice quality good or excellent in 75%.

→ A system operator can lower the percentage values states 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 (2%) for initiating calls at busy hour. This is an average value. If the B.P is higher than 2%. Especially when car accidents occur at such certain cell sites

→ To decrease the blocking probability requires a good system plan & a sufficent number of radio channels.

3) Number of dropped calls : During 'Q' calls in a hour, if a call is droped & Q-1 calls are completed. then the call drop rate is 1/Q. The drop rate must be kept low.

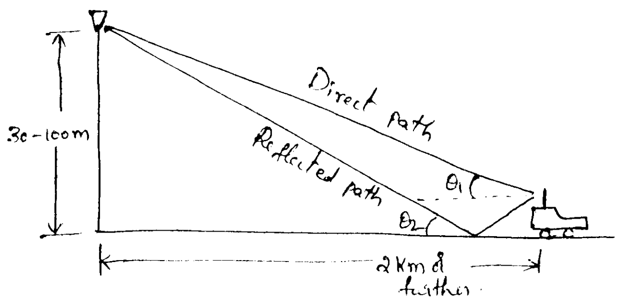
→ A high drop rate may cause by either coverage problems or hand off problems related to inadequate channel availability

Special features : A system would like to provide as many special features as possible like
a) Call forwarding
b) Call waiting
c) Voice stored box.
d) Automatic roaming & Navigation services.

However some times the customers may not be willing to pay extra charges for these special features.

Uniqness of Mobile Radio Environment:

Mobile Radio Tx'on Model:



- In general the propagation path loss increases not only with frequency but also with distance
- If the antenna hight at cell site is 30-100 m & the mobile unit about 3 m & the distance b/w cell site & the mobile unit is usually 2Km or more, then the incident angles of both the direct wave & the reflected wave are very small.
- The incident angle of direct wave is θ_1 & incident angle of reflected wave is θ_2. Here θ_1 is also called the elevation angle
- The propagation path loss would be 40 dB/dec, ie 40 dB loss at a singleal receiver will be observed by the mobile unit as it moves from 1 to 10 Km.

$\therefore$ C is inversely propotional to R^4

$$C \propto R^{-4} = \alpha R^{-4}$$

Here C is received carrier power

R is distance measured from Tx'er to Rx'er

α is constant.

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

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

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

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

when $R_2 = 2R_1$

$\Delta C = -12$ dB

when $R_2 = 10 R_1$

$\Delta C = -40$ dB

- The 40dB/dec is general rule for mobile radio environment. & it is also easy to compare to the free space propagation of 20dB/dec.

$$C \propto R^{-2} \quad \text{(free space)}$$

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

$= 20 \log \frac{R_1}{R_2}$ (free space)

∴ → In a real mobile radio environment, the propagation path loss slope varies as $C \propto R^{-\gamma}$

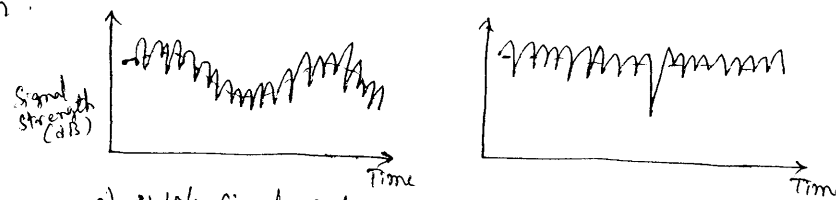
$C = \alpha R^{-\gamma}$

Here γ usually lies b/w 2 to 5 depending on the actual cond & it cannot be lower than 2, which is for free space condition.

The decibel scale expression is: $\boxed{C = 10 \log \alpha - 10 \gamma \log R \quad dB}$

Severe fading: If the antenna hight of the mobile unit is lower than its typical surroundings, and the carrier frequency wavelength is much less than the sizes of surrounding structures; then the multipath waves are generated.

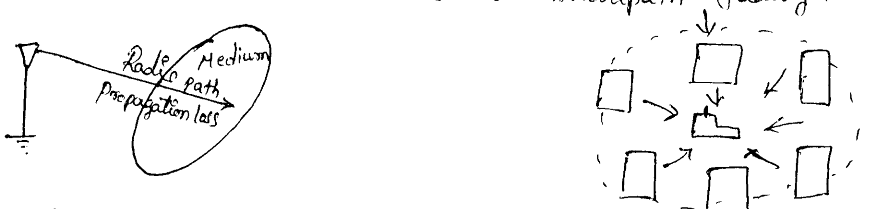
→ At the mobile unit, the sum of multipath causes the signal fading phenomenon.



a) Mobile signal fading b) A short term signal fading

→ when a mobile unit is standing still, its receiver only receives a signal strength at that spot. So a constant signal is observed

→ when a mobile unit is moving, the fading structure of the wave in the space is received. it is multipath fading.



a) propagation loss b) Multipath fading

Delay spread: In the mobile radio environment, as a result of multipath reflections, the signal tried from a cell site & arriving at a mobile unit will be different paths so the lengths are different, & time arrival are different.

→ For an impulse transmitted at cell site, by the time this impulse is received at the mobile unit it is no longer an impulse but rather a pulse with spread width is called Delay spread

Types of Environment	Delay Spread (Δ) in μs
Inside the Building	< 0.1
open area	< 0.2
Suburban area	0.5
Urban area	3

Coherence Bandwidth : The Coherance Bandwidth is defined bandwidth in which either the amplitudes or phases of two received signals have a degree of Similarity

→ The delay spread is a natural phenomenon & Coherence Bandwidth is a defined Criterian related to the delay spread.

→ A Coherence Bandwidth for two fading amplitudes of two received signals is $B_c = \frac{1}{2\pi\Delta}$

→ A Coherence Bandwidth for two random phases of two received Signals is

$$B_c' = \frac{1}{4\pi\Delta}$$

Direct wave path : A direct wave path is a path clear from the terrain Contour.

Line of Sight path : It is a path clear from buildings & when it occurs, the average received signal at the mobile unit at 1 mi intercept is higher, athough the ~~uod~~ path loss slope remains the same

Obstructive path : when the terrain Contour block the direct wave path we Call it as obstructive path.

Noise level in Cellular frequency Band :

→ The thermal noise KTB at a temparature T of 290 k (17°c) & a bandwidth B of 30 KHz is -129 dBm.

→ Assume that the received front end noise is 9 dB & the noise level is -120 dBm.

There are two kinds of manmade noise, Ignition noise generated by the vehicles & the noise generated by 800 MHz Emissions.

K is Boltzman's Constant

& $KT = -174$ dBm/Hz at $T = 290$ k.

The Ignition noise : In the past 800 MHZ was not widely used, therefore the manmade noise at 800 MHZ is merely generated by the vechicles ignition noise. The automotive noise generated at 800 MHZ with a Bandwidth of 30 KHZ.

The 800 MHZ Emission Noise : The 800 MHZ Emission noise Can be measured at an Idle channel in 869 to 894 MHZ region while the mobile receiver is operating on a Car battery in a no traffic spot in a City

→ In this Case no automotive ignition noise is involved & no Cochannel operation is in the proximity of the Idle channel Rx'er.

→ we found that in Some areas the noise level is 2 to 3dB higher than −120 dBm at the Cell Sites & 3 to 4dB higher than −120dB at the mobile Stations.

Amplifier noise : A mobile radio signal is received by a receiving antenna, Either at the Cell site or mobile unit will be amplified by an amplifier. So the signal is affected by amplifier noise.

Assume that the amplifier has an amplifier power gain g.

available noise power at the output is N_o

I/P SNR is P_s/N_i

o/P SNR is P_o/N_o

Internal amplifier Noise is N_a

then the output

$$\frac{P_o}{N_o} = \frac{g P_s}{g(N_i) + N_a} = \frac{P_s}{N_i + (N_a/g)}$$

$$\text{Noise figure} = \frac{\text{Max Possible S/N Ratio}}{\text{Actual S/N Ratio at o/P}}$$

$$F = \frac{P_s / KTB}{P_o/N_o} = \frac{N_o}{(P_o/P_s)\, KTB}$$

$$F = \frac{P_s / KTB}{P_s / [N_i + N_a/g]} = \frac{N_i + (N_a/g)}{KTB}$$

∴ The noise figure is a reference measurement between a minimum noise level due to thermal noise & noise level generated by both the External & internal noise of an amplifier.

→ peration of Cellular Systems :

The operation can be divided into four parts and a Hand off Procedure

a) Mobile unit utilization
b) Mobile originated call
c) Network originated call
d) Call termination
e) Handoff Procedure.

a) Mobile unit utilization :

→ when a user sitting in a car activates the receiver of mobile unit, the receiver scans some channels which are designated among the total channels. It then selects the strongest & locks for a certain time.

→ The locking strongest setup channel usually means selecting the nearest cell site. It is called self location scheme.

→ The advantage is it eliminates the load on the Tx'on at the cell site for locating the mobile unit

→ The disadvantage is that no location information of idle mobile unit appears at each cell site.

→ So in future when land line originated calls increases a feature called "Registration" can be used.

b) Mobile originated Call :

→ The user places the called number into the mobile unit after chec whether the number is correct & pushes the 'Send' button.

→ A request for service is sent on a selected setup channel obtai from a selflocation scheme

→ The cell site receives it and selects the best directive anten for the voice channel to use

→ At the same time the cell site sends a request to MTSO v a high speed Datalink. The MTSO selects an appropriate vo channel for the call, and the cell site acts on it through the best directive antenna to link the Mobile unit.

c) Network originated Call :

→ A land line party dials a number of mobile unit. The telephone

Company zone offices recognizes that the numbers is mobile & forwards the call to the MTSO.

→ The MTSO sends a paging message to certain cell sites based on the mobile unit number & the search algorithm

→ The mobile unit recognizes its own identification on a strong setup channel locks onto it and responds to the cell site

d) 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

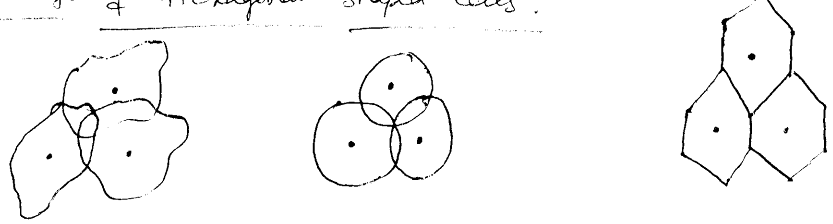
e) Handoff procedure:

→ During the call, 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 handoff system switches the call to a new frequency channel in a new cell site without either terminating the call or alerting the user. The call is continues as long as the user is talking. The user doesnot notice the handoff occurences.

→ Handoff was first used by the AMPS system, then renamed by Handover by the European system.

Marketing Image of Hexagonal Shaped Cells:



Real Ideal Hexagonal Cells

→ we have to realize that hexagonal shaped communication cells are artifici and that such a shape cannot be generated in the real world.

→ Engineers draw hexagonal shaped cell on a layout to simplify the planning & design of a cellular system bcz it approches a circular shape i.e the ideal power coverage area

→ The circular shapes have overlapped areas which makes the drawing unclear. But the hexagonal shaped cells fit the planned area nicely & no gap, no overlap b/w the hexagonal cells.

, anning a Cellular System :

→ For planning a Cellular System we have to determine two elements
a) Regulations
b) Market Situation

Regulations: The federal regulations administrated 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 There are 3 tasks to be handled by marketing dept

(i) prediction of gross income

→ we have to determine the population, average income, business types & business zones so that the gross income can be predicted

(ii) Understanding Competitors :

→ we also need to know the Competitors situation, Coverage, System Performance, and number of Customers

→ Any System should provide a unique & Outstanding Service to overcome the Competition.

(iii) Decision of geographic Coverage :

→ Initiating a cellular mobile service in a given area by Creating a plan that uses minimum no. of Cell sites to Cover the whole area

→ The number of voice channels required to handle the traffic load at the busy hours should be determined

→ Studying the interference problems like Co-channel, adjacent channel interferences, intermodulation products at the Cell sites & finding the ways to reduce them

→ Studying the blocking probability of Each Call at Each cell site & trying to minimize it

→ planning to absorb more new Customers. It depends up on the service charges, System performance, & Seasons of the year.

Trunking efficiency:

→ To Explore the trunking Efficiency degradation, Comparing one Carrier / market and ~~other~~ two/more Carriers /market

→ Compare the trunking Efficiency between one Cellular System per market operating 666 channels & two Cellular systems per market Each operating 333 channels

→ Assume that all frequency Channels are Equally divided into Seven (7) Subareas Called Cells.

In Each cell the blocking probability of 0.02 is assumed. and also the average Calling time is assumed as 1.76 min.

→ From Appendix table

$$N_1 = \frac{666}{7} \Rightarrow 95 \rightarrow \overset{B.P}{0.02} \rightarrow \overset{\text{Offered load}}{A_1 = 83.1}$$

$$N_2 = \frac{333}{7} \Rightarrow 47.5 \rightarrow 0.02 \rightarrow A_2 = 38$$

Since two Carriers Each operating 333 channels are Considered then the total offered load is $2A_2$

$$A_1 \geq 2A_2 \quad \text{—} \quad (1)$$

By Converting Equation (1) the number of users who Can be Served in a busy hour, the avg calling time is 1.76 min. then the number of Calls per hour Served in a Cell Can Expressed as

$$Q_i = \frac{A \times 60}{1.76} \text{ Calls/h.}$$

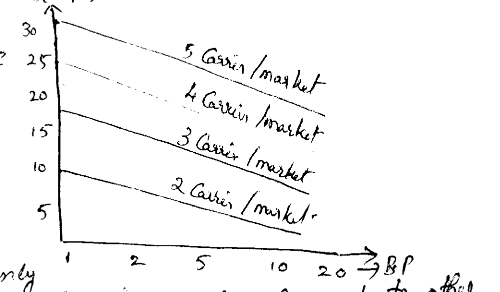
$$Q = \begin{cases} 2832.95 \text{ Calls/h} & (1 \text{ Carrier /market}) \\ 1295.45 \times 2 = 2590.9 \text{ Calls/h} & (2 \text{ Carriers /market}) \end{cases}$$

The trunking Efficiency degradation factor Can be Calculated as

$$\eta_e = \frac{2832.95 - 2590.9}{2832.95} = 8.5\%.$$

→ (i) The degradation of trunking Efficiency decreases as B.P increases

(ii) As the number of Carriers / market increases the degradation increases.



∴ For a 2% B.P, the trunking Efficiency of one Carrier /market does Shows a greater advantage when Compared to other Scenarios

ialog Cellular Systems

→ 1) Cellular Systems in the united states have 150 major market areas and these are licenced by FCC They have been classified by their Population into 5 groups & Each group has 30 Cities

1) 1 – 30 → very large Cities
2) 31 – 60 → large cities
3) 61 – 90 → Medium Cities
4) 91 – 120 → below medium Cities
5) 121 – 150 → Small Cities.

→ 2) Japan: Nippon Telegraph & Telephone Corporation (NTT) developed an 800 mHz land mobile telephone system & put into Service in Tokyo in 1979 The total number of channels was 600 & channel Bandwidth was 25 KHz

→ 3) United Kingdom: In 1982 the united Kingdom announced two Competing national cellular radio networks. The UK System is Called TACS (Total access Communication system). The two Competitors networks ~~are~~ in UK are

Cellnet → 300 Spectral channels → 200 cell sites → Covering 82% of UK
Vodafone started operations late & served same areas as cellnet

→ 4) Canadian System In 1978, a system Called AURORA was designed for the Alberta Government Telephone (AGT)

Aurora 400 System use 400 mHz & does not have a handoff Capabilities
Aurora 800 System use 800 mHz & Implemented Handoff Capability

→ 5) Nordic System: Its frequency is 450 mHz By using the Aurora 800 System they Convert 450 mHz to 800 MHz.

Its bandwidth is 10 mHz which has 200 channels with a bandwi of 25 KHz per channel This System Provides handoff & roaming Capabi They use repeaters to increase the Coverage in a low traffic a

6) France. They operating the Telephones at 160 mHz & Can access the System in 10 regional areas. & no handoff feature

7) Spain uses 450 mHz & introduced in 1982. & it was the fir ~~first~~ Cellular System in Europe. The Channel Bandwidth is 25 KH

8) Australia, Kuwait will operate at 800 mHz & Covering big Cities

Australia uses Ericsson's AXE – 10 Switching N/w
Kuwait uses NEC's Switches & Provides 12 Sites

9) Hong Long has 3 Systems they are United Kingdom, United States, Japanese Systems to provide Cellular Systems

Digital Cellular Systems :

→ In 1992 the first digital Cellular System GSM (Global System for Mobile) was developed in Germany.

GSM is a European Standard System

→ In 1993, an NA-TDMA (North American) System was developed in United States

→ In 1995, CDMA System was developed by United States

→ A Japanese system PDC (Personal Digital Cellular) was deployed in Osaka in 1994.

→ Analog Cellular Systems are limited to using frequency division multiple access Schemes. But Digital Cellular Systems use FDMA, TDMA, CDMA when a multiple access scheme is choosen for a particular System. they offer roaming & i.e Compatibility throughout the outside Continent & interaction with ISDN, which offers the Capability to Extend the Single Subscriber line System to a multiservice System with various Services, which are Currently offered only through Diverse telecommunications network.

Unit - II Elements of Cellular Mobile Radio System Design

→ Based on the Concept of frequency Spectrum utilization, the Cellular mobile radio system design is divided into 5 Elements. They 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 per cell 'Q' in Each Cell site we have to know 1) the Size of the Cell
2) Traffic Conditions

Maximum number of frequency channels per Cell :

The max number of frequency channels per cell N is closely related to an average Calling time. If an Average Calling time $T = 1.76$ min & the max Calls per hour per cell Q, then the offered load $A = \frac{QT}{60}$ Erlang

(

Q1) let the max Calls per hour Q_i in one cell will be 3000 and an average Calling time T be 1.76 min. The blocking probability B is 2 then find the offered load ?

$$A = \frac{Q_i \times T}{60} \text{ Erlangs}$$

$$= \frac{3000 \times 1.76}{60} = 88$$

Q2) If there are 50 channels in a cell to handle ~~the calls~~ all the Calls and the average is 100 s per call with the blocking probability of 2%. then how many Calls Can be handled in this Cell ?

$N = 50$

$B = 2\%$

$T = 100$

The offered load Can be from appendix table is $A = 40.3$

$$A = \frac{Q_i \times T}{60} \text{ Erlangs}$$

The no of Calls per hour in a cell is $\Big\} \rightarrow Q_i = \frac{40.3 \times 3600}{100} = 1451$ Calls per hour.

Q3) If the System has 7 Cell reuse pattern is assumed with the $B = 2\%$, $T = 100$, $N = 50$ then the total number of required Channels for a $K = 7$ reuse System is

$$N_t = 50 \times 7 = 350$$

→ If a large area is Covered by 28 Cells i.e $K_t = 28$ then the total number of Customers $M_t = \sum_{i=1}^{K_t} M_i$ in the System increases.

→ We assume that the number of Subscribers per Cell M_i is related to the percentage of Calls used in busy hours (η_c) and the number of Calls per hour per Cell Q_i as

$$M_i = f(Q_i, \eta_c)$$

Here Q_i is the function of blocking probability B, the average Calling time T, and the number of channels N. then

$$Q_i = f(B, T, N)$$

) Concept of Frequency Reuse channels :

→ Frequency reuse is the Core Concept of Cellular mobile radio System i,e the users in different geographic locations (different cells) may Simultaneously use the Same frequency channel.

→ The frequency reuse Concept increases the Spectrum Efficiency. but if the System is not properly designed then Interference may occur.

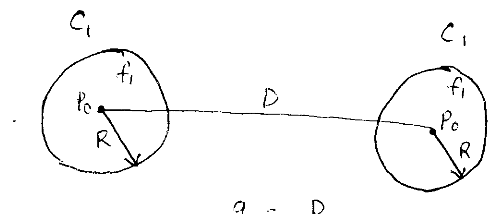
→ Interference due to the Common use of Same channel is Called Co-channel Interference and it is the major Concept in frequency reuse.

→ The frequency reuse Concept Can be used in the time domain & Space domain frequency reuse in time domain results in the Occupation of the Same frequency in different time slots. It is Called TDM

Frequency reuse in the Space domain Can be divided into two Catageries

a) Same frequency assigned in two different geographic areas Such as Am & Fm radio Stations using the Same frequency in different Cities

b) Same frequency repeatedly used in the Same general area in one Cellular System. There are many Cochannels Cells in the System. The total frequency Spectrum allocation is divided into K frequency reuse patterns



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

Frequency Reuse Distance : The minimum distance which allows the Same frequency to be reused will be depends up on

a) The number of Co-channels Cells in vicinity of Center Cell

b) The type of geographic terrain Contour

c) The antenna height

d) The transmitted Power at Each Cell site

The frequency reuse distance D Can be determined from

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

where K is the frequency reuse pattern

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

→ If all the cellsites transmitt the same power, the K increases and the frequency reuse distance D increases.
The increased D reduces the cochannel interference may occur

→ Theoritically a large K is desired, however the total number of allocated channels is fixed. when K is too large, the number of channels assigned in each of K cells become small.
If the total number of channels are divided into two network systems serving in the same area then spectrum inefficiency increases.

→ If we go for smallest number of K then we have to estimating cochannel interference & selecting the minimum frequency reuse dist. D to reduce co-channel interference.

Number of Customers in the System:

while designing a system, we have to know i) the maximum no. of calls per hour per cell is driven by the traffic conditions at each cell

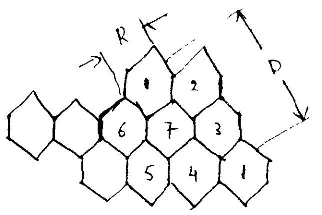
Q: During a busy hour, the number of calls per hour Q_i for Ea of 10 cells is 2000, 1500, 3000, 500, 1000, 1200, 1800, 2500, 2800, 90
Assume that 60 % of calls will be used during this period i.e ($\eta_c = 0.6$). then find the total number of customers in the system

$$Q_t = \sum_{i=1}^{10} Q_i = 17,200 \text{ Calls per hour.}$$

$$\eta_c = 0.6$$

The number of customers in the system is

$M_t = f(Q_i, \eta_c)$ $\qquad M_t = \dfrac{17,200}{0.6} = 28,667$



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

K=7

) Cochannel Interference Reduction Factor :

→ Reusing an identical frequency channel in different cells is limited by Cochannel interference between Cells. we have to kept the minimum frequency reuse distance inorder to reduce the Cochannel interference

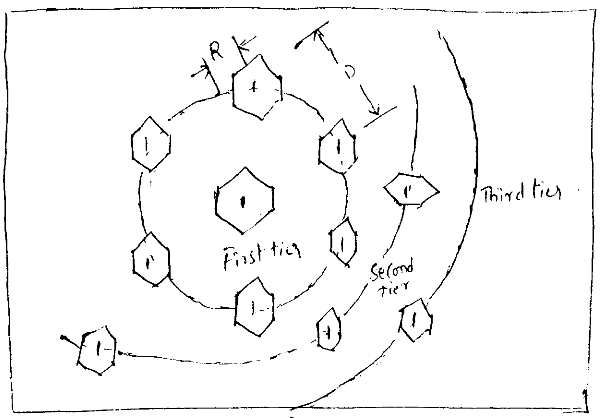
→ Cochannel interference is a function of parameter q defined as

$$q = \frac{D}{R} \quad — ①$$

when the ratio 'q' increases, Cochannel interference decreases. and the frequency reuse distance D is a function of K_I & C/I

$$D = f(K_I, C/I) \quad — ②$$

where K_I is the number of Cochannel interfering cells in the first tier



Six Effective Interfering Cells of Cell 1

C/I is the received Carrier to interference ratio at the desired mobile Receiver

$$\frac{C}{I} = \frac{C}{\sum_{K=1}^{K_I} I_K} \quad — ③$$

→ In a fully Equipped hexagonal shaped Cellular System, there are always Six Cochannel interfering cells in the first tier as shown in figure i.e $K_I = 6$

→ Assume that the local noise is much less than the interference level and Can be neglected then

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{K=1}^{K_I} D_K^{-\gamma}} \quad — ④$$

Here γ is a propagation path loss slope determined by the actual terrain Environment

In mobile radio medium γ is usually assumed to be 4

K_I is the number of Cochannel interfering cells & is Equal to 6 in fully developed System

→ The Six Cochannel interfering cells in the second tier cause weaker interference than those in the first tier. So the second tier of interference cells are negligible

Substituting Eq ① into equation ④

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

$$= \frac{1}{\sum_{K=1}^{K_I} (q_K)^{-\gamma}}$$

where q_K is the cochannel interference reduction factor with Kth cochannel interfering cell $q_K = \frac{D_K}{R}$

3) The Desired Carrier to Interference Ratio:

→ The desired C/I in an omni directional antenna system has two cases

a) The signal & cochannel interference received by the mobile unit

b) The signal & cochannel interference received by the cell site

→ As long as the received carrier to interference ratios at both the mobile unit & the cell site are the same, then the system is called a Balanced System.

→ Assume that all D_K are the same for simplicity then $D = D_K$ & $q = q_K$

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{K=1}^{K_I} D_K^{-\gamma}}$$

$$= \frac{R^{-\gamma}}{6 D^{-\gamma}}$$

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

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

$$q = \left[6 \; C/I\right]^{1/\gamma}$$

The value of C/I is based on the required system performance and the specified value of 'γ' is based on the terrain Environment

→ Since a C/I of 18 dB is measured by the acceptance of voice quality from present cellular mobile receivers

$$q = (6 \times 63.1)^{1/4} = 4.41 \quad — ⑥$$

→ The Bell lab, publication decided that $q = 4.6$ is best for minimum Cochannel interference

$$\therefore \quad q = \frac{D}{R} = 4.6 \quad — (b)$$

Comparing the values of q obtained from above expressions are results very close

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

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

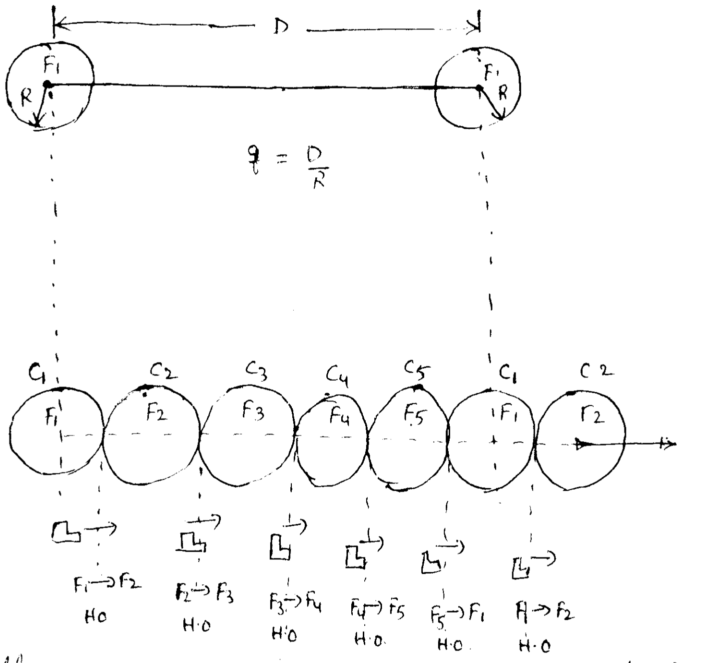
$$4.6 = \sqrt{3K}$$

$$K = 7$$

∴ The Seven cell reuse pattern is needed for a C/I of 18 dB.

4) <u>Handoff Mechanism</u> :

→ It is a unique feature that allows Cellular Systems to operate as effectively in a mobile system.



→ Two Cochannel cells using the frequency F_1 separated by a distance D and the radius R, distance D are governed by the value of q.

→ The other frequency channels such as F_2, F_3, and F_4 between two Cochannel cells in order to provide a Communication System in whole ar

→ The fill in frequencies F_2, F_3, F_4 are also assigned to their correspond cells C_2, C_3, C_4 according to the same value of 'q'.

→ A mobile unit is starting a call in cell C_1 and then moves to C_2 The call can be dropped and reinitiated in the frequency channel from F_1 to F_2 while the mobile unit moves from cell C_1 to cell C_2

→ This process of changing frequencies can be done automatically by the System without the user's intervention. This process of handoff is carried out in the Cellular System

5) Cell Splitting :

→ when the cell traffic in an area increases, we must split the cell s that we can reuse frequency more often This involves reducing the radius of a cell by half and splitting an old cell into four new small cells.

$$\text{New cell radius} = \frac{\text{old cell radius}}{2}$$

$$\text{New cell area} = \frac{\text{old cell area}}{4}$$

Transmitted power after splitting :

→ Let the received power at the cell boundary is P_r is obtained for the transmitted power P_t. where P_t is a function of the cell radius in the mobile radio environment

$$P_r = \alpha P_{t_1} R_1^{-\gamma} \quad — ①$$

$$P_r = \alpha P_{t_2}\left(\frac{R_1}{2}\right)^{-\gamma} \quad — ② \qquad \left(\because R_0 = \frac{R_1}{2}\right)$$

Equating ① & ②

$$\cancel{\alpha} P_{t_1} \cancel{R_1^{-\gamma}} = \cancel{\alpha} P_{t_2}\left(\frac{R_1}{2}\right)^{-\gamma}$$

$$P_{t_1} = P_{t2}(16) \Rightarrow P_{t_2} = \frac{P_{t1}}{16}$$

where P_{t1} is old cell transmitted power
P_{t2} is New cell transmitted power.
R_1 is old cell radius
R_0 is new cell radius

$$P_{t2} = \frac{P_{t1}}{16}$$

(or)

$$P_{t2} = P_{t_1} - 12 \text{ dB}.$$

→ The new transmitted power must be 12 dB less than the old transmitted power.

→ The new co-channel interference reduction factor q_2, after cell splitting it is also equal to the value of q i.e q is constant

→ A general formula for a new cell which is split repeatedly 'n' times and every time the new radius is one half of the old one then $R_n = \frac{R_0}{2^n}$

$$\boxed{P_{tn} = P_{t0} - n(12)} \text{ dB}$$

→ The traffic load can increase four times in the same area after the original cell is split into four subcells. Each subcell can again be split into four subcells, which would allow traffic to increase 16 times.

→ As the cell splitting continues, the general formula can be expressed as

$$\text{New traffic load} = (4)^n \times \text{The traffic load of startup cell.}$$

where n is the number of splittings. For $n=4$, this means that an original start up cell has split four times. The traffic load is 256 times larger than the traffic load of the start up cell.

→ The size of splitting is depend on two factors

a) The radio aspect: The size of small cell is dependent on how well the coverage pattern can be controlled.

b) The capacity of switching processor: The smaller the cells, the more handoffs will occur, and more cell splitting process is needed. The capacity of switching processor, is a larger factor than the handling of coverage areas of small cells

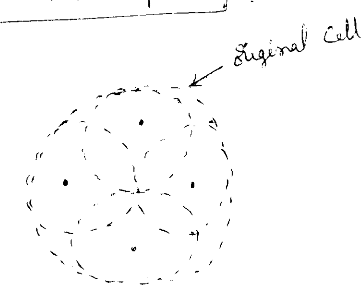
→ Effect on splitting:

a) Cell splitting affects the neighbouring cells. Splitting cell causes an unbalanced situation in power & frequency reuse distance

b) Inorder to eliminate the interference being transmitted from the large cells to the small cells is difficult.

→ The two kinds of cell splitting are 1) Permanent splitting
2) Dynamic splitting.

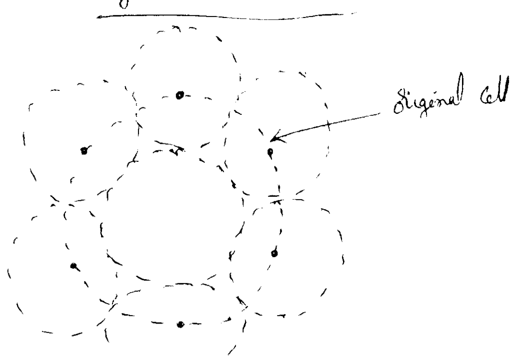
Permanent Splitting:



(1) The original cell site is not used

(2) The splitting is done at lowest traffic areas

Dynamic Splitting

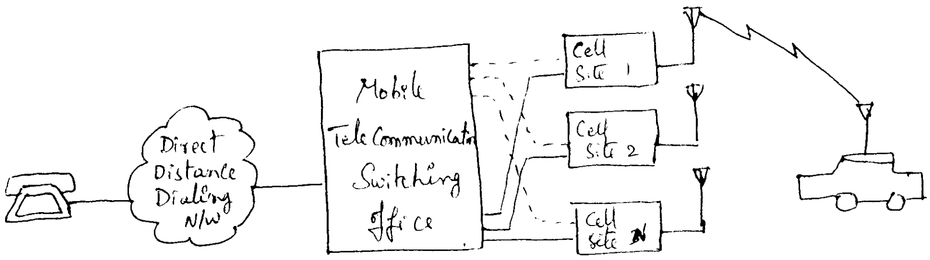


1) The original cell site is used

2) This splitting is done at heavy traffic areas

3) This scheme is based on utilizes the allocated spectrum efficiency in real time

→ Consideration of the Components of Cellular Systems :



Antennas : a) Antenna pattern, antenna gain, antenna tilting & antenna hight all effect the cellular system design

b) The antenna pattern can be omnidirectional, directional & any shape in both the vertical & horizontal planes.

c) Antenna gain compensates for the transmitted power.

d) Different antenna patterns, gains at the cell site & at the mobile un would effect the system performance & so must be considered in the system design.

e) Antenna tilting can reduce the interference to the neighbouring cell & enhance the weak spots in the cell.

f) The height of the cell site antenna can effect the area & shape of the coverage in the system

MTSO : a) The capacity of switching equipment would be maximum for designing a cellular system.

b) The future trend seems to be the utilization of system handoff i,e th switching equipment can link to other switching equipments so that a call can be carried from one system to another system withou the call being droped.

Data links :

a) Each data link can carry multiple channel data from the cell site to the MTSO. This fast speed data transmission cannot be passed throu a regular telephone line. Therefore data bank devices are needed

b) They can be multiplexed, many data channels passing through a wide band T-carrier wire line & going through a microwave rac link where the frequency is much higher than 850 MHz.

c) T_1 carrier wire lines are costly with compare to the use of microwave links.