# UNIT-II

## Cellular Mobile Radio Systems

**Limitation of conventional mobile telephone systems over cellular mobile system:**

① **Limited Service capability:** A conventional MTS is designed

(i) Select one (or) more channels from a specific frequency allocation for use in autonomous geographic zones.

(ii) The coverage area of each zone should be as large as possible such that the transmitted power should be as high as possible. (i.e high power larger cell)

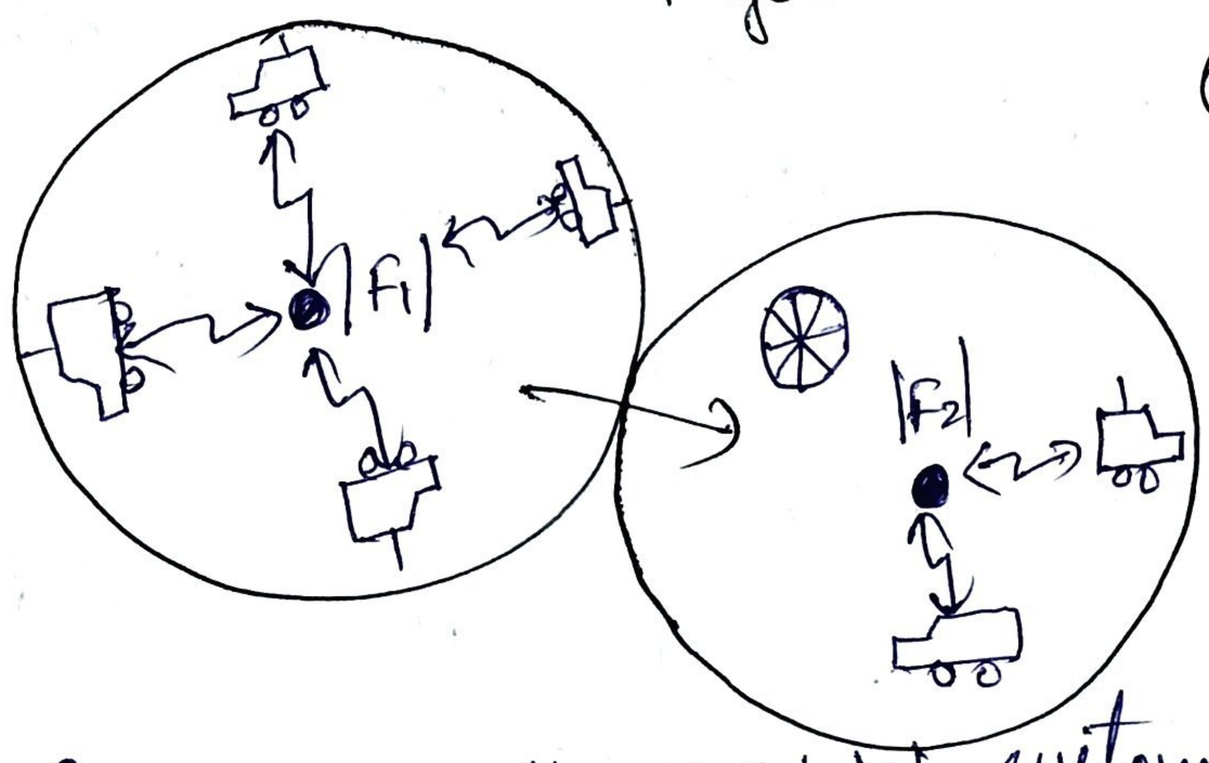


fig: Conventional Mobile system

→ The user has to reinitiate the call when moving from one zone to a new zone, because call will be dropped.

⟶ No handoff capability.

**Handoff:** It is a process of automatically changing frequency when mobile unit moves from one frequency zone to new/ different frequency zone, so that conversation will be continued without redialing.

→ Another drawback is the no. of active users limited to the number of channels assigned to a particular frequency zone.

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② Poor Service performance :-

→ In the past, total 33 channels were allocated to 3 mobile telephone systems:

(i) Mobile Telephone Service (MTS) :- it operates around 40MHz, provide 11 channels.

(ii) Improved Mobile Telephone service (IMTS) :- It operates around 150MHz, provide 11 channels. MJ systems.

(iii) IMTS MK systems :- It operates at 450MHz, provide 11 channels.

∴ Total 33 channels must cover an area 50 mi in diameter

→ In 1976, New York city had 6 channels of

(i) MJ serving 320 customers, with another 2400 customers on a waiting list.

(ii) MK serving 225 customers, with another 1300 customers on a waiting list.

∴ The large number of subscribers created a high blocking probability during busy hours.

Thus, a high-capacity system for mobile telephones was needed.

③ Inefficient frequency spectrum utilization :- In a conventional MTS, the frequency utilization measurement ($M_0$) is defined as the "maximum number of customers that could be served by one channel at the busy hour".

$$M_0 = \frac{\text{no. of customers}}{\text{channel}} \; ; \; M_0 = 53 \text{ for MJ system}$$

$$= 37 \text{ for MK system}$$

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## Calculation of blocking probability by applying Erlang B-mo

(2)

- Assume :
  - an average calling time = 1.76 min
  - no. of channels = 6
  - each channel serving 2 different numbers of customers.

(i) The offered load:

$$A = \frac{\text{Avg. calling time (min)} \times \text{total customers}}{60 \text{ min}} \text{ erla}$$

$$A_1 = \frac{1.76 \times 53 \times 6}{60} = 9.33 \text{ erlangs (MJ system)}$$

$$A_2 = \frac{1.76 \times 37 \times 6}{60} = 6.51 \text{ erlangs (MK system)}$$

(ii) The blocking probabilities:

$B_1 = 50\%$ (MJ system) → half the initiating calls will be blocked.

$B_2 = 30\%$ (MK system) (very high blocking probability)

Note:- To reduce blocking probability, decrease $M_0$ value.

→ The conventional system does not utilize the spectrum efficiently since each channel can only serve one customer at a time in a whole area.

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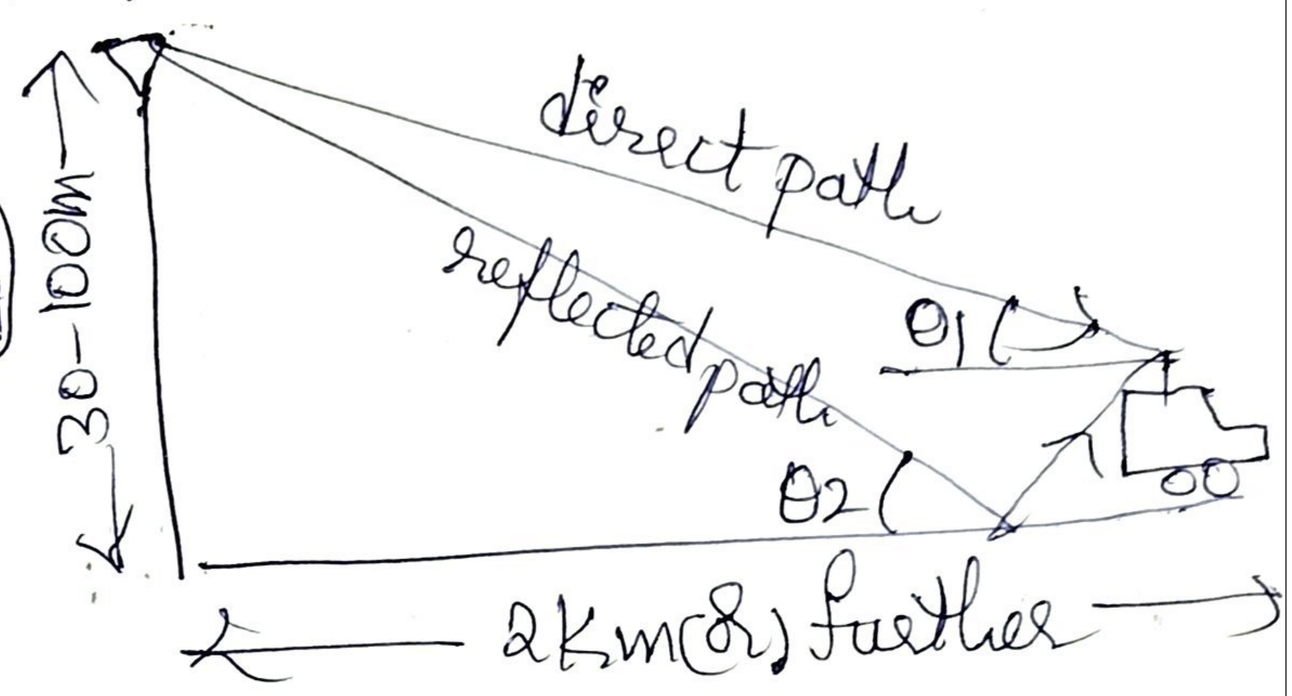
# Uniqueness of Mobile radio Environment:

## ① The propagation Attenuation:

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

Let $\theta_1$ — incident angle of direct wave
$\theta_2$ — incident angle of reflected wave.




→ The propagation path loss = 40 dB/dec (real mobile radio environment)

i.e 40dB loss at a signal receiver will be observed by the mobile unit as it moves from 1 to 10km.

- The propagation path loss = 20 dB/dec (freespace).

∴ C is inversely proportional to $R^4$.

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

where C — received carrier/signal power
R — distance measured from Tx to Rx
$\alpha$ — constant.

Also, $C \propto R^{-2} = \alpha R^{-2}$ (freespace)

→ The difference in power reception at two different distances $R_1$ and $R_2$ will result in.

$$\frac{C_2}{C_1} = \left(\frac{R_2}{R_1}\right)^{-4} \quad ; \quad \frac{C_2}{C_1} = \left(\frac{R_2}{R_1}\right)^{-2} \text{ (freespace)}.$$

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→ The decibel expression is :

$$\Delta C = C_2(\text{in dB}) - C_1(\text{in dB}) = 10 \log \frac{C_2}{C_1}$$

$$= 40 \log \frac{R_1}{R_2} \text{ (real mobile radio enviroment)}$$

$$= 20 \log \frac{R_1}{R_2} \text{ (freespace)}$$

Note: (i) when $R_2 = 2R_1$ ; $\Delta C = -12$ dB (mobile radio)
$= -6$ dB (freespace).

(ii) when $R_2 = 10R_1$ ; $\Delta C = -40$ dB (mobile radio)
$= -20$ dB (freespace).

★ In general, $\boxed{C \propto R^{-\gamma} = \alpha R^{-\gamma}}$

$\gamma$ value lies between 2 & 5 depending on actual conditions.

$$C = 10 \log \alpha - 10\gamma \log R \text{ (in dB)}.$$

(2) Severe Fading :-

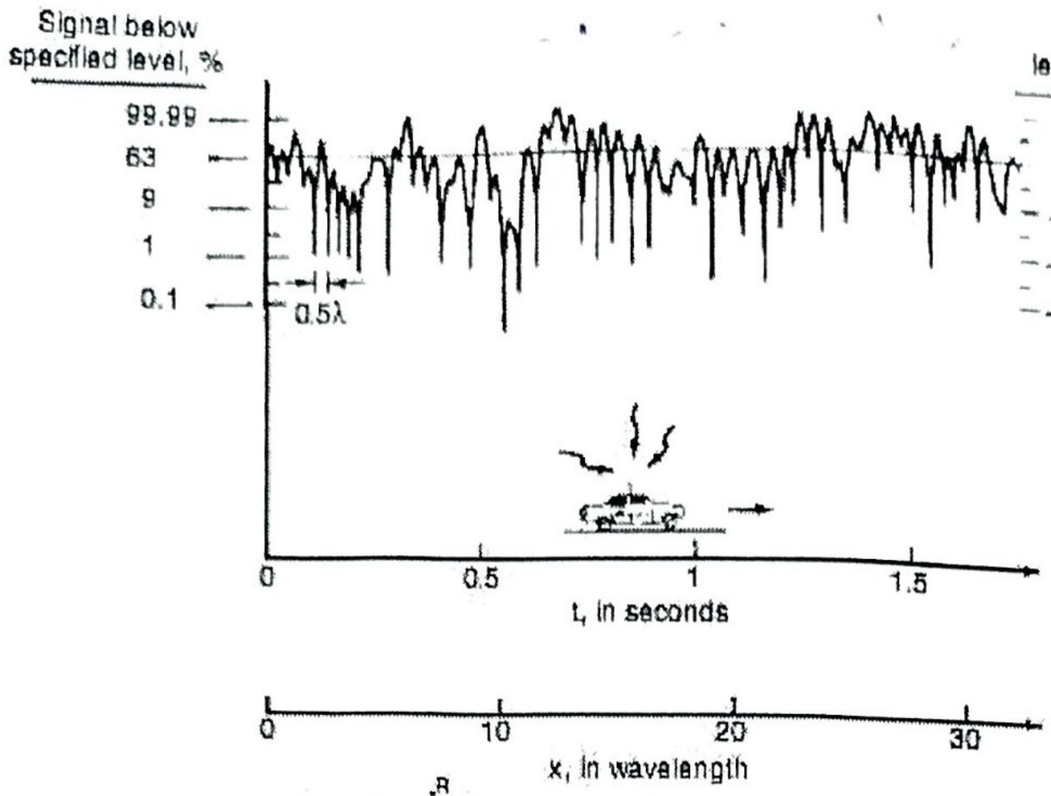
→ if antenna height of mobile unit < its surroundings & Carrier frequency wavelength << sizes of the surrounding structures, multi-path waves are generated.

• At the mobile unit, the sum of the multi-path waves causes a signal-fading phenomenon.

→ The signal fluctuates in a range of about 40dB (10 dB above & 30dB below the average signal).

→ In baseband, at every $\lambda/2$ in space → nulls of the fluctuations are visualized as shown in fig: (all nulls do not occur at same level

→ if mobile unit moves fast, rate of fluctuation is fast...




| R level, dB (With respect to rms value) | $\bar{n}_R$ | $\bar{t}_R$ | CDF = $\bar{n}_R \times \bar{t}_R$ |
|---|---|---|---|
| 10 | 0.00014 | 7142.14 | 0.9999 |
| 0 | 0.36788 | 1.71 | 0.6291 |
| −10 | 0.28593 | 0.31476 | 0.09 |
| −20 | 0.1 | 0.1 | 0.01 |
| −30 | 0.0315 | 0.03168 | 0.001 |

(from Fig. 2.10)

$P(r \le R) = \int_0^R P(r)dr$ cumulative probability distribution (CDF) = $\bar{n}_R \cdot \bar{t}_R$

$\bar{n}(R) = \frac{\beta V}{\sqrt{2\pi}} \times n_R$ level crossing rate

$\bar{t}(R) = \frac{\sqrt{2\pi}}{\beta V} \times \bar{t}_R$ average duration of fades

$p(r) = re^{-r^2}$ Rayleigh distribution

**Fig.1.4: A typical fading signal received while the mobile unit is moving**

③ <u>Model of transmission medium</u>:

→ A mobile radio signal $r(t)$ can be artificially characterized by two components $m(t)$ and $r_0(t)$ based on normal physical phenomenon. $\boxed{r(t) = m(t)\, r_0(t)}$

i) The component $m(t)$ is called local mean, long-term fading and its variation is due to the terrain contour between the base station and mobile unit.

- It can be obtained from $m(t_1) = \frac{1}{2T}\int_{t_1-T}^{t_1+T} r(t)dt$

where $2T$ — time interval for averaging $r(t)$.

$T$ — 40 to 80 fades (fading rate of $r(t)$).

$m(t_1)$ — envelope of $r(t)$.

- Also, it can expressed in spatial scale: $m(x_1) = \frac{1}{2L}\int_{x_1-L}^{x_1+L} r(x)dx$

where $2L$ — 20 to 40 wavelengths.

36 & 50 samples used in 40 wavelengths to obtain adequate and dependable mean.

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(ii) The short-term fading $r_0$ is obtained by (4)

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

is also called as multi-path fading (or) Rayleigh fading and its variation is due to the waves reflected from the surrounding buildings & other structures.

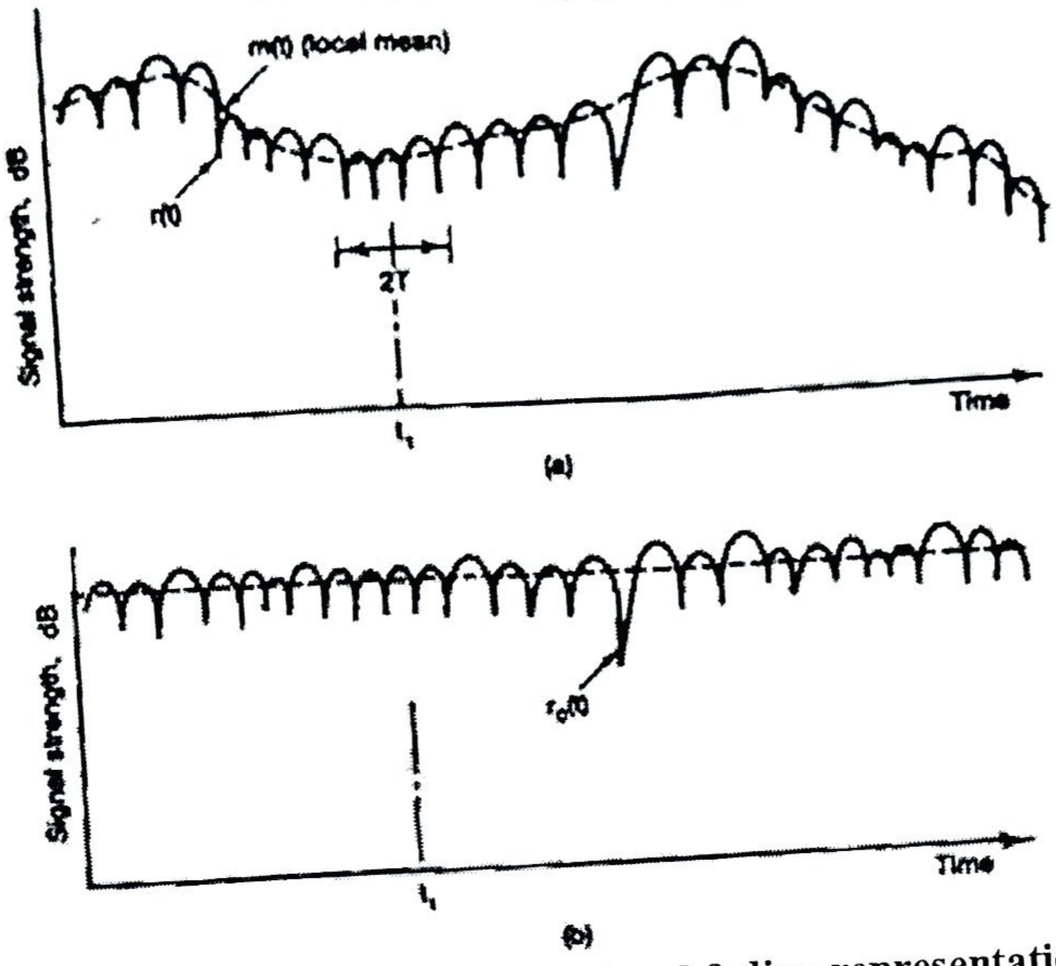
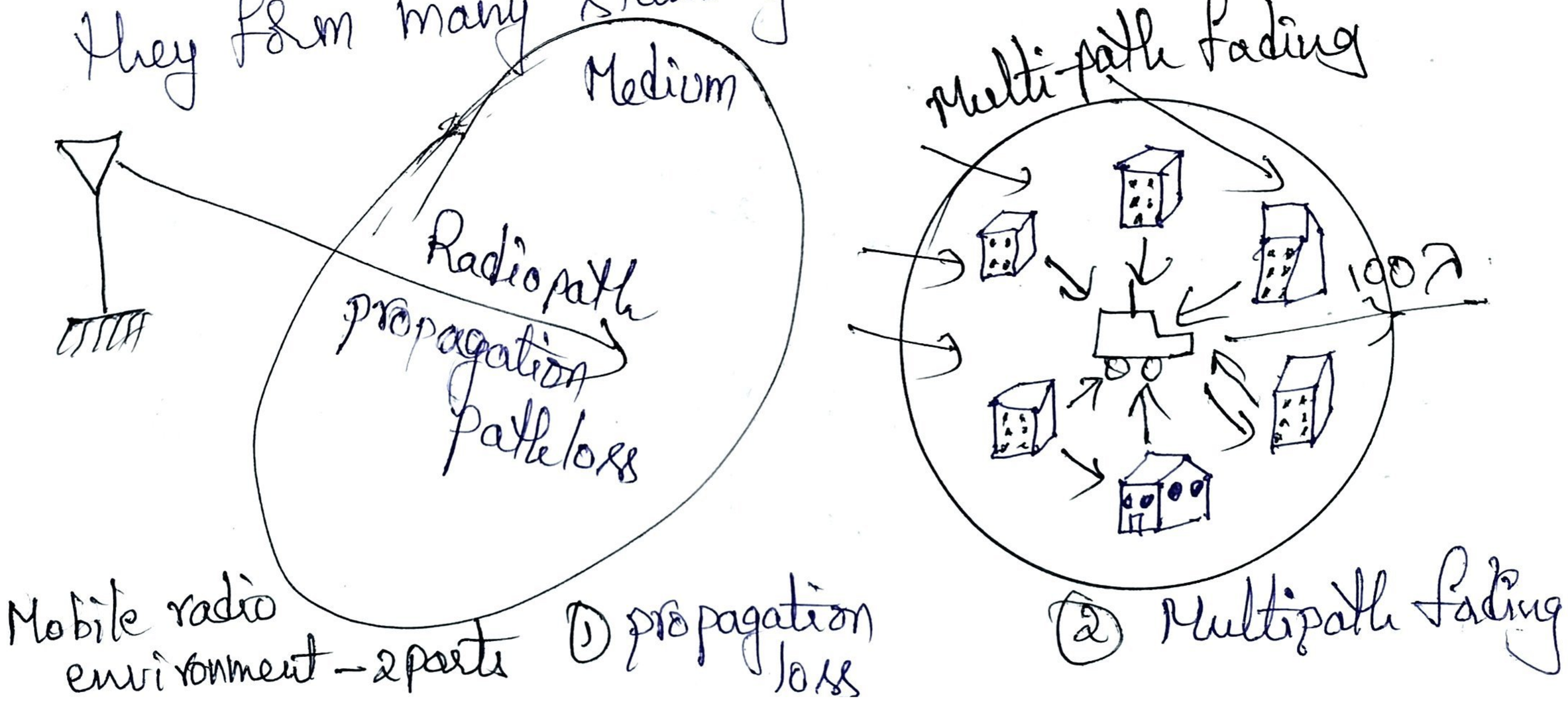



**Fig.1.3: A mobile radio signal fading representation**

(4) <u>Mobile fading characteristics:-</u>

→ In the mobile radio environment, when multi-path waves bounce back & forth due to buildings & houses, they form many standing wave patns in space as shown

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→ Those standing-wave pairs are summed together and become an irregular wave-fading structure.

→ when a mobile unit is
(i) standing, its receiver receives a signal strength at that spot, a constant signal is observed.
(ii) moving, the fading structure of the wave in space is received.

∴ As it is a multipath fading, the recorded fading becomes fast as the vehicle moves faster.

## Operation of Cellular systems:

### ① Mobile Unit Initialization:-

→ The user activates the mobile unit.
→ The receiver scan 21 set-up channels from designed 333 channels.
→ It then selects the strongest cell sites. This is called self-location scheme.

### ② Mobile Originated Call:

→ The user places the called number into an originated register in the mobile unit, checks to see that the number is correct, and pushes the "send" button.

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→ A request for service is sent on a selected set-up channel obtained from a self-location scheme.

→ The cell site receives it, and 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, and 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.

③ Network Originated Call:-

→ A land-line party dials a mobile unit number. The telephone company zone office recognizes that the number is mobile and 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.

→ 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 and responds to the cell site.

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→ The mobile unit also follows the instructions to tune to an assigned voice channel & initiate user alert to company zone office.

④ Call termination:-

→ When the mobile user turns off the transmitter, a particular signal transmits to the cell site and both sides free the voice channel.

→ The mobile unit resumes monitoring pages through the strongest set-up channel.

⑤ Handoff procedure:-

→ During the call, 2 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) alerting the user.

→ The call continues as long as the user is talking. The user does not notice the handoff occurrences.



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## Consideration of the components of cellular systems :- (6)

(1) **Antenna** :- Antenna-pattern, gain, tilting & height, all affect the cellular system design.

(i) **Antenna pattern** :- It can be omnidirectional, directional any shape in both vertical & horizontal planes.

(ii) **Antenna gain** compensates for the transmitted power.

* Different Antenna patterns & gain at cell site & at mobile unit affect the system performance, must consider in system design
* Antenna patterns in cellular systems are different from patterns in free space.

ex:- if mobile unit travels around a cell site with many (i) buildings, omni-directional antenna will not duplicate the omni pattern.

(ii) Front-to-back (FBR) ratio of directional antenna is 20 dB in freespace
10 dB at cell site.

(iii) **Antenna tilting** :- It can reduce interference to neighboring cells & enhance weak spots in the cell.

(iv) **Antenna height** :- The height of the cell-site antenna can affect the area & shape of the coverage in system.

(2) **Switching Equipment** :-

→ The capacity of switching equipment in cellular systems based on the capacity of the processor associated with the switches (not on no. of switch ports).

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→ In cellular systems, it is important to consider when switching equipment reaches the maximum (or its full capacity) that itself is the service life of the switching equipment.

→ If switching equipment is designed in modules (or) as distributed switches,

- More modules can be added to Increase the capacity of equipment
- Digital switches are more suitable for decentralized systems.

→ In future, switching equipment may utilize of system handoff.

i.e switching equipment can link to other switching equipment, so that a call can be carried from one system to another system without call being dropped.

## (3) Data Links / Gate Lists :-

→ Data links are important in the cellular system, although they are not directly affected by it.

usage :- → They are used to carry multiple channel data - 10 Kbps per channel from cell site to MTSO. data transmitted

purpose :- Regular telephone line cannot allow fast-speed data transmission. Therefore data bank devices needed.

→ They (data link devices) can be multiplexed, many data channels passing through a wide band T-Carrier Wire line (or) Microwave radio link whose frequency is much higher than 850 MHz.

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Note:- (i) Leasing T1-carrier wire lines through telephone companies can be costly.

(ii) Although availability of microwave link has to be considered as the use of microwaves may be a long-term money saver.

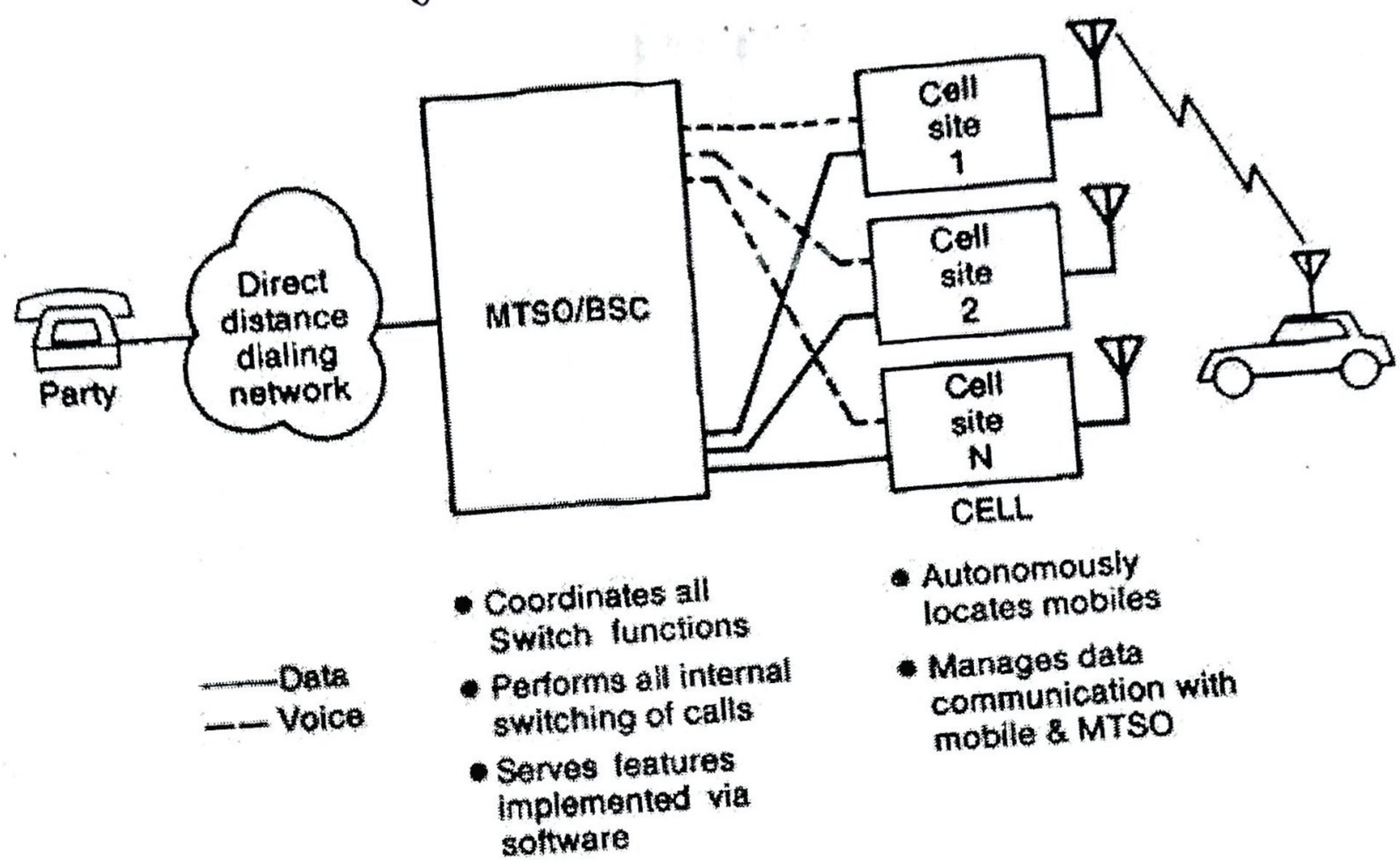


**Fig.1.8: A general view of cellular telecommunications system**

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**Basic Cellular System:** A basic cellular system consists of 3 parts: ① Mobile Unit ② MTSO (Mobile telephone switching office). ③ Cell site, along with connections to link the 3 subsystems as shown:

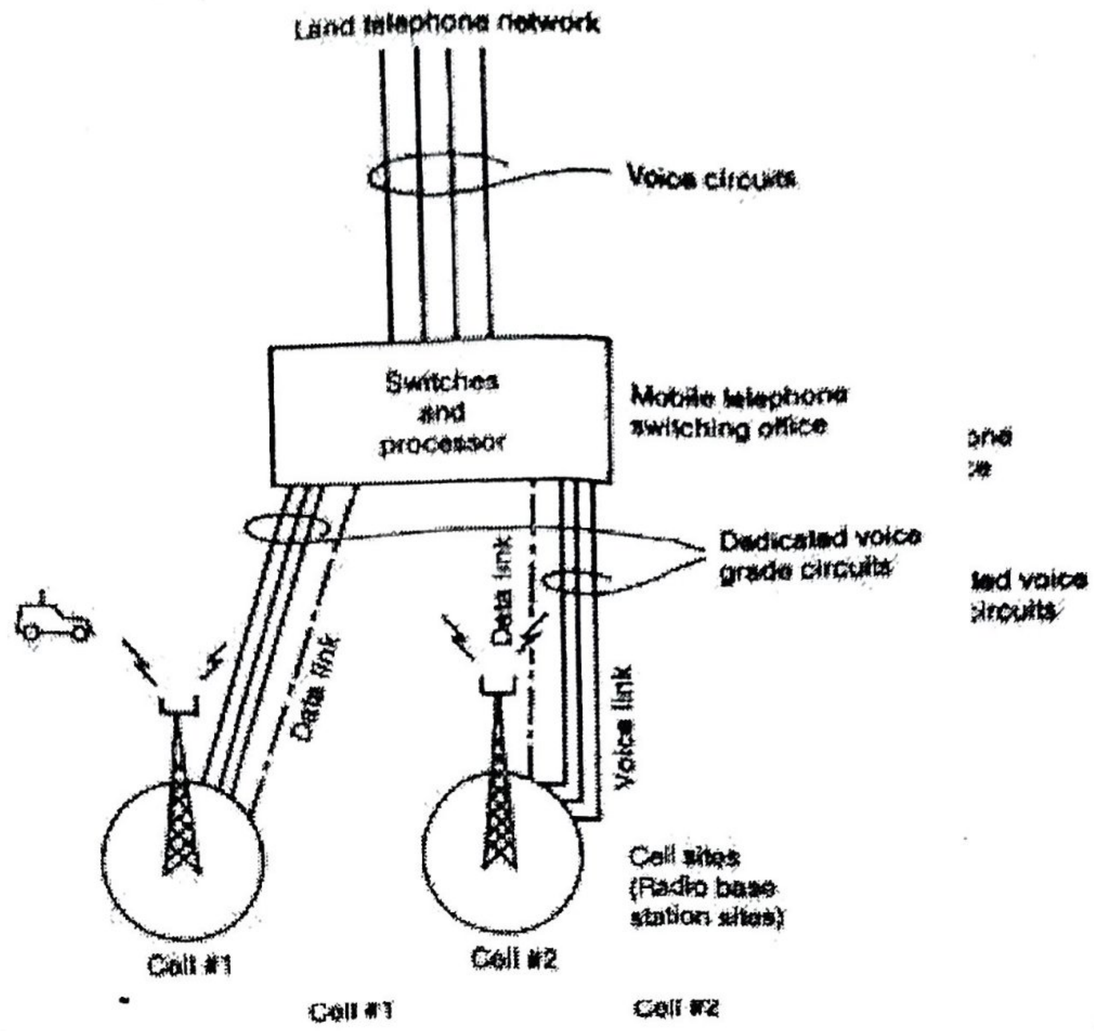


**Fig.1.6: Basic cellular system**

① **Mobile Units:** A mobile telephone unit contains a control unit, transceiver & an antenna system.

② **Cell site:** It provides interface between MTSO & mobile units. It has a control unit, radio cabinets, antennas, a power plant and data terminals.

③ **MTSO:** The switching office, which is the heart of cellular mobile system used as central coordinating element for all cell sites, contains the cellular processor & switches.

- **processor:** It provides central coordination & administration.
- **Switches:** The cellular switch, either analog & digital switches calls to connect mobile subscribers to the nation wide telephone network.
- MTSO uses voice trunks similar to telephone company interoffice voice trunks.
- MTSO interfaces with telephone company zone offices, [illegible] processes & handles billing activities.

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## (4) Connections / Data links:-

→ The radio & high speed data links connect the 3 subsystems

- MTSO also contains data links between the processor & the switch, between cell sites & the processor.
- The radio link carries the voice & signaling between the mobile unit & the cell site.

→ Each Mobile unit can only use one channel at a time for its communication link.

- Since the channel is not fixed, it can be any one in the entire band assigned by the serving area, with each site having multi-channel capabilities that can connect simultaneously to many mobile units.

→ The high-speed data links cannot be transmitted over standard telephone trunks and therefore must use (i) Microwave links (or) T-carries (wire lines

— They both carry voice & data between cellsite and the MTSO.

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## Hexagonal-Shaped cells:

→ The hexagonal shaped cells properly fit into the planned area with no gap & no overlap between the cells.

→ The cellular system which depend on the hexagonal cells is made implementable either by a simple mechanism or by a statistical approach.

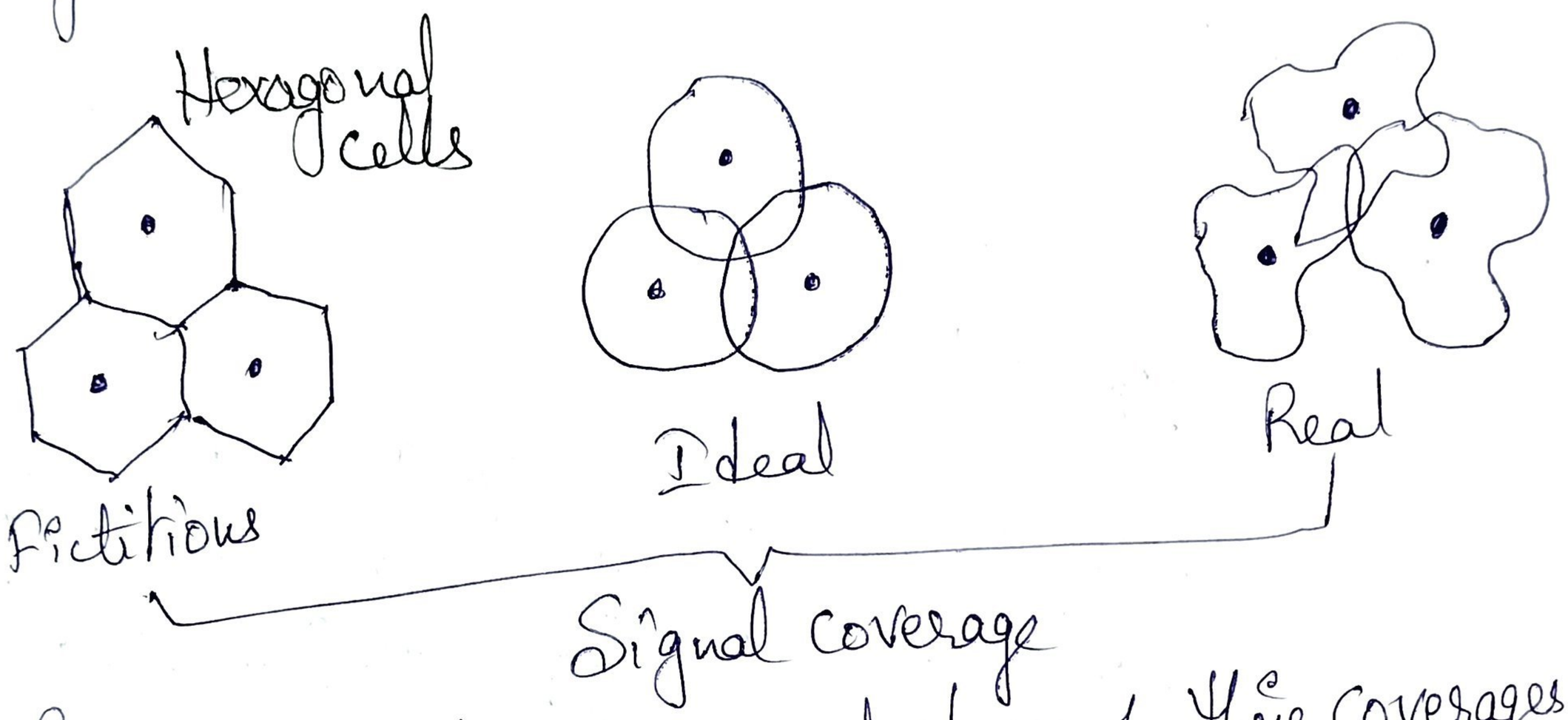


fig: Hexagonal cells & real shapes of their coverages.

## Analog cellular systems:

→ cellular telephone systems can be Analog or Digital.

→ older cellular systems are analog such as:

(i) AMPS (Advanced Mobile phone systems)

(ii) TACS (Total Access Communication system)

(iii) NMT (Nordic Mobile Telephone).

→ With analog system the audio/voice signal is directly modulated on to a carrier.

ex:- FM radio — where audio signal is translated to the RF signal.

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→ With analog transmissions, interference (RF noise or some other anomaly that affects the transmitted signal) gets translated directly into the recovered signal.

- There is no check that the received signal is authentic.

## Different countries with different Analog systems:-

① **United states:-** There are 150 major market areas in US where licenses for cellular systems can be granted by FCC (Federal Communications commission).

- They classified into 5 groups based on their population
- Each group has 30 cities.

1. Top 30 markets — very large cities
2. Top 31 to 60 markets — Large-sized cities
3. Top 61 to 90 markets — Medium-sized cities
4. Top 91 to 120 markets — below medium-sized cities
5. Top 121 to 150 markets — small sized cities.

② **Japan:-** In 1979, In tokyo area Nippon telegraph & Telephone Corporation (NTT) developed an 800MHz Land mobile telephone system (AMPS system).

- It access ≃ 40,000 subscribers in 500 cities.

→ Consider, Japanese MTS network configuration as shown in the figure:

- In 1985, system operated over a spectrum of 30MHz, total channels — 600, channel BW — 25KHz.

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(3) United kingdom :- In 1982, UK govt. announced 2 national cellular network operators, cellnet & vodafone. (10)

- UK system is TACS with total channels — 1000 (600 — assigned & 400 — reserved), with channel BW — 25KHz.

(4) Canadian system :- In 1978, AURORA system designed for Alberta Govt. telephone (AGT), providing MTS at 400MHz

- AURORA-800MHz is ongoing developmental work.

AURORA-400 system

→ 40,000 subscribers in 1920 x 960km area.

→ 40 channels + 20 channels (frequency reuse)

→ $f_0$ = 400 MHz

→ No handoff capability

AURORA-800 system

→ Truly freq. transparent

→ $f_0$ = 800MHz

→ The handoff capability is implemented.

(5) Nordic system :- Denmark, Norway, sweden & Finland with saudi Arabia & spain used system is called NMT network.

(200 channels with BW = 25KHz per channel, and 1,00,000 — subscribers)

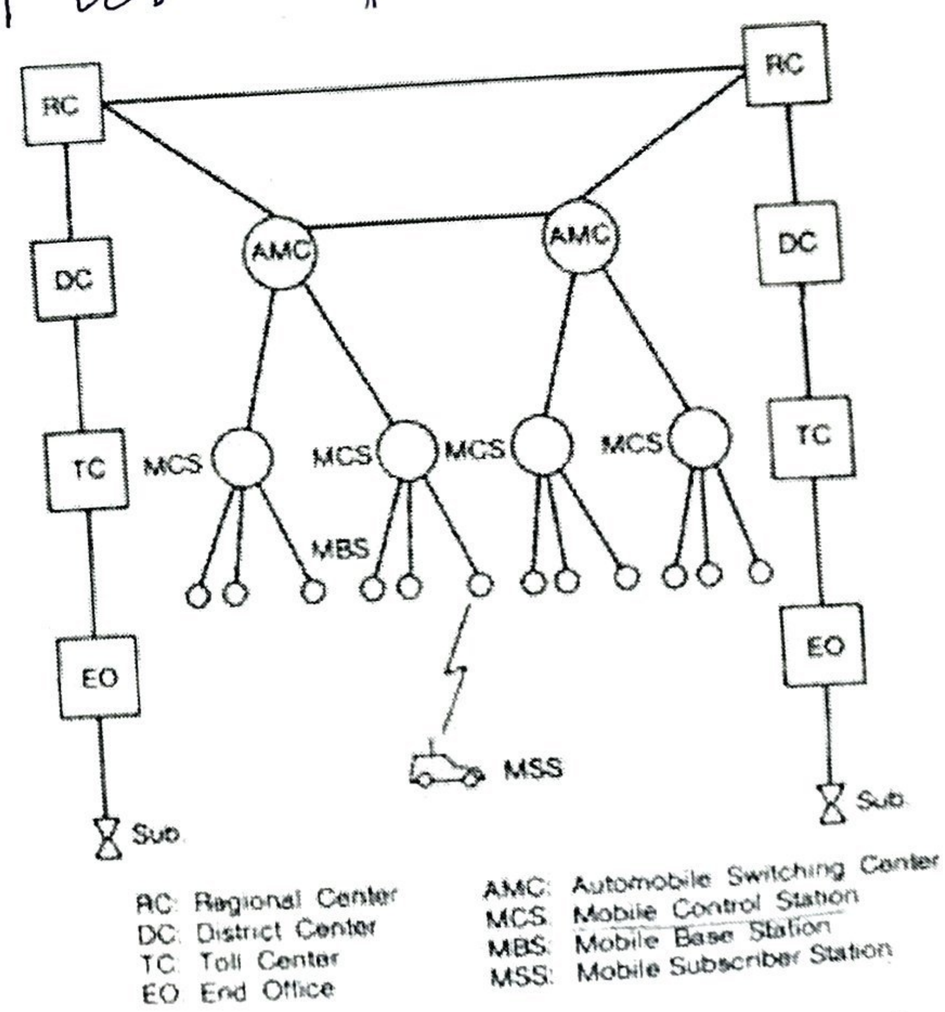


**Fig.1.9: Japanese mobile telephone service network configuration**

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# Digital Cellular systems:-

→ Cellular Telephone systems can be Analog & digital.

→ Newer systems such as:
GSM – Global system for Mobile.
CDMA – Code division Multiplexing access.
PCS – Personal communication system
are digital.

→ With digital systems, the audio is converted to digitized samples.

→ In digital transmission, 1's and 0's cannot be confused or distorted during transmission, extra data is included to detect & correct any errors.

→ In 1992, the first digital cellular system (special Mobile group) was deployed in Germany.
· GSM – European standard system.

→ US:- In US, An NA-TDMA system (IS-54) 1993 and CDMA system (IS-95) developed 1995.

→ Japan:- In June 1994, In Osaka PDC (personal digital cellular) was deployed.

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# Evolution of Cellular systems



## ① 1G wireless technology:

→ This started with the AMPS at Bell Labs, installed first in 1982.

- using analog signals
- It's speed was upto 2.4 Kbps

carrier frequency is typically of 30 KHz @ 800 MHz.

drawbacks:- poor battery, poor voice quality, large in size, No security, frequency call drop (no handoff)

## ② 2G Wireless technology:

→ It enables services such as text messages, picture msgs and MMS (Multi-media Message).

- provides better quality & capacity
- widely used in 90's – 2000
- allows multiple users on a single channel.
- supports voice as well as data.
- allows, easy compression & multiplexing of digital radio signals.
- 2G technologies divided into TDMA based & CDMA based standards
- speed 9.6 kbps
- Carrier frequency is of 200 KHz @ GSM-900 MHz, 1800 MHz
  CDMA: 800 MHz

drawbacks:- weaker digital signal

- These systems are unable to handle complex data such as videos.

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## (3) 2.5G wireless technology :-

→ 2.5G → 2G + GPRS (General Packet Radio service), used in 2001-2004. (evolution from GSM)
technology

→ In addition to circuit switched data, packet switched data was implemented.

→ Enhanced multi-media & streaming video are possible

→ supports web browsing, carrier frequency is same as 2G.

→ provides services such as:
WAP — wireless application protocol access.
MMS, Internet communication services
email & world wide web access

**Features :-**

→ phone calls
→ web browsing
→ send receive email messages
→ speed: 64 – 144 kbps
→ Camera phones.

## (4) 3G wireless technology :-

→ speed of data increased from 144 kbps – 2Mbps.

→ provides faster communication, send/Receive large value email messages, high speed web, More security than 2G

→ TV streaming / Mobile TV / phone calls during 2004-05

→ Carrier frequency is 5MHz

**Applications :-** video on demand, video conferencing, location-based services and GPS (Global Positioning system)

**drawbacks :-**
- High bandwidth Requirement
- Expensive 3G phones
- Large cell phones.

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## (5) 4G wireless technology :-

→ provides 100Mbps – 1Gbps speed.
→ More security, high capacity, low cost per bit.
→ Improves the capacity & coverage & ensures user fairness.
→ Introduces multi-carrier to be able to use UW BW (ultra wide BW) upto 100MHz of spectrum supporting very high data rates
→ LTE (long term Evolution) is a standard for wireless communication of high speed data for mobile phones & data terminals.
→ Supports atleast 200 active data clients in every 5MHz cell.
→ Based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity & speed using new modulation techniques.
→ Ability to manage fast moving mobiles and supports MBSFN (Multicast Broadcast Single frequency Network).

Note :- EDGE – Enhanced Data rates for GSM communications system.
UMTS – Universal Mobile Telecommunications system.
HSPA – High speed packet Access.

Drawbacks of 4G :-
- Battery uses is more.
- Hard to implement
- Need complicated hardware
- Expensive equipment required to implement next generation network

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## (6) 5G Wireless technology :-

→ The routers/switch we are going to use in 5G network would provide high connectivity with wireless device.

- It is 10 times more faster than 4G.
- It has a expected speed of 1Gbps.
- Lower cost than the previous version.

**Features :-**

- uploading & downloading speed of 5G touching the peak (up to 1Gbps)
- Better & fast solution.
- highly supportable to wireless worldwide web
- Large phone memory, Dialing speed, clarity in Audio/video.
- 5G technology is going to give tough competition to computers & Laptops.

## Frequency-reuse concept :-

→ In this frequency-reuse system, users in different geographic locations (different cells) may simultaneously use the same frequency. (As spectrum is limited & costly)

- Thus, spectrum efficiency increases. leads to
- common use of same channel ~~is called~~ cochannel interference.

→ (i) frequency reuse in the time domain results in the occupation of the same frequency in different time slots → TDM

(ii) frequency reuse in the space domain :

- Same frequency assigned in two different

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geographic areas, such as AM (or) FM radio stations using same frequency in different cities.



- Same frequency repeatedly used in a same area.

→ The total frequency spectrum allocation is divided into 'K' frequency reuse patterns as illustrated in figure for K = 4, 7, 12 and 19. (K = N = cluster size).

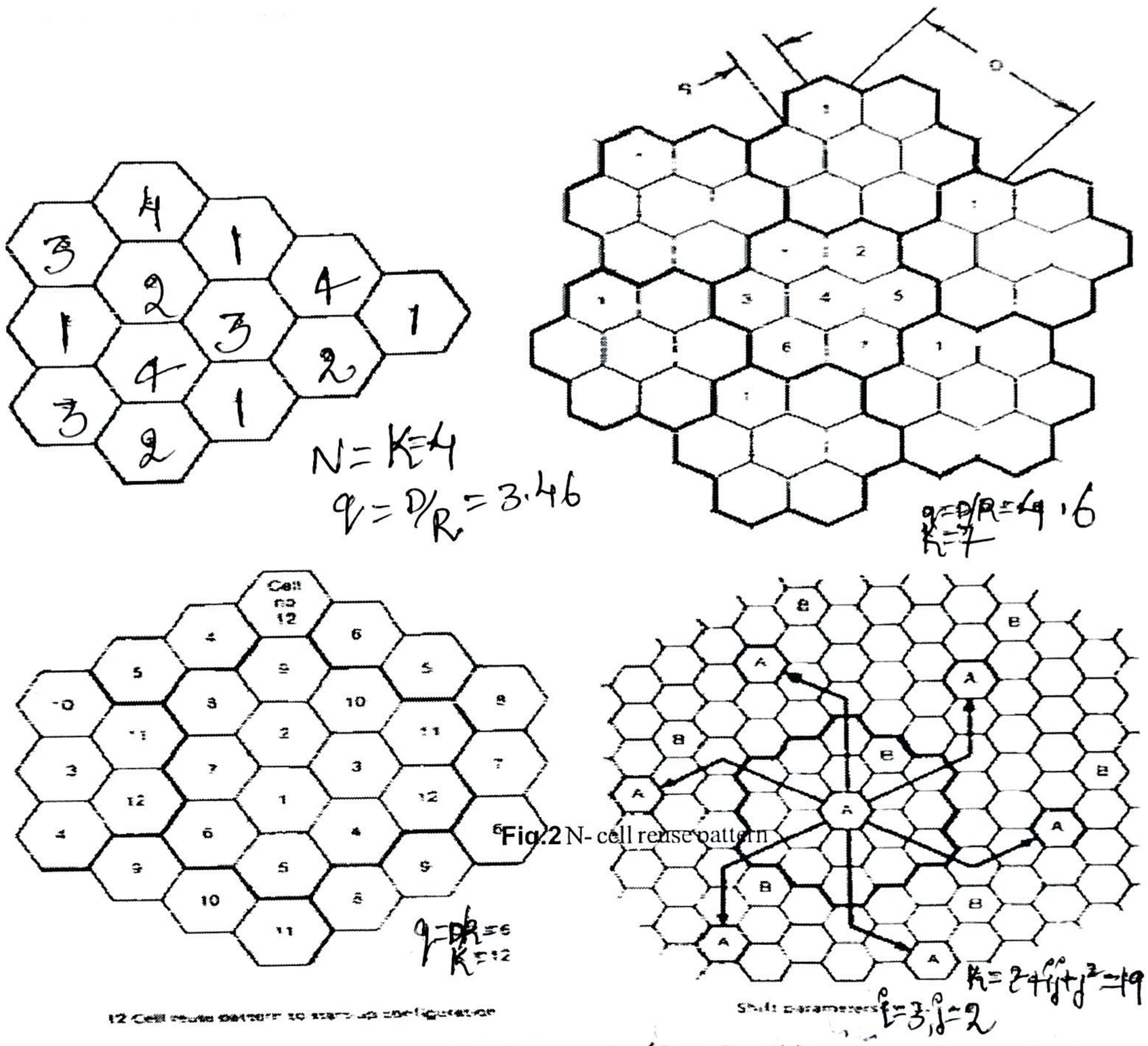


Fig:- N-cell reuse pattern.

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## Frequence Reuse Distance:-

→ The minimum distance that allows the same frequency to be reused will depend on many factors;

(i) number of cochannel cells in the area
(ii) type of geographic terrain contour
(iii) Antenna height
(iv) Transmitted power at each cell site.

→ The frequence reuse distance (D) can be determined from

$$\boxed{D = \sqrt{3K}\,R} \quad (\text{or}) \quad \boxed{q = \frac{D}{R} = \sqrt{3K}}$$

where K – frequency reuse pattern shown in fig. below –

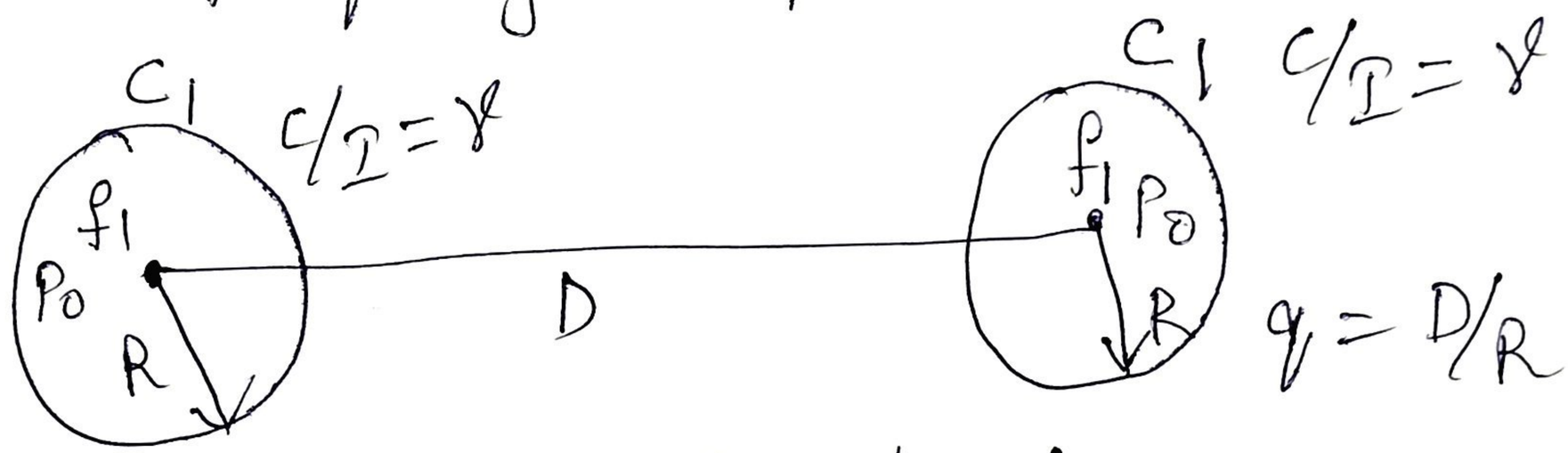


fig: The ratio of D/R.

**Note:-**

$D = 3.46R$ ; $K = 4$
$= 4.6R$ ; $K = 7$
$= 6R$ ; $K = 12$
$= 7.55R$ ; $K = 19$.

→ if all the cell sites transmit the same power, then K increases ⇒ D increases ⇒ reduces the chance of occuring cochannel interference.

## Frequency Reuse Ratio:-

→ Assuming hexagonal shape cells of equal size

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

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∴ where, D – distance between the centers of cells
R – Radius of the cell
q – Reuse ratio
K – cluster size

(15)

→ for K = 7 and R = 5 km then $D = \sqrt{3K}\,R = 22.91$ km
ex:
i.e Minimum distance ≃ 4.6 R.

## Number of channels in a Cellular System :-

→ In order to compute the capacity in a wireless cellular system, let
S – no. of channels (frequencies) per cluster
k – no. of channels per cell
N – no. of cells per cluster

∴ $\boxed{S = kN}$ channels/cluster.

• Let
M – no. of clusters per entire system
C – total no. of channels available per system.

here, The number 'C', is a measure of capacity of the system – important to service provider since it determines the max. traffic capacity.

• higher capacity ⇒ higher potential revenue to the service provider.

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

Note:- ① Large N ⇒ $\frac{D}{R}$ – large ② Small N ⇒ co-channel cells closer together.
③ value of N is a function of how much interference a mobile (or) base station tolerate while maintaining sufficient

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quality of communications.

(4) frequency reuse factor of a cellular system is given by $1/N$, since each cell in cluster is assigned $\frac{1}{N}$ of total available channels in the system.

Z.

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# Cellular Traffic:

**Trunking:** Accommodate a large no. of users in a limited radio spectrum, by sharing the small number of channels in a cell.

- provides access to each user from a pool of available channels.

→ **Erlang:-** Measure of (traffic intensity & avg. channel occupancy)

- A radio channel occupied for 30 min during an hour carries 0.5 erlangs of traffic.

(1) **Set-up time:-** Time required to allocate a trunked radio channel to a requesting user.

(2) **Blocked Call:** Call which cannot be completed at a time of request, due to congestion. Also referred as a lost call.

(3) **Holding Time:** Average duration of a typical call, denoted by H (in sec).

(4) **Traffic Intensity:-** Measure of channel time utilization (in erlangs). That is it measures the time utilization of single or multiple channels (denoted by A). Also dimensionless quantity.

(5) **Load:-** Traffic intensity across the entire trunked radio system, measured in Erlangs.

(6) **Request Rate:** The avg. no. of call requests per unit time (denoted by $\lambda$/sec)

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→ In trunking Theory, to make capacity estimates in trunked systems:

(i) Traffic intensity offered by each user = Call request rate multiplied by the holding time.

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

(ii) For a system containing 'U' users, unspecified no. of channels then the total offered traffic intensity (A) is given as $\boxed{A = U A_u}$

(iii) Let c-channel trunked system, then

$$A_c = \frac{U A_u}{c}$$

Note: The offered traffic is not necessarily carried by the trunked system. (i.e only offered to trunked system).

(i) when offered traffic > c (max. capacity of system).

⇒ Carried traffic becomes limited due to limited capacity.

where c — max possible carried traffic (total no. of channels)

ex:- AMPS system:- GOS — 2% blocking

i.e 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour.

Types of Trunked system:-

(1) 1st type: No queuing for call requests. (M/M/m/m queue).

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i.e. every user who requests service,

(i) No setup time (i.e given immediate access) to a channel, if it is available.

(ii) if no channels available, requesting user is blocked.

- This type of trunking is called blocked calls cleared. determined by poisson distribution. (exponential distribution)

∴ The erlang – B formula determines the probability that a call is blocked, is a measure of GOS for a trunked system.

$$\therefore Pr[\text{blocking}] = \frac{\left(\frac{A^C}{C!}\right)}{\sum_{K=0}^{C} \frac{A^K}{K!}} = GOS$$

where C – no. of trunked channels

A – Total offered traffic.

(2) 2nd Type: A queue is provided to hold blocked calls. If a channel not available immediately, the call request may be delayed until channel becomes available. This type of trunking is called Blocked Calls delayed. (erlang – C formula)

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

The average delay D for all calls in queued system

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

where $\frac{H}{C-A}$ — average delay for those calls which are queued.

## Grade of Service (GOS):

→ The ability of a user to access a trunked system during the busiest hour.

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

$$Pr[\text{delay} > t] = Pr[\text{delay} > 0]\, Pr[\text{delay} > t \mid \text{delay} > 0]$$

$$= Pr[\text{delay} > 0] \exp\left(-\frac{(C-A)t}{H}\right)$$

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



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# Cellular structures:

① **Macro Cells:** These cells are the base stations that provide coverage to a large area with inter site distance (ISD) from hundreds of meters to several km.

→ They fulfill the baseline coverage for any LTE network providing connectivity and all the time.

→ power consumption varies from 1000 to 4500.

- They have sectored antennas normally covering 120° per sector

② **Microcells:** They have lower transmit power than Macro BS's, they are smaller base stations with full features used to cover both indoor & outdoor areas.

- It can cover a range of few meters to 1-2 km.
- power consumption ranges from 50W to 1500.
- They are generally used for indoor & outdoor such as hot-spots.

③ **Picocells:** They have lower transmit power than Macro BS's, they have omni-directional antennas unlike Macro BSs (which are sectored).

→ The transmit power ranges from 250mW to 2W.

→ They are generally used for indoor purposes around hot-spots like offices, railway stations etc.

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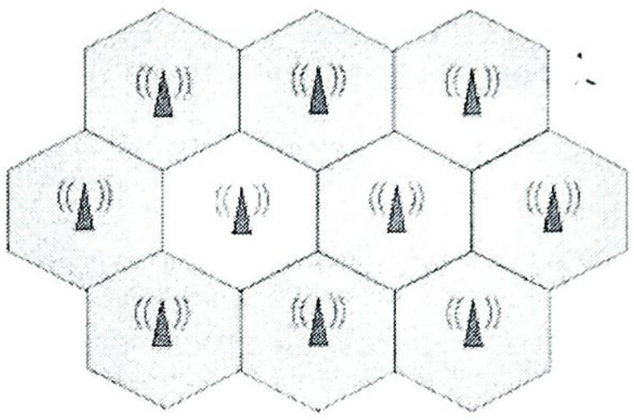
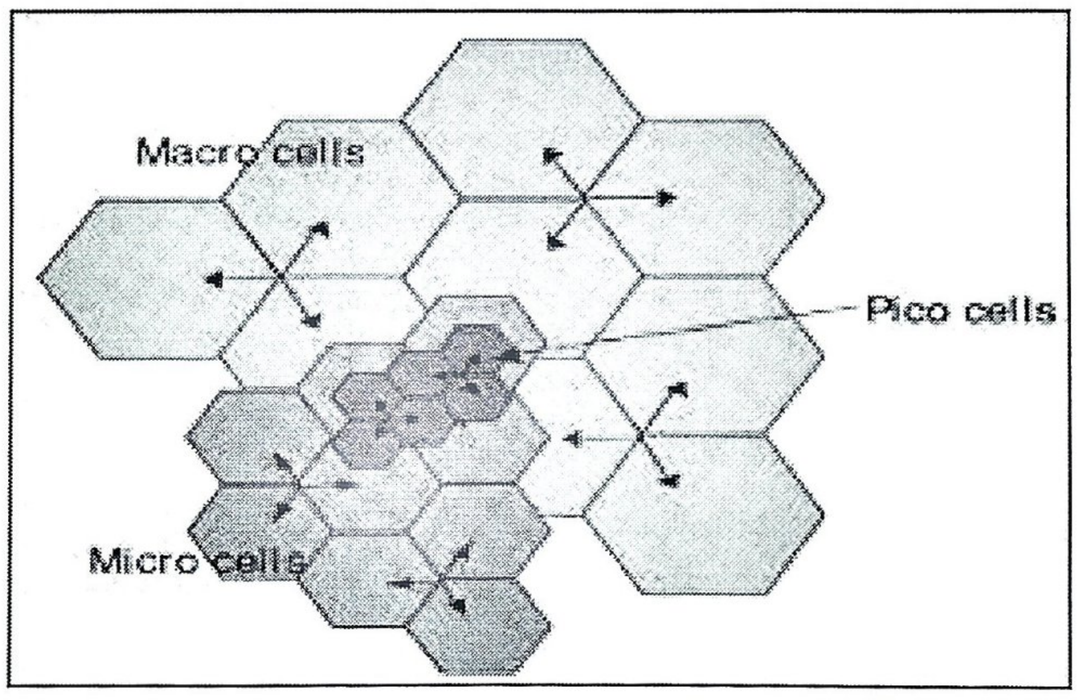
(4) Femto Cell: These are also known as Home Base stations, are deployment for small rooms & home requirements, for very small coverage range of < 30m. (10m)

→ They have omni-directional antennas, transmit power is around < 100mW.

- They could be plugged in using a DSL line (or) modem cable. (Digital subscriber line).

Macro, Micro, Femto and Pico Cells



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# Cell splitting:

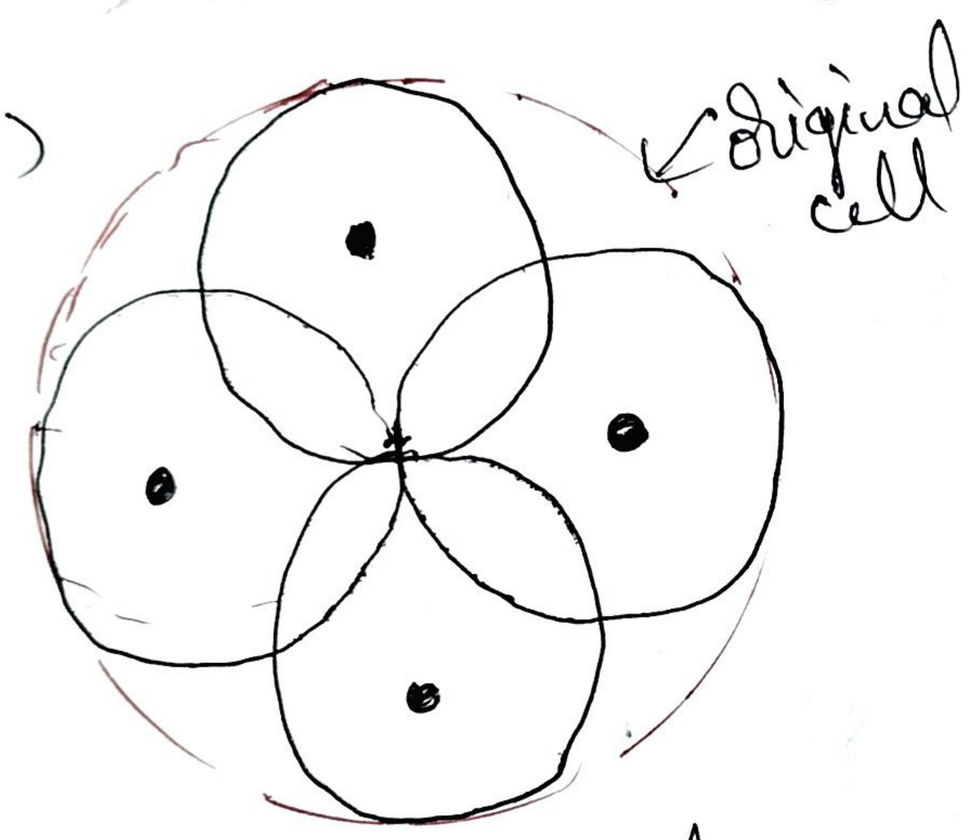
→ Cell splitting is the concept, used to improve the utilization of spectrum efficiency during the implementation of a cellular mobile system.

→ when traffic density starts to build up and the frequency channels $F_i$ in the cell $C_i$ cannot provide enough mobile calls, the original cell can be split into smaller cells.

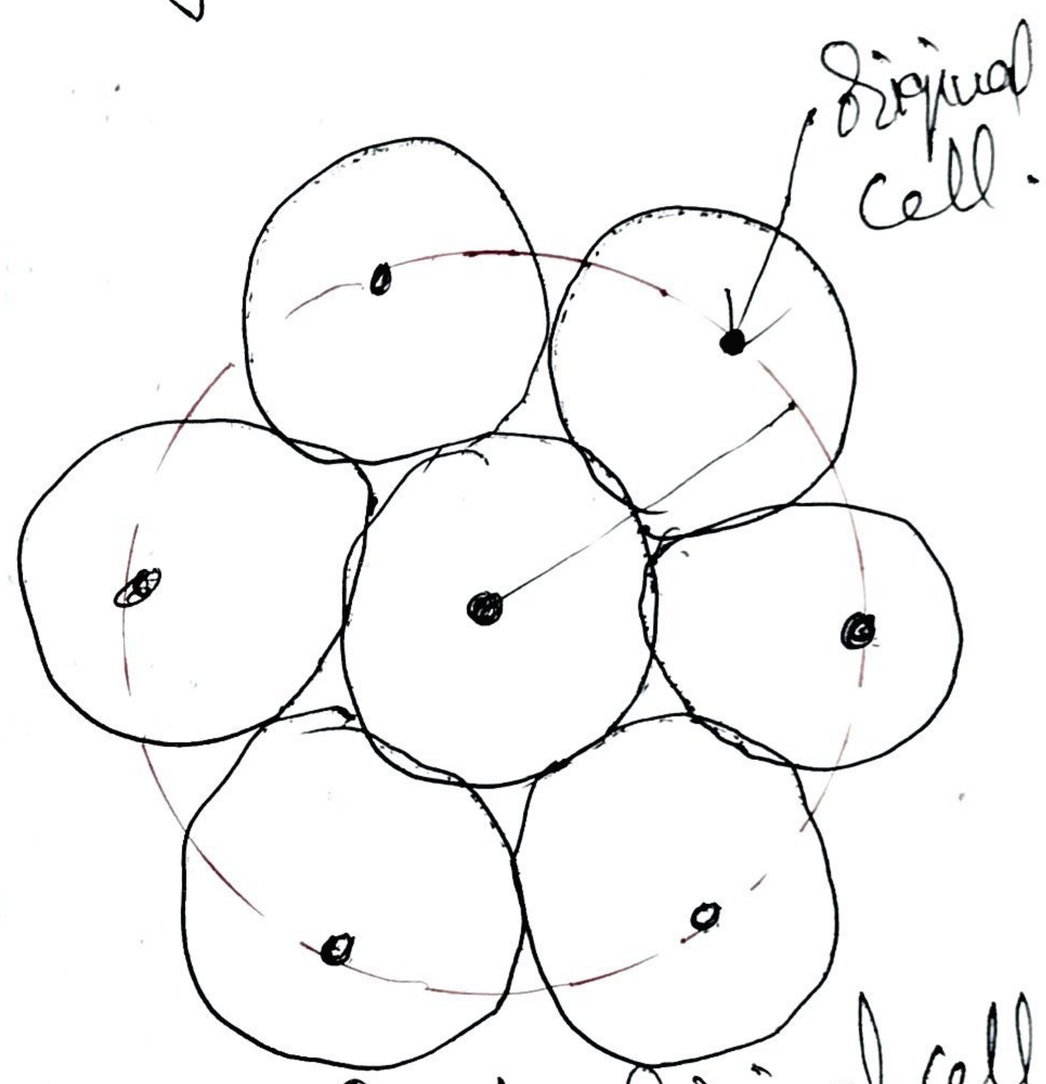
- The new radius is one-half of the original radius

→ There are 2 ways of splitting:

(i)




fig(a): Original cell is not used. (site)




fig(b). Original cell site is used.

→ (i) New cell radius $= \dfrac{\text{Old Cell radius}}{2}$

(ii) Then, New cell area $= \dfrac{\text{old Cell area}}{4}$

(iii) Let each new cell carry the same maximum traffic load of the old cell, then

New traffic load/Unit area $= 4 \times \dfrac{\text{Traffic load}}{\text{Unit area}}$

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There are 2 kinds of cell-splitting techniques:-

① permanent splitting:-

→ The installation of every new split cell has to be planned ahead of time, the following considerable factors such as:
(i) Number of channels
(ii) Transmitted power
(iii) Assigned frequencies
(iv) choosing cell-site selection
(v) Traffic load consideration etc.

→ when ready,
- The actual service cut-over should be set at the lowest traffic point, usually at midnight on a week
- Because of this cut-over, only a few calls will be dropped, assuming that the downtime of the system is within 2 h.

② Dynamic splitting:-

→ This scheme is based on the usage of allocated spectrum efficiency in real time.

→ The algorithm for dynamically splitting cell sites is a tedious job, as we cannot afford to have one single cell unused during cell splitting at heavy traffic hours.

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# Cell Sectoring :

① Increasing channels
② decreasing interference.

→ Cells are divided into a number of wedge-shaped sectors, each with their own set of channels.

→ Sectoring is another way to increase capacity :- In this method, a cell has the same coverage space but instead of using a single omni-directional antenna that transmits in all directions, either 3 & 6 directional antennas are used, each with beamwidth of about 120° or 60° as shown below:

→ Each sector causes interference to the cells that are in its transmission angle only.

(i) No sectoring : 6 interfering co-channel cells from the first-tier co-channels cells cause interference.

(ii) 120° sectoring :- 2 & 3 co-channel cells cause interference.

(iii) 60° sectoring :- 1 & 2 co-channel cells cause interferen

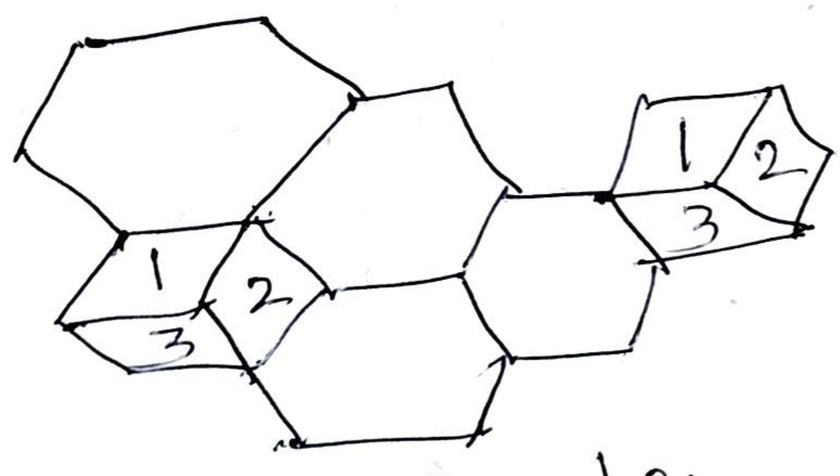


fig (a) 120° sectoring

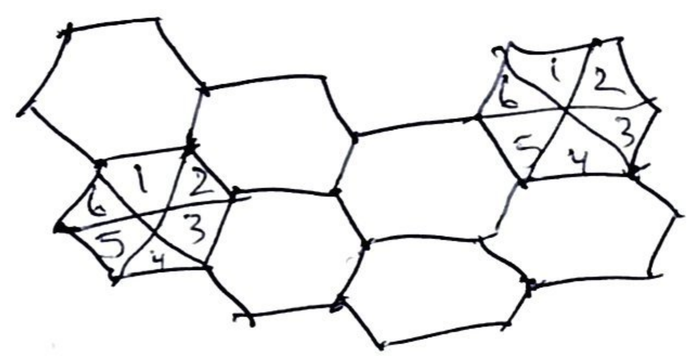


fig (b): 60° sectoring.

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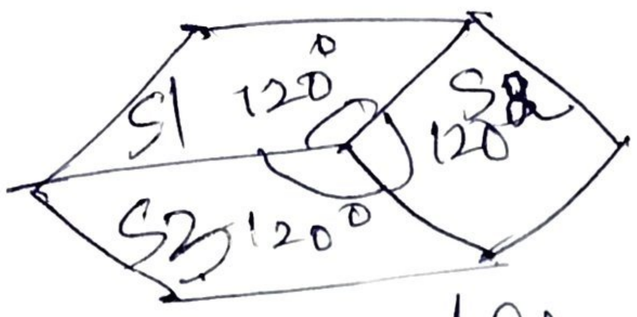


120° sectoring

60° sectoring.

→ Consider, a fig: that shows cluster size of N=4 in which only 2 of 6 co-channel cells cause interference to the middle cell for the sector (S2) — 120° cell sectoring.

- The other 4 cells, although they are radiating at same frequencies cause no interference because middle cell is not in their radiation angles.

60° cell sectoring: only one cell cause interference.

∴ The number of co-channel interfering cell depends on the cluster size & shape.

CIR (co-channel interference ratio):

(i) $\frac{C}{I} = \frac{1}{6q^{-\gamma}} = \frac{q^{\gamma}}{6}$ (due to 6 interfering cells) (in case of omni-directional antenna).

(ii) $\frac{C}{I} = \frac{1}{2q^{-\gamma}} = \frac{q^{\gamma}}{2}$ (due to 2 interfering cells) (in case of directional antennas)

where q – cochannel interference reduction factor

& $\gamma$ – path loss exponential constant.

here, The denominator reduced from 6 to 2 indicates the reduced number of interference sources.

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## SIR (Signal to Interference ratio):

→ The sectoring reduces no. of interfering towers → SIR is increased for the same cluster size.

## Handoff Mechanism:

→ when dividing a cell into sectors requires a handoff to progress call when a mobile unit travels into a new sector.

→ The need of handoffs between sectors and between cells does not directly reduce the no. of customers, but increase the complexity of the system.

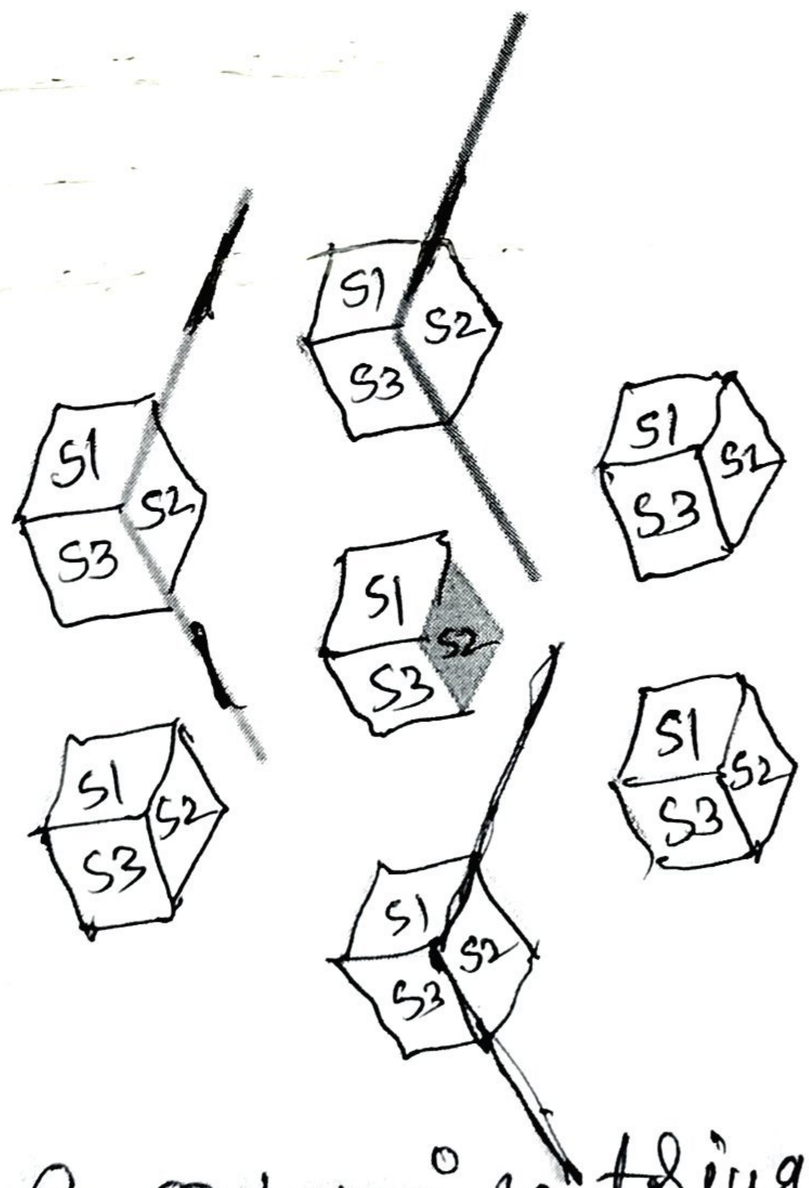


fig (a):- 120° sectoring

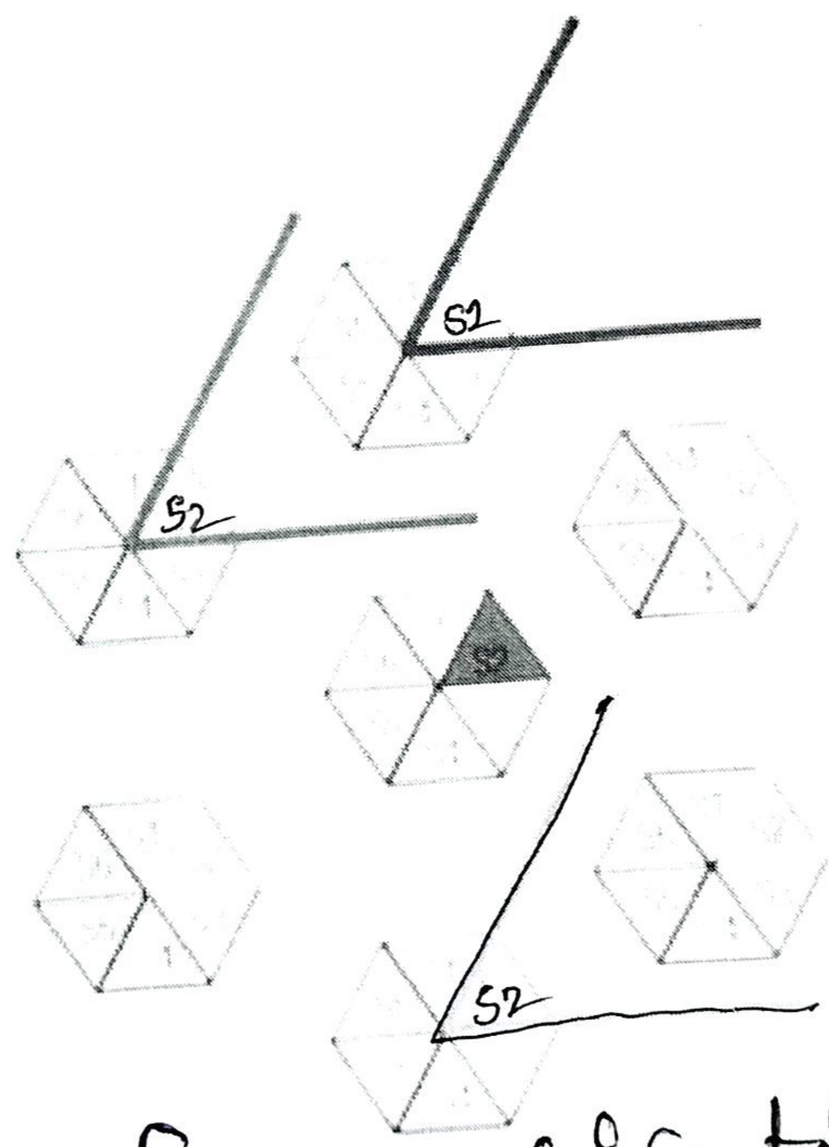


fig (b):- 60° sectoring

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