UNIT- 1

Introduction and Evolution of Mobile Radio Communication

★ **Evolution of Mobile Radio communication:**

- **Reasons for devoloping a cellular Mobile Telephone system**
  1. Limitations of conventional Mobile Telephone systems
  2. Spectrum efficiency considerations
  3. Technology, Feasibility and service Affordability

1. **Limitations of conventional Mobile Telephone systems**

There are following three limitations of conventional mobile telephone systems:

i. limited service capacity:

The primary disadvantage is that 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 possible.

Secondly, a 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.

Also the number of active users is limited to the number of channels assigned to a particular frequency zone.

ii. Poor service Performance:

The large number of subscribers created a high blocking probability during busy hours. Hence a high capacity system for mobile telephones was required.

iii. Insufficient Frequency Spectrum Utilization:

The conventional system does not utilize the spectrum efficiently as each channel can only serves one customer at a time. Hence a new cellular system that measures the frequency spectrum utilization differently and proves to be efficient is required.

2. Spectrum Efficiency considerations:

A major problem faced by the radio communication industry is the limitation of the available radio frequency spectrum. But for frequency allocation, the FCC seeks systems that require minimal bandwidth but provide high usage and customer satisfaction.

An ideal mobile system would operate within a limited assigned frequency band and would serve an almost unlimited number of users in unlimited areas. To achieve the ideal mobile systems some of the approaches are:

i. Single-Side Band (SSB)

It divides the allocated frequency band into maximum number of channels.

ii. Cellular:

Reuses the allocated frequency band in different geographical areas.

iii. Spread Spectrum or Frequency Hopped:

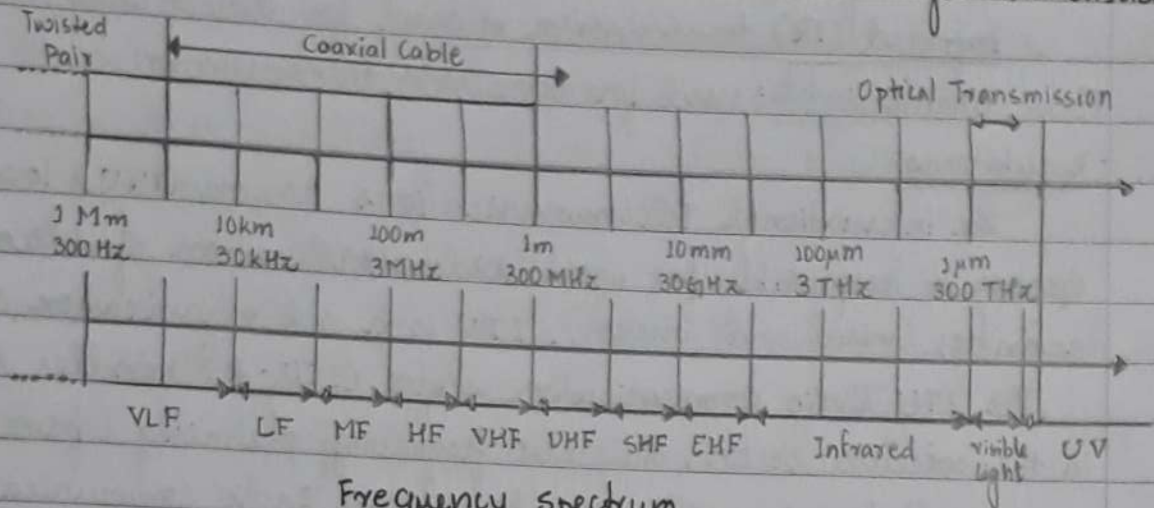
Generates many codes over a wide frequency band.

3. Technology, Feasibility and service Affordability:

Microprocessors and microcomputers were used for controlling many complicated features and functions with less power and size, also LSI circuits reduced the size of mobile transceivers so that they easily fit into the standard automobile. This lead to the development of advanced mobile phone systems.

★ Frequencies for Radio Transmission:

Radio Transmissions can take place using many different frequency bands. Each band exhibits certain advantages and disadvantages.



Frequency spectrum

The wavelength is directly coupled to the frequency;

$\lambda = \frac{c}{f}$ where $c = 3 \times 10^8 m/s$ (speed of light in vacuum)
f is frequency.

Frequencies upto several hundred kHz : Twisted pair copper wires
Frequencies of several hundred MHz : coaxial cable
Frequency ranges of several hundred THz : Fiber optics.
Radio transmission starts at several kHz.

VLF : Very Low Frequency range : These are very long waves.

LF : Low Frequency Range : Used by Submarines as they can penetrate water and can follow the earth's surface.

MF : Medium Frequency Range
HF : High Frequency Range
] For transmission of hundreds of radio stations either as amplitude modulation (AM : 520 kHz – 1605.5 kHz), as short wave (SW : 5.9 MHz – 26.1 MHz) or as frequency modulation (FM : 87.5 MHz – 108 MHz). The short waves are typically used for radio transmission around the world enabled by reflection at the ionosphere.

VHF : Very High Frequency Range
UHF : Ultra High Frequency Range
] TV stations. UHF is also used for mobile phones (analog).

SHF : Super High Frequency Range : used for directed microwave links and fixed satellite services.

EHF: Extremely High Frequency Range: comes close to infrared.
All the Radio frequencies are regulated inorder to avoid interference.

Infrared (IR) transmission is used for direct links.

Visible light: used for wireless transmission.

- Regulations:

The International Telecommunications Union (ITU) located in Geneva is responsible for worldwide coordination of telecommunication activities (wired and wireless). ITU is a sub-organization of the UN.

The ITU Radio communication sector (ITU-R) handles standardization in the wireless sector, thus also frequency planning (formerly known as Consultative committee for International Radio communication (CCIR)).

The ITU-R has split the world into three regions:

Region 1: Europe, the Middle East, countries of the former Soviet Union and Africa

Region 2: Greenland, North and south America

Region 3: the Far East, Australia and New Zealand

To achieve some harmonization, the ITU-R holds periodic conferences, the world Radio conference (WRC) to discuss and decide frequency allocations for all three regions

* FCC Allocation for Mobile Radio Transmission:

The Federal Communications Commission (FCC) decided to choose:

- Mobile Radio communications: 800 MHz because of several spectrum limitations at lower frequency band.
- FM Broadcasting: 100 MHz
- Television Broadcasting: 41 MHz to 960 MHz
- Air to Ground systems: 118 to 136 MHz
- Military Aircraft: 225 to 400 MHz
- Maritime Mobile Service: 160 MHz
- Fixed station services: 300 to 100 MHz

It was difficult for the FCC to allocate a spectrum in the lower portions of the 30 to 400MHz band since the services of this band had been overcrowded.

On the other hand, mobile radio transmission cannot be applied at 10GHz or above because severe propagation path loss, multipath fading and rain activity make the medium improper for mobile communications.

It may be noted that although 800 MHz is not the ideal transmission medium for mobile radio, it has been demonstrated that a cellular mobile system that does not go beyond this frequency band can be deployed.

★ Wireless Communication Standards:

1. First Generation cellular systems

The first generation cellular systems make use of analog FM scheme for speech transmission. The individual calls use different frequencies and share the available spectrum through a particular multiple access technique known as Frequency-Division Multiple~~xing~~ Access (FDMA) which is an analog transmission technique that is inherently narrowband.

First Generation Analog Cellular Systems

REGION	AMERICA	EUROPE	JAPAN
Parameter	AMPS	ETACS	NTT
Multiple Access	FDMA	FDMA	FDMA
Duplexing	FDD	FDD	FDD
Forward channel	869 - 894 MHz	935 - 960 MHz	870 - 885 MHz
Reverse channel	824 - 849 MHz	890 - 915 MHz	925 - 940 MHz
channel spacing	30 kHz	25 kHz	25 kHz
Data Rate	10 kbps	8 kbps	0.3 kbps
Spectral Efficiency	0.33 bps/Hz	0.33 bps/Hz	0.012 bps/Hz
capacity	832 channels	1000 channels	600 channels
	25MHz uplink band 25MHz downlink	25MHz uplink band 25MHz downlink	15MHz uplink band 15MHz downlink

AMPS: Advanced Mobile Phone Systems: America and Australia
ETACS: European Total Access communications System
NTT: Nippon Telephone and Telegraph

2. Second Generation cellular systems:

The second generation cellular systems are completely digital. These cellular systems employ either TDMA (Time division multiple access) or CDMA (code division multiple access) as the multiple access technology. The digital technology allows greater sharing of the radio hardware in the base station among the multiple users and provides a larger capacity to support more users per base station per MHz of spectrum as compared to analog systems. Other advantages are:

- natural integration with the evolving digital wireline network
- flexibility for supporting multimedia services
- flexibility for capacity expansion
- reduction in RF transmit power
- encryption for communication privacy
- reduction in system complexity

CDMA: Code Division Multiple Access
~~North~~ America: IS-95

TDMA: Time Division Multiple Access
Europe: Pan-European GSM (Group Special Mobile or Global system for Mobile communications) and DCS 1800 (Digital cellular system).
North America: IS-54, IS-136
Japan: PDC (Personal Digital cellular) systems.

Although, the second generation wireless systems offer higher transmission rates with greater flexibility than the first generation systems, they are nevertheless narrowband systems.

In cellular communications, location management is important.
IS-54 in North America with companion standard IS-41
GSM in Europe: MAP (Mobile Applications Port) both are two-tiered network architecture

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Second Generation Digital cellular Systems

REGION	US	Europe	Japan	US
PARAMETER	IS-54	GSM	PDC	IS-95
Multiple Access	TDMA/FDD	TDMA/FDD	TDMA/FDD	CDMA
Modulation	π/4 DQPSK	GMSK	π/4 DQPSK	QPSK/OQPSK
Forward Channel	869-894 MHz	935-960 MHz	810-826 MHz	869-894 MHz
Reverse Channel	824-849 MHz	890-915 MHz	940-956 MHz	824-849 MHz
Channel Spacing	30 kHz	200 kHz	25 kHz	1.250 kHz
Data Chip Rate	48.6 kbps	270.833 kbps	42 kbps	1.2288 Mcps
Speech codec rate	7.95 kbps	13.4 kbps	6.7 kbps	1.2/2.4/4.8/9.6 kbps

- IS-54 in North America

In frequency domain, modulation scheme is π/4 shifted Differential Quadrature Phase shift keying (DQPSK). In time domain, one TDMA frame consists of six time slots supporting three full rate users or six half-rate users, each slot having a duration of approximately 6.67ms

- GSM in Europe

The modulation scheme used is Gaussian filtered Minimum shift keying (GMSK). In time domain, one TDMA frame consists of eight time slots, each of 0.57 ms duration. Each user transmits periodically in every eighth slot and receives in the corresponding slot.

- PDC in Japan

The system is TDMA-based with three slots multiplexed onto each carrier. The modulation scheme is π/4 shifted DQPSK.

- IS-95 in North America

It is a CDMA-based standard. Users share a common channel for transmission within a cell. Users in adjacent cells also use the same radio channel i.e., the frequency spectrum is reused from cell to cell. The modulation scheme for uplink is offset Quadrature Phase shift keying (OQPSK) and for downlink is QPSK. Forward and Reverse links use different spreading processes. Rake receivers are used at both the base stations and mobile station to resolve and to combine multipath components.

3. Third Generation Wireless communication Networks:

Third Generation standardization activities were initiated in Europe and North America under the names IMT-2000 and cdma-2000. IMT-2000 (International Mobile Tellcommunications 2000) is a wide-band direct-sequence code division multiple access (DS-CDMA), while cdma-2000 is a multicarrier CDMA (MC-CDMA).

ITU has adopted the recommendations of both IMT-2000 and cdma-2000 under the banner of Harmonized Global 3G (G3G). Both IMT-2000 and cdma-2000 use frequency division duplex (FDD) to support two-way transmissions with frequency isolations. TDD (time division duplex) has also been suggested as a third 3G mode. The gist of harmonization is that both ANSI-41 and GSM MAP based services should be fully supported in the Radio Access Network with all 3G CDMA modes.

The third generation cellular systems will be equipped with the infrastucture which are as follows to support Personal Communication Systems (PCS).

- public land mobile networks (PLMNs)
- mobile Internet Protocol (Mobile IP)
- wireless asynchronous transfer mode (WATM) networks
- low earth orbit (LEO) satellite networks.

Features of 3G: i. support Multimedia Services.
ii. Higher Transmission Rate

It means that the signal bandwidth is large compared with the coherence bandwidth of the channel, then different frequency components of the signal experience different fading characteristics. To combat frequency selective fading Orthogonal Frequency Division Multiplexing (OFDM) is adopted. This done be partitioning signal into narrow continuous frequency bands and then each band is modulated onto a different subcarrier and is sent over the channel in parallel. This can be achieved by converting the high rate serial data sequence into a number of lower rate parallel sequences

Mobiles can be located anywhere within the footprint of a base station. If every mobile transmits the same power level, the signal received at the cell-site receiver from the mobiles closest to it will be the strongest. This is known as the near-far problem and the power levels need to be controlled to smooth out the near-far effect. Power control, rate allocation and service scheduling are radio resource management functions.

iii. Capacity and Impact of User Mobility

The capacity of cellular systems is enlarged through efficient employment of the available bandwidth i.e., by frequency reuse.

Although decreasing cell size allows for a higher degree of frequency reuse to increase system capacity, the trade-off for this benefit is that mobile users tend to move in and out of cells much more frequently. To maintain service continuity, the connection of a mobile user must be handed off from the serving base station to base station of the target cell. Also the mobile needs to identify the current location within the cellular array so that messages can be delivered to the new location. As a result, a reduction in the cell size translates to a larger overhead for mobility management (i.e., handoff management and location management) in the network.

UMTS: Universal Mobile Telecommunication System is the worldwide 3G standard.

4. Fourth Generation:

Features:

- Sophisticated systems
- Adaptive Modulation and Spectral efficiency
- Bandwidth efficient Multiple Access Technology
- Quality of service for next generation multimedia
- Interprobability with existing wireless standards and all IP packet switched networks.

4G technology was introduced in year 2004.
Data transmission speed/bit rate of 5Mbps to 1000 Mbps.

Standards:

4G technology uses LTE (Long Term Evolution) standards. It supports mobile web acess, cloud computing, global mobility support and high definition mobile TV.

4G also enable a VoLTE (voice over Long Term Evolution) standard for high speed wireless communication for mobile phones and data terminals including IoT devices and wearable.

OFDM (Orthogonal Frequency Division Multiplexing)

OFDM can be used as a multip-access scheme by partitioning different subcarriers among multiple users. This scheme is referred as OFDMA and is used in LTE standard.

OFDM converts a frequency selective broad band channel into several narrowband flat fading channels where the MIMO models and techniques work well.

Evolution of WiMAX

Along with LTE, WiMax (World Wide Interoperability for Microwave Access) represents 4G of wireless internet. It is similar to WiFi which allows users to connect to the internet without wires.

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BEYOND 4G

Fifth Generation (5G) Technology

- 5G refers to fifth generation
- 5G started from late 2010s
- complete wireless communication with almost no limitations
- It is highly supported by WWWW (Wireless World Wide Web).
- Aims at higher capacity than current 4G, allowing a higher density of mobile broadband users.
- Supports interactive multimedia, voice streaming and enhanced security.

Advantages:

- Data bandwidth of 1Gbps or higher
- Globally accessible
- High connectivity
- Very high data rate
- very high capacity
- very low latency
- Massive number of devices

Applications:

- Government: smart cities, public safety, public transport,
- consumer: Gaming, wearables, HD/4K/8K video,
- Enterprise: Healthcare, robotics, agriculture, retail, logistics, manufacturing, education, automobile

UNIT - 2

Mobile Communication Concepts

* **Introduction:**

With limitation in spectral width, the maximum number of users (capacity) that can be supported in a wireless mobile system is an important performance measure. If the system is supported by a single base station, a high power transmitter is required to support a large number of users. The system capacity can be enlarged by arranging small cells, each requiring only low power transmitter, in a cellular array.

* **Concept of cellular communications:**

System capacity can be interpreted as the largest number of users that can be supported during any one use of the channel.

If a single transmitter were used to cover a larger geographical area, a very high power transmitter and very high antenna would be required where users will share the same set of frequencies or radio chanels. But in this case radio resources (frequencies) are not efficiently utilized.

In cellular communications same set of radio resources were assigned to serve a smaller geographical area and then reused to serve another small geographical area, it would be possible to expand the system capacity. We need to take care that the use of same frequencies to serve more than one geographical area does not introduce reception interference between users in the two areas (if interference is present it should be within the acceptable range).

Thus these geographical areas must be physically separated from each other to avoid unacceptable interference. This way of replicating identically structured and operated geographical regions gives rise to the concept of cellular communications.

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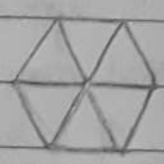
Cell: a geographical region that can be a single small area that is served by a single base station or a cluster of cells. Each base station in the cluster is connected to a mobile switching center (MSC) by wirelines. An MSC has more computing power and can perform more functions than an individual base station. Most of the operations are handled by MSC.

★ Cell Fundamentals:

In radio propagation it is easier to obtain insight and understanding for system design by visualizing all cells as having the same shape and uniform cell size.

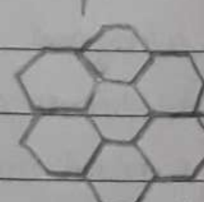
For cells of the same shape to form a tessellation so that there are no ambiguous areas that belong to multiple cells or to no cell, the cell shape can be only equilateral triangle, square or regular hexagon.

A hexagonal cell is the closest approximation to a circle of these three polygons. For a given radius the hexagon has the largest area. Using hexagonal cells requires the fewest number of cells to cover a geographical area.


Triangular

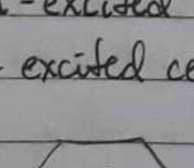

Square

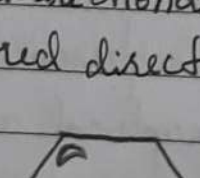
It approximates a circular radiation patter which could occur for an omnidirection base station antenna. The base station transmitters are depicted as either being in the center of the cell (center-excited cells) or on three of the six cell vertices (edge-excited cells).


Hexagonal

Center-excited cells: omnidirectional antennas

Edge-excited cells: sectored directional antennas

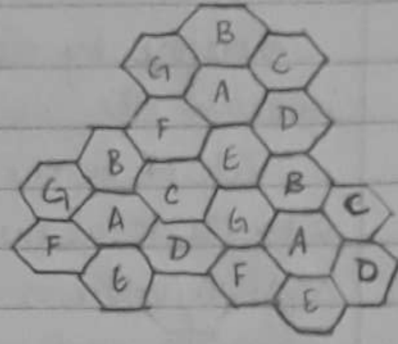

Center-excited cell


Edge-excited cell

★ Frequency Reuse Concept:

The designing process of selecting and assigning channel groups for all of the cellular base stations within a system is termed as frequency planning or frequency reuse concept.

In adjacent cells, the base stations are allocated those channel groups which contain completely different channels than neighboring cells. Also we can limit the coverage to within the boundary limit of the cells so that same group of channels maybe used to cover different cells which are separated by a distance large enough to keep interference levels within tolerable limits.



★ Concept of cell cluster:

If the available channels are reused for transmission of additional traffic it is possible to expand the system capacity. Two or more different cells can use the same set of frequencies if the nearest cells are separated such that interference is at acceptable range. Cells which use the same set of frequencies are referred to as co-channel cells and the interference between them is called as co-channel interference.

The space between adjacent co-channel cells can be filled with other cells that use different frequencies to provide frequency isolation. A group of cells that use a different set of frequencies in each cell is called a cell cluster.

N: cluster size, number of cells in a cluster

K: total number of channels without frequency reuse

N is also referred to as the frequency reuse factor of the cellular system.

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- Capacity increase by Frequency Reuse concept:

Let us consider each cell is allocated J channels ($J \leq K$). If K channels are divided among the N cells into unique and disjoint channel groups each with J channels, then

$$K = JN \quad \text{——— (1)}$$

Therefore by decreasing the cluster size (N), it is possible to increase the capacity per cell (J).

Let M be the number of times the cluster is replicated and C be the total number of channels used in the entire cellular system with in frequency system. The C is the system capacity and is given by:

$$C = MJN \quad \text{——— (2)}$$

If N is decreased and J is increased proportional by keeping K ($K = JN$) as constant, it is essential to replicate the smaller cluster more times in order to cover the same geographical area.

Therefore when M is increased, the system capacity C is increased. Hence when N is minimalized, C is maximized.

Example:

Q1: Given a cellular system in which there are a total of 1001 radio channels available for handling traffic. It is also given that the area of a cell is 6 km^2 and the area of the entire system is 2100 km^2.

i. Calculate the system capacity for the cluster size 7

ii. How many times would the cluster of size 4 have to be replicated inorder to approximately cover the entire cellular area?

iii. Calculate the system capacity if the cluster size is 4

iv. Does decreasing the cluster size increase the system capacity? Explain.

Given:

The total number of available channels : $K = 1001$

Area of cell : $A_{cell} = 6\ km^2$

Area of cellular system : $A_{sys} = 2100\ km^2$

i. cluster size : $N = 7$

The number of channels per cell

$$J = \frac{K}{N} = \frac{1001}{7} = 143 \text{ channels/cell}$$

Area coverage of a cluster

$$A_{cluster} = N \times A_{cell} = 7 \times 6 = 42\ km^2$$

Number of times that the cluster has to be replicated to cover the entire system

$$M = \frac{A_{sys}}{A_{cluster}} = \frac{2100}{42} = 50 \text{ times}$$

Therefore, the system capacity is

$$C = MJN = 50(143)7 = \underline{50050 \text{ channels}}$$

ii. cluster size : $N = 4$

Area coverage of a cluster

$$A_{cluster} = N \times A_{cell} = 4 \times 6 = 24\ km^2$$

Therefore, number of times the cluster has to be replicated to cover the entire system is

$$M = \frac{A_{sys}}{A_{cluster}} = \frac{2100}{24} = \underline{87 \text{ times}}$$

iii. cluster size : $N = 4$

Number of channels per cell is

$$J = \frac{K}{N} = \frac{1001}{4} = 250 \text{ channels/cell}$$

Therefore, system capacity is

$$C = MJN = 87 \times 250 \times 4 = \underline{87000 \text{ channels}}$$

iv. From i and iii it shows that decrease in N from 7 to 4 has caused increase in system capacity C from 50050 to 87000 channels. Thus decreasing cluster size increases the system capacity.

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- Cellular Layout for Frequency Reuse:

Rule to determine the Nearest co-channel neighbors.

step 1: Move i cells along any chain of hexagons

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

These cochannels cells must be separated in such a way that there is no co-channel interference.

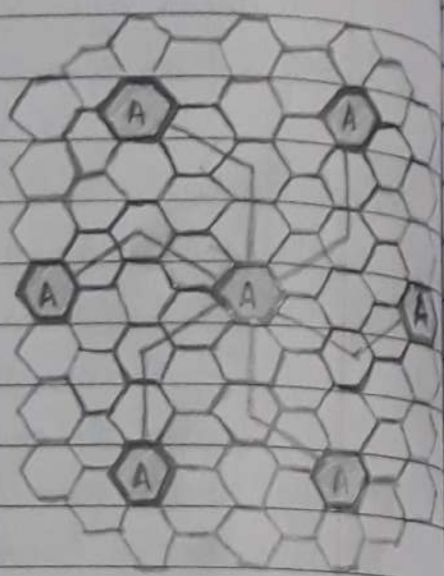
The cluster size N is related to i and j such that:

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

Ex: $i = 2$ and $j = 1$

$$N = 2^2 + 2(1) + 1^2 = 7$$

The frequency reuse factor is 7 since each cell contains one-seventh of the total number of available channels.



$i = 2$; $j = 1$

- Advantages of cellular systems:
  - the use of low power transmitter
  - an allowance for frequency reuse

As the distance between co-channel cells increases the co-channel interference will decrease. If the cell size is fixed, the average signal-to-cochannel interference ratio will be independent of the transmitted power of each cell.

Example:

Q2: Given a cellular system with a total bandwidth of 30MHz which uses two 25kHz simplex channels to provide full duplex voice and control channels. Assuming that the system uses a nine-cell reuse pattern and 1MHz of the total bandwidth is allocated for control channels.

i. calculate the total available channels

ii. determine the number of control channels

iii. determine the number of voice channels per cell

iv. determine an equitable distribution of control and voice channels in each cell.

→ Given: $N = 9$

Total bandwidth = 30 MHz

channel bandwidth = $25k \times 2 = 50\,kHz$ / duplex channel

i. The total number of available channels is

$$\frac{30 \times 10^6}{50 \times 10^3} = \underline{600 \text{ channels}}$$

ii. The number of control channels is

$$\frac{1 \times 10^6}{50 \times 10^3} = \underline{20 \text{ control channels}}$$

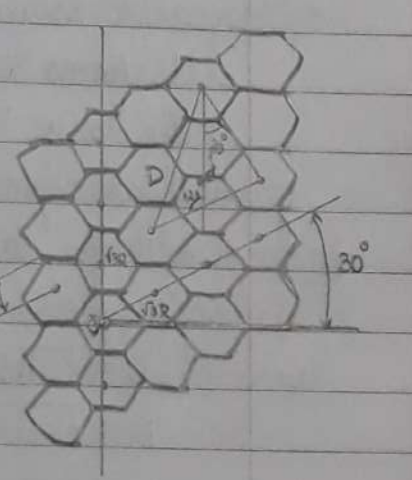
iii. The number of voice channels per cell is

$$\frac{600-20}{9} = \frac{580}{9} = \underline{64} \text{ voice channels per cell}$$

iv. A maximum of 20 channels can be used as control channels. For $N=9$, 7 cells with 2 control channels and 64 voice channels each and 2 cells with 3 control channels and 66 voice channels each. This allocation is not unique.

★ <u>Geometry of hexagonal cell</u>

R is the radius of the hexagonal cell (center to vertex). A hexagon has exactly six equidistant neighbors. The 60° angle is bounded by the vertical line and the 30° angle of line which joins centers of the hexagonal cells.



The distance between the centers of two adjacent cells is $\sqrt{3}R$.

Let D_{norm} be the distance between centers of candidate cell and nearest co-channel cell, normalized with respect to the distance between the centers of two adjacent cells, $\sqrt{3}R$.

The normalized distance between two adjacent cells is unity ($i=0$ and $j=1$ or $i=1$ and $j=0$)

Let D be the actual distance between the centers of two adjacent co-channel cells. D is a function of Dnorm and R

From the figure.

$$D_{norm}^2 = j^2 \cos^2(30^\circ) + (i + j\sin(30^\circ))^2$$

$$D_{norm}^2 = i^2 + ij + j^2$$

but $N = i^2 + j^2 + ij$

Therefore

$$D_{norm}^2 = N \Rightarrow D_{norm} = \sqrt{N}$$

with actual distance $\sqrt{3}R$ between the centres of two adjacent hexagonal cells, the actual distance between the centre of the candidate cell and the other of a nearest co-channel cell is

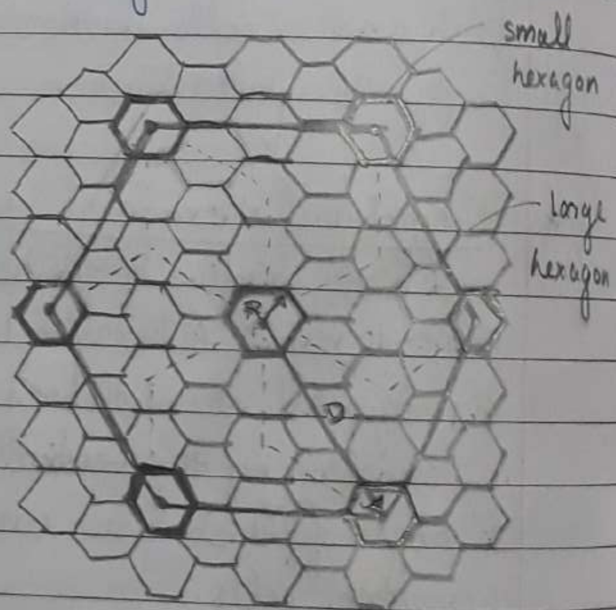
$$D = D_{norm}\sqrt{3}R$$

$$\boxed{D = \sqrt{3N}R}$$

Example

Q3: Verify that the cell cluster size is $N = i^2 + ij + j^2$ where i and j are the integer parameters determining the cochannel cells

- A candidate cell has 6 nearest co-channel cells. By joining the centers of the 6 nearest neighboring co-channel cells forms a large hexagon. The large hexagon has radius equal to D, which is also the co-channel cell separation.



$$D = \sqrt{3}R D_{norm}$$

$$D = \sqrt{3(i^2 + ij + j^2)}R$$

In general, the area of a hexagon is proportional to the square of its radius. Let $\beta = 2.598$ be the proportional constant. Then the area of the large hexagon with radius D is

$$A_{large} = \beta D^2 = \beta[3(i^2 + ij + j^2)R^2]$$

The area of a cell (small hexagon) with radius R will be

$$A_{small} = \beta R^2$$

The number of cells in the large hexagon is

$$\frac{A_{large}}{A_{small}} = \frac{\beta[3(i^2+ij+i^2)]R^2}{\beta R^2} = 3(i^2+ij+j^2) \quad \text{——— } ①$$

On the other hand, the large hexagon encloses the center cluster of N cells plus 1/3 the number of the cells associated with six other peripheral large hexagons.

Therefore the total number of cells enclosed by the large hexagon is given by:

$$N + 6\left(\frac{1}{3}N\right) = 3N \quad \text{——— } ②$$

From eq ① and ②, we get:

$$\underline{N = i^2 + ij + j^2}$$

Hence Proved.

★ **Frequency Reuse Ratio:**

The frequency reuse ratio is represented by 'q'. It is expressed as: $q \triangleq \frac{D}{R}$

Since, frequency reuse leads to co-channel cell operation, q is also referred to as the co-chanel reuse ratio.

$$q = \sqrt{3N}$$

q increases with N and since smaller value of N has the effect of increasing the capacity of the cellular system and at the same time increasing co-channel interference, the choice of q or N has to be made such that the signal-to-co-channel interference ratio is at an acceptable level.

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★ Co-channel and Adjacent channel Interference:

Interference from other mobiles at the cell-site receiver in the same cell is **intracell interference**. Interference from other cells is called as **intercell interference**.

– Co-channel Interference:

Wireless channels are interference limited. Except for the co-channel cells, other neighboring cells will operate at frequencies different from those of the candidate cell so that interference from non co-channel cells will be minimal. Intercell interference is thus dominated by co-channel interference.

Let S be the power of the desired signal and I be the power of the co-channel interference at the output of the receiver demodulator. Let N_I be the number of co-channel interfering cells and I_i be the interference power caused by transmissions from the i^{th} interfering co-channel cell base station.

The signal to co-channel interference ratio (S/I) at the desired mobile receiver is given by

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

Let D_i be the distance between the i^{th} interferer and the mobile. The received interference I_i at a given mobile due to the i^{th} interfering cell is proportional to $(D_i)^{-k}$ where k is the path loss exponent. The path loss exponent k is normally determined by measurement.

The inherent background noise can be neglected in an interference dominated environment. The desired received signal power S is proportional to r^{-k} where r is the distance between the mobile and the serving base station.

When the transmitted powers from all base stations are equal and the path loss exponent is the same throughout the geographical area, the co-channel interference from the i^{th}

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co-channel cell. I_i for all i depends on D_i and k only.
The S/I at a typical mobile receiver can be approximated by:

$$\frac{S}{I} = \frac{r^{-k}}{\sum_{i=1}^{N_I} D_i^{-k}}$$

The degree of co channel interference is a function of the location of the mobile within the cell of the serving base station. When the mobile is located at the cell boundary ($r \doteq R$) the worst case co-channel interference occurs and the power of the desired signal is minimum.

For hexagonal shaped cellular systems there are always size cochannel interference cells in the first tier (second, third.... tier are neglected).

$\therefore N_I = 6$, here $r = R$ and $D_i \simeq D$ for $i = 1, 2, \ldots N_I$.

Hence
$$\frac{S}{I} = \frac{\left(\frac{D}{R}\right)^k}{N_I} = \frac{q^k}{N_I} = \frac{(\sqrt{3N})^k}{N_I}$$

Thus the frequency reuse ratio can be expressed as:
$$q = \left(N_I \times \frac{S}{I}\right)^{1/k} = \left(6 \times \frac{S}{I}\right)^{1/k}$$

For the US AMPS analog FM system
$S/I = 18$ dB or greater is acceptable.
with path loss exponent of $k = 4$, frequency reuse ratio is
$$q = (6 \times 10^{1.8})^{1/4} = 4.41$$
Hence the cluster size N should be
$$N = \frac{q^2}{3} = 6.49 \simeq 7$$

Example

Q4: The acceptable signal to cochannel interference ratio in a certain cellular communications situation is $S/I = 20$ dB or 100. Also, from measurements, it is determined that $k = 4$. What will be the minimum cluster size?

The frequency reuse ratio can be calculated as

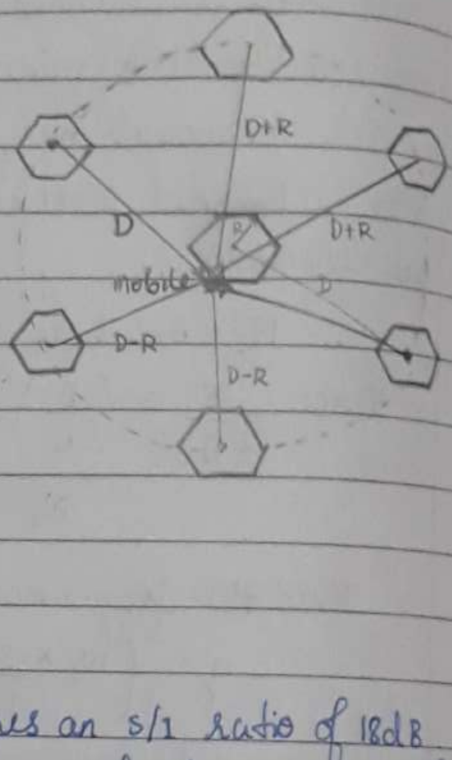
$$q = (6 \times 100)^{1/4} = \underline{4.9492}$$

The cluster size is given by

$$N = \frac{q^2}{3} = 8.165 \simeq \underline{9}$$

If N is less than 9, the S/I value would be below the acceptable level of 20 dB

When mobile is at the cell boundary the worst co-channel interference is experienced.



S/I can be expressed as:

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

wkt $D/R = q$

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

Example:

Q5: Given a cellular system that requires an S/I ratio of 18dB.

i. For a frequency reuse factor of 7, calculate the worst case signal to co-channel interference ratio.

ii. Is a frequency reuse factor of 7 acceptable in terms of co-channel interference? If not, what would be a better choice of frequency reuse factor?

i. For N = 7, the frequency reuse factor is

$$q = \sqrt{3N} = 4.6$$

Assuming path loss exponent $k = 4$, the worst case signal to cochannel interference ratio is

$$\frac{S}{I} = \frac{1}{2(4.6-1)^{-4} + 2(4.6)^{-4} + 2(4.6+1)^{-4}} = 54.3 = 17.3\,dB$$

ii. The value of S/I for a 7 frequency reuse factor is below the acceptable level of 18dB. To increase S/I we need to decrease I which can be achieved by increasing the frequency reuse factor, N.

For $N = 9$, $q = \sqrt{3N} = 5.20$, hence $S/I = 95.66 = 19.8\,dB$

This value of S/I is above the acceptable level of 18 dB. Hence a frequency reuse factor of 9 is suitable choice.

NOTE:

An increase of frequency reuse factor yields an acceptable S/I level but this decreases the system capacity which is not tolerable. From an operational point of view, catering to the worst case scenario which rarely occurs may not be desirable.

- Adjacent Channel Interference:

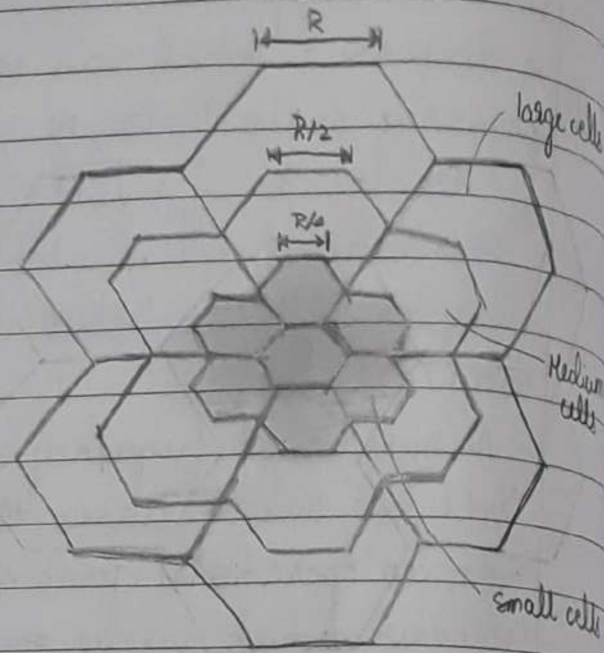
Adjacent Channel Interference (ACI) results from signals which are adjacent in frequency to the desired signal. It is mainly due to imperfect receiver filters which allow nearby frequencies to leak into the passband.

To reduce Adjacent Channel Interference (ACI) we should:

- use modulation schemes which have low out-of-band radiation (ex. MSK is better than QPSK and GMSK better than MSK).
- carefully design the bandpass filter at the receiver front end.
- use proper channel interleaving by assigning adjacent channels to different cells
- avoid using adjacent channels in adjacent cells to further reduce ACI if the cell cluster size is large enough.
- separate the uplink and downlink properly by TDD or FDD

* Various Mechanisms for capacity Increase:

1. Cell Splitting:



Cell splitting is to subdivide a congested cell into smaller cells each with its own base station and a corresponding reduction in antenna height and transmit power. With more cells, there will be more clusters in the same coverage area. This is equivalent to replicating a cell cluster more times i.e, the replication factor M is increased. Hence, the cell splitting increases the capacity of a cellular system as it increases the number of times that channels are reused.

The central area is assumed to be saturated with traffic. (call blocking probability in the area exceeds the acceptance level).

Original large cells (radius = R) $\xrightarrow{\text{split}}$ Medium cells (radius = R/2) $\xrightarrow{\text{split}}$ Small cells (radius = R/4)

The cell splitting reduces the call blocking probability in the area and increases the frequency with which mobiles hand off from cell to cell.

Let d: distance between the transmitter and receiver
d_0: distance from transmitter to a close-in-reference point.
P_0: the power received at the close-in-reference point.

The average received power is given by:

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

k : path loss exponent.

Taking logarithm

$$P_{r(dBW)} = P_{0(dBW)} - 10k \log_{10}\left(\frac{d}{d_0}\right) \qquad d \geq d_0$$

Let P_{t_1} : transmit power of the large cell base station

P_{t_2} : transmit power of the medium cell base station.

The received power P_r at the large (old) cell boundary is proportional to $P_{t_1} R^{-k}$ and P_r at the medium (new) cell boundary is proportional to $P_{t_2}(R/2)^{-k}$. On the basis of equal received power

$$P_{t_1} R^{-k} = P_{t_2} (R/2)^{-k}$$

$$\frac{P_{t_1}}{P_{t_2}} = 2^k$$

Taking logarithm,

$$10 \log_{10}\left(\frac{P_{t_1}}{P_{t_2}}\right) = 10k \log_{10} 2 = 3k\,dB$$

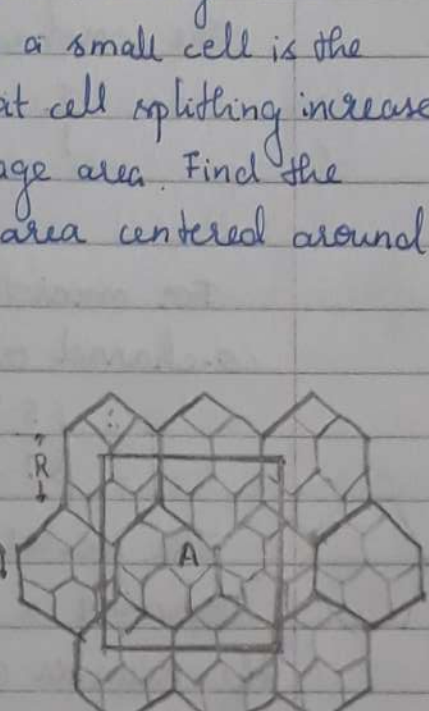
For $k = 4$ $\frac{P_{t_1}}{P_{t_2}} = 12\,dB$, Thus with cell splitting where the new cell is 1/2 of that of the old cell we can achieve a 12dB reduction in the transmit power.

Example

Q6: The original cells have radius R. These cells are split into smaller cells each of radius R/2. Assume that each base station is allocated 60 channels regardless of the cell size. There are obviously more small cells than original cells in the same coverage area. Because the number of channels allocated in a small cell is the same as that in a large cell, it is obvious that cell splitting increases the number of channels with the same coverage area. Find the number of channels contained in a $3 \times 3\ km^2$ area centered around (small) cell 'A' for the following cases:

i. without cell splitting
(i.e., just the original large cells)

ii. with cell splitting
(i.e., using the small cells)



— To cover an area of $3 \times 3\ km^2$ centered around cell A, we need to cover 1.5 km to the right, left, up and down. This area consists of more smaller cells than larger cells.

Because of edge effect, the number of either type of cells contained within the square can only be an estimate. Approximately there are 4 large cells (visual observation)

With a 1/2 radius split, the number of small cells within the square would be

$$\left(\frac{R}{R/2}\right)^2 \times \text{number of large cells} = 4 \times 4 = 16 \text{ small cells.}$$

This calculation is correct only if the enclosed area is infinitely large. With a finite area it is necessary to take edge effect into consideration, so it will be less than 16. A reasonable estimate would be 15 small cells.

i. The number of channels is $4 \times 60 = 240$ channels

ii. The number of channels contained in the square, with cell splitting is $15 \times 60 = 900$ channels which is 3.75 times without splitting. Therefore it is almost a 4-fold increase.

2. <u>Sectoring</u>: (Directional Antennas)

Directional antennas can increase the system capacity relative to that of omnidirectional antennas.

The worst case S/I is given by:

$$\frac{S}{I} = \frac{R^{-k}}{\sum_{i=1}^{N_I} D_i^{-k}}$$ where N_I depends on the form of antenna used.

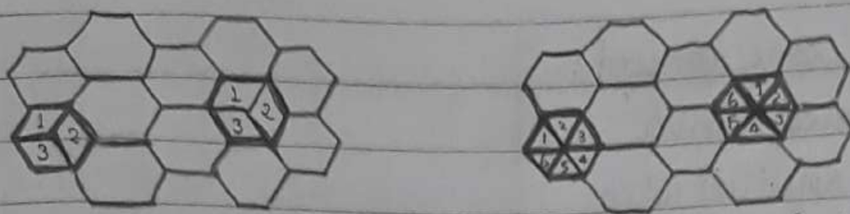
For omnidirectional antennas: $N=6$ for first tier of co-channel cells with $D_i \cong D$, $i = 1, 2, \ldots, N_I$

$$\therefore \left(\frac{S}{I}\right)_{omni} = \frac{1}{6} q^k \qquad \text{where } q = \frac{D}{R}$$

The sectorization can be done in multiples of 60°. Assuming a 7-cell reuse for the 3-sector case (120°/sector) the number of interferers in the first tier is reduced from 6 to 2.

$$\left(\frac{S}{I}\right)_{omni} = \frac{1}{6} q^k \qquad \left(\frac{S}{I}\right)_{120} = \frac{1}{2} q^k$$

Antenna sectorization



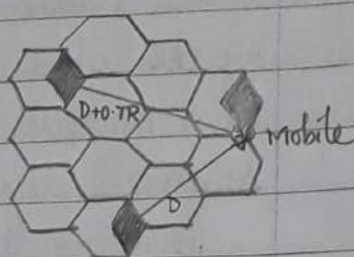
a. 3 sectors of 120° each   b. 6 sectors of 60° each

The increase in the signal-to-interference ratio is then

$$\frac{\left(\frac{S}{I}\right)_{120}}{\left(\frac{S}{I}\right)_{omni}} = 3$$

Therefore, the capacity increases by using directional antennas.

A worst case scenario in a 120° sectorization where the mobile is located at the corner of the cell.



R is the cell radius and D is the distance between the adjacent co-channel cells.

In the 3-sector case, the mobile experiences interference from one sector of each of the two interfering cells with the distance approximation shown and a path loss exponent of $k=4$

$$\left(\frac{S}{I}\right)_{120^\circ} = \frac{R^{-4}}{D^{-4}+(D+0.7R)^{-4}} = \frac{1}{q^{-4}+(q+0.7)^{-4}}$$

<u>Example</u>

Q7: With a frequency reuse factor of 7, base stations using omnidirectional antennas cannot satisfy the 18 dB signal to co-channel interference requirement. Determine whether the use of 120° sectoring and 7-cell frequency reuse would satisfy the 18dB requirement.

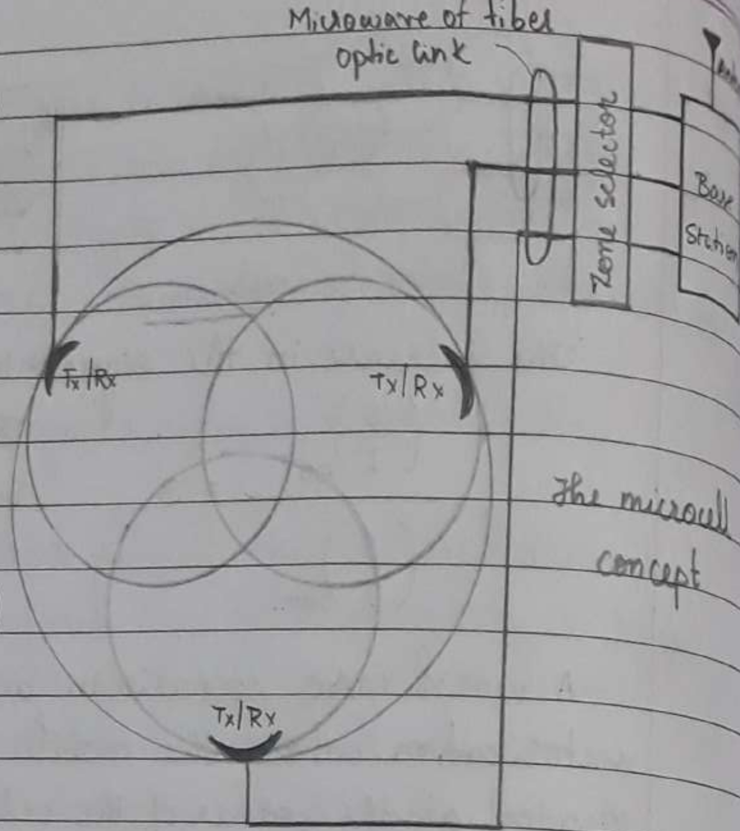
– For a 7-cell reuse, $q = \sqrt{3\times 7} = 4.6$

$$\left(\frac{S}{I}\right)_{120^\circ} = \frac{1}{q^{-4}+(q+0.7)^{-4}} = \frac{1}{(4.6)^{-4}+(4.6+0.7)^{-4}} = 285 \approx 24.5\text{dB}$$

Since this is greater than 18dB, the 3 sector worst case for a 7-cell reuse is acceptable.

3. Microcell zone concept:

The increased number of handoffs required when sectoring is employed results in a increase load on the switching and control link elements of the mobile system. A solution to this problem was proposed by Lee which was based on a microcell concept for seven cell reuse.



The microcell concept

In microcell zone concept each of the three zone sites are connected to a single base station and share the same radio equipment. Multiple zones and a single base station make up a cell.

As a mobile travels within the cell, it is served by the zone with the strongest signal. This approach is superior to sectoring since antennas are placed at the outer edges of the cell and any base station channel may be assigned to any zone by the base station. As a mobile travels from one zone to another within the cell, it retains the same cell as the base station simply switches the channel to a different zone site. Thus a given channel is active only in the particular zone in which the mobile is travelling and hence the base station is localized and interference is reduced.

The advantage of the zone cell technique is that while the cell maintains a particular coverage radius, the co-channel interference in the cellular system is reduced since a large central base station is replaced by several lower powered transmitters at the edge of the cell. This increases the signal quality and also leads to an increase in capacity without the degradation in trunking efficiency caused by sectoring

★ Channel Assignment Strategies:

1. Fixed Channel Assignment (FCA):

In FCA, each cell is allocated a predetermined set of voice channels. Any call attempt within the cell can only be served by the unused channels in that particular cell. To improve utilization, a borrowing option maybe considered where a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied and the neighboring cell has spare channels. The MSC is the natural subsystem to oversee function such as channel borrowing.

2. Dynamic Channel Assignment (DCA):

In DCA, voice channels are not alloted to different cells on a permanent basis. Each time a call request is made, the serving base station requests a channel from the MSC which determines the availability of channel and executes its allocation procedure accordingly. The MSC only allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference.

DCA reduces the likelihood of call blocking which increases the trunking capacity of the system, since all available channels under the control of the MSC are accessible to all of the cells. DCA strategies require the MSC to collect real-time data on channel occupancy, traffic distribution and radio signal quality of all channels on a continuous basis in order to manage handoff.

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★ Handoff Strategies:

The switching of an ongoing call to a different channel or cell (base station) is known as handover or handoff.

- The purpose of hand off are as follows:
  - If the quality of a communication has become worse than a threshold, a decision of handoff is made for rescuing connection.
  - It keeps a continuous connection with a moving mobile that is it avoids call termination.
  - It improves the cellular network performance by reducing the call drop rate and the congestion rate.
  - It frees up some capacity for other users.

- Handoff Parameters:

The following basic parameters are needed to determine whether a handoff is required or not.

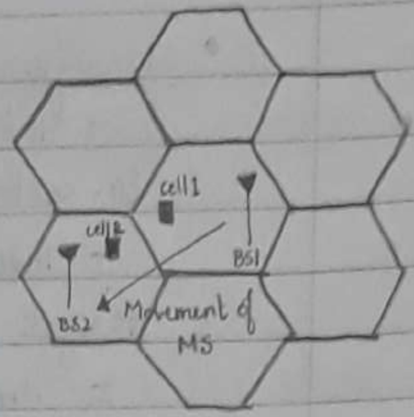
1. signal strength of the base station with which communication is being made.
2. Signal strength of the surrounding base stations
3. Availability of channels.

The handoff parameters are measured in the following way:

1. Signal strengths of base stations are measured by the mobile devices.
2. Channel availability status is known at the cellular network.
3. cellular network makes the decision about when the hand over is to take place in which channel of which cell.

- Handoff process in cellular mobile communication:

The mobile phone continuously monitors the signal strength of the surrounding base station including the one which is currently being used and it feeds this information back. When the strength of the signal from the current base station starts to fall to minimum acceptable level the cellular network looks at the reported signal strength from other base stations reported by the mobile. It then checks for channel availability, if it finds a channel it informs the new base station to reserve a channel for the incoming mobile. When ready, the current base station passes the



Handoff between BS1 and BS2 (cell 1 to cell 2)

information from the new channel to the mobile. When the mobile on the new channel sends a message, it informs to the network that it has arrived. If this message is successfully sent and received then the network shuts down communication with the mobile on the old channel, freeing it up for other users and all the communication takes place on the new channel.

For example: When the mobile is moving from BS1 to BS2 the signal strength of BS1 reduces to minimum acceptable level and the signal strength of BS2 is dominated. Then the call automatically connects to BS2 and hence the call is transferred without interruption.

Handoff situation worsens if the number of mobile users per cell increases. With the increased rate of mobile users per cell, a big cell can be divided into more number of smaller cells. Hence, more number of handoff situations occurs.

- Types of handoffs:
  - Classification based on natures of handoff:
    - Hard Handoff: break-before-make handoff
    - Soft Handoff: make-before-break handoff
    - Softer Handoff: occurs when the mobile is communicating with two sectors of the same base station in a given cell simultaneously.

- Classification based on Purposes of handoff:
  - Intra-cell handoff: the handoff in between sector to-sector (360° to three 120° individual areas).
  - Inter-cell handoff: handoff when the source and target are in different cells.
  - Inter-system handoff: handoff when a mobile moves away from one system controlled by an MSC and enters in to another system controlled by a different MSC.
- Classification based on Algorithms of Handoff:
  - MCHO: Mobile-controlled Handoff
  - NCHO: Network-controlled Handoff
  - MAHO: Mobile-Assisted Handoff

SLE : UNIT - 2 : Mobile communication concepts

Concepts of femto, pico, micro, macro cells and umbrella cell approach

→ **Femto cell:**

- small, fully featured, low powered cellular base station
- connected to a mobile operator's network via a standard broadband DSL or cable service
- They are so small that they resemble Wi-Fi modems
- Designed for homes and business establishments
- Originally known as access point base stations
- Homes : 2 to 4 mobile phone users simultaneously
  Enterprises: 8 to 16 simultaneous users
- To maximize full potential, household members or coworkers are encouraged to subscribe to the same mobile carrier
- Used in Wideband code Division Multiple Access (WCDMA), networks.
- The signal received by the femto cell are sent to the mobile operator's switching centers via the broadband IP network as encrypted data.

→ **Pico Cell:**

- A small cellular base station alternative to a repeater or distributed antenna system.
- Used to extend wireless services to building interiors or other areas that cannot be reached by networks that serve larger cell towers.
- Useful in securing voice and data connectivity to smaller interior areas.
- Size varies from a laptop computer to entire room.
- Maintained and operated by a larger network provider

→ **Micro cells:**

- Used to enhance or extend the signal strength in a certain small area (public place)
- Different mobile network companies have different ranges of microcells attached to the towers and the range can be controlled by varying the power supplied.
- Used in airports, malls and other crowded places where more people are connected to a single tower.
- Provides a small region of coverage with a strong signal strength for more devices to connect or where service is poor or non existant.

→ **Macro cells:**

- Its function is to provide radio coverage to a large area of mobile network access.
- Different from microcell: large coverage area and high efficiency output.
- Coverage distance varies depending on the frequency and bandwidth of the signals as well as physical obstructions in the area.
- Antennas must be at heights for an unhindered and clear view of surroundings.
- Used in areas such as highways and rural areas where large stretches have rarely any service within a few kilometers.

→ **Umbrella cell:**

microcells - low traffic speed
macrocells - high traffic speed
The smaller cell is grouped and assumed to be under a larger cell. This is an umbrella concept. It can be used to provide a large area to

large umbrella cell for high speed traffic

small microcells for low speed traffic

high speed users while small area coverage to users that travel at low speeds.

Advantages:

- A large coverage area to high speed users
- Minimize the number of handoffs for high speed users
- Provide addition micro-cell channel for pedestrian user
- The base station alone can decide whether to hand the user into the co-located microcell without the intervention of the MSC if the velocity of the user is decreasing.

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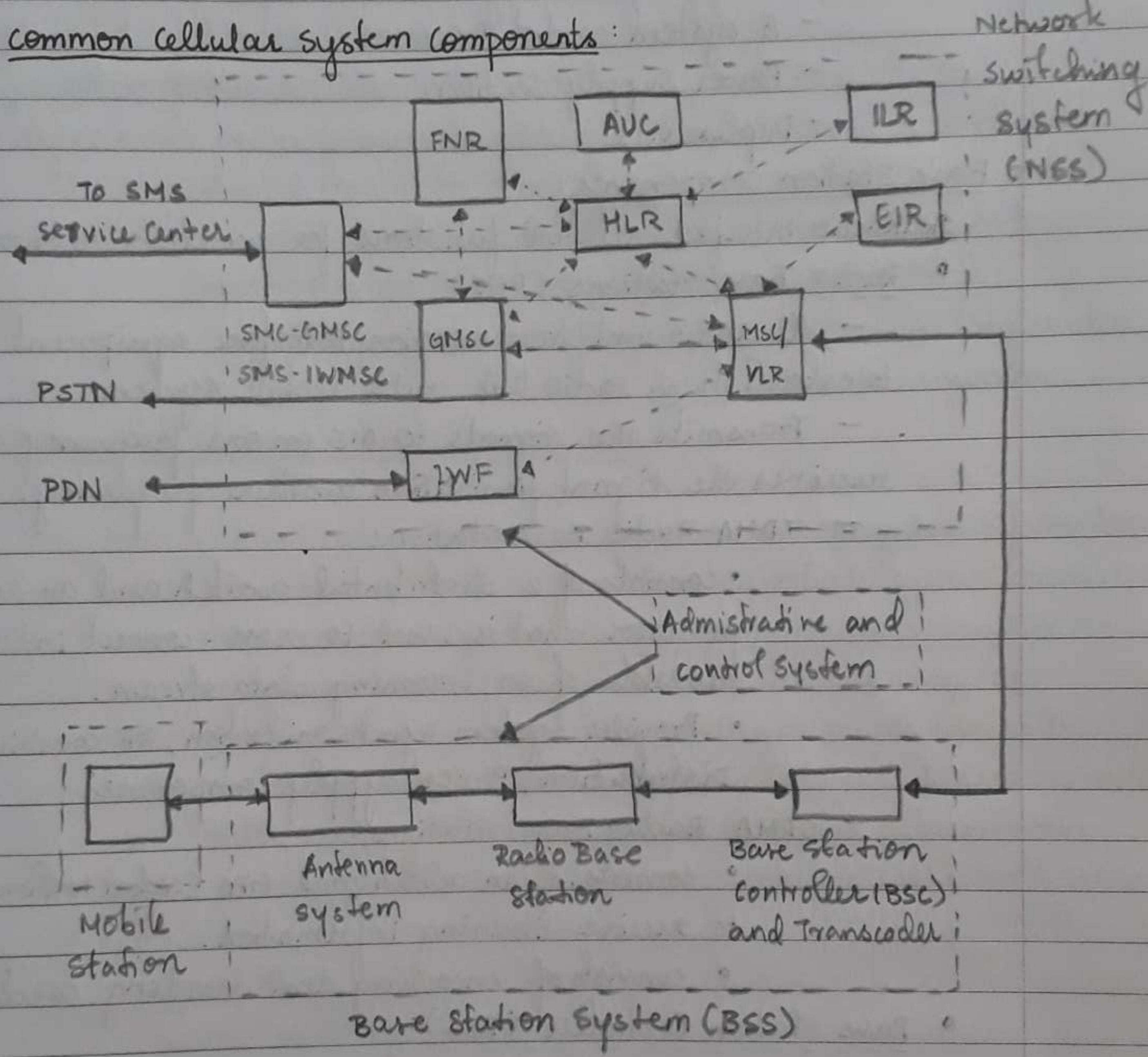
UNIT - 3

Common Cellular System Components

★ **common cellular system components :**



- **Subscriber Device**
  - Also called as mobile station or End terminal.
  - Link between the customer and wireless network
  - Means to provide subscriber to control and input the information and display its operational status
  - To sample, digitize and process audio and other multimedia signals, transmit and receive RF signals, provide power to operate

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- Basic sections:
  - Man-machine interface: telephone keyboard, display.
  - RF Transceiver section: modem of air interface RF signals
  - A signal processing section: sampling, coding, audio video processing
  - A system control Processor: subscriber device management
  - Power supply section: power to energize the system.
  - Duplexer: bidirectional communication over a single path

— Base station components:

- Radio interface related functions for wireless network.
- Radio Base Stations (RBS)
  - All radio and transmission interface equipment needed to establish a radio link with mobile system.
  - Transmits the signals to MS on one frequency and receives the signal from MS on another frequency.
  - TDMA Radio Base stations
    - consists of a distributed switch and an associated processor that is used to cross-connect individual timeslots of an incoming data stream.
    - Provides system synchronization, RF combining and Distribution, Power supply components
  - CDMA Radio Base stations:
    - consists of an additional GPS (Global Positioning system) to receive timining information.
    - consists of encoding and decoding cards.
- Base station Controller (BSC):
  - Supervise the operation of RBSs
  - Manages radio resources for Base Transceiver system (BTS)
  - Assigns frequency and time slots for all mobile stations in its area
  - Handles call setup
  - Handover for each mobile station
  - Radio Power control.

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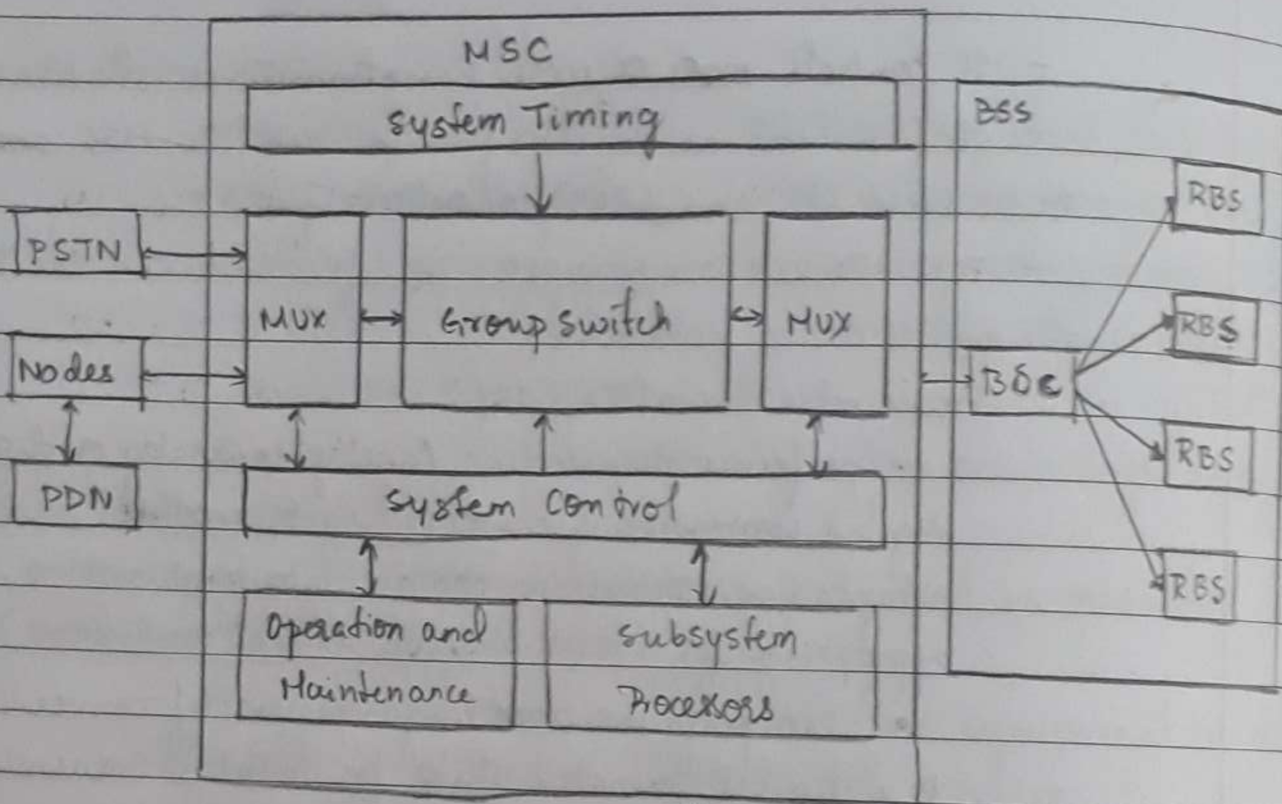
- It controls one or more base transceiver stations (BTS)
- It functions as an interface between the MSC and all the Radio Base stations (RBS) controlled by the BSC.
- PCN : Packet core Network : interface between the BSC and the public data network.
- Transcoder Controller (TRC)
    - performs transcoding (analog-to-analog or digital-to-digital conversion of one encoding to another) and rate adaptation (Deteming optimal data transmission rate appropriate for current wireless channel conditions)
    - also performs vocoding - process of converting audio to a digital format suitable for cellular transmission.

- Network switching system components:
    - FNR : Flexible Number Routing
      AUC : Authentication center : authentication and encryption information
      ILR : Interworking Location Register : support inter system roaming
      HLR : Home location Register : stores information about every user
      white list / black list EIR : Equipment Identify Register : track handsets using IMEI
      MSC : Mobile switching Center : setup, routing, supervise voice calls
      VLR : Visitor Location Register : temporary database when new MS enters
      IWF : Inter working Function : interface to various data networks
      GMSC : Gateway Mobile Switching center : interface wireless mobile network to other telecomm networks
    - consists of functional Database
        - Network privileges
        - Supplementary services
        - Present SDs location
        - Maintain Radio Link connections
    - Mobile switching Center : setting up and control of voice calls, providing voice path continuity through the hand off process, call routing to a roaming subscriber, subscriber registeration and location updating, subscriber data updating, authentication of mobile stations, delivery of short messages.

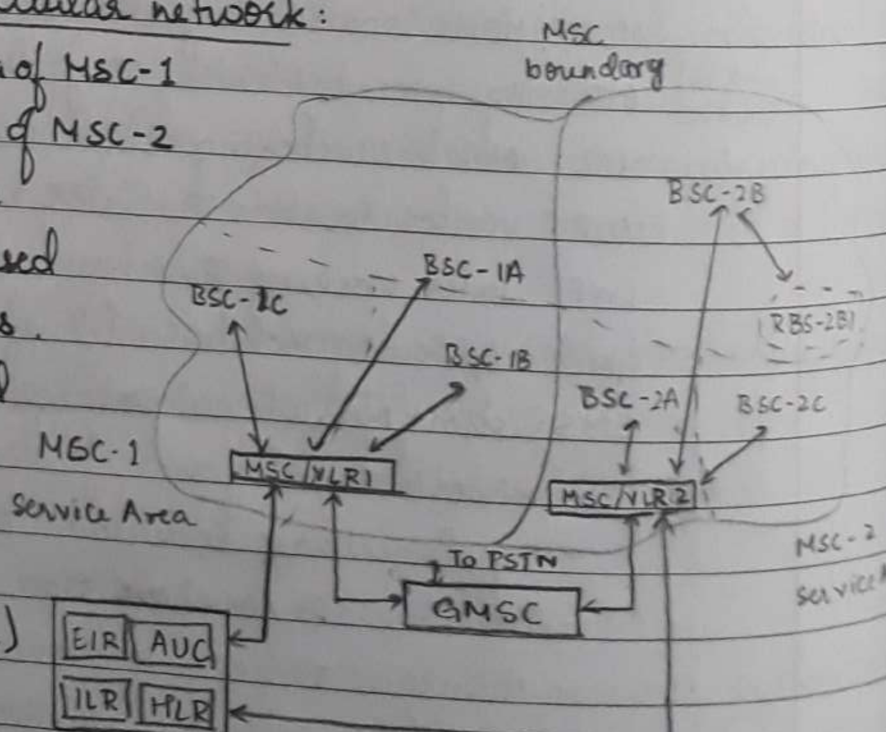


Typical MSC system

* **Hardware and software views of cellular network:**

- **Hardware view of cellular network:**

Left side : service area of MSC-1
Right side: service area of MSC-2
MSC-1 interfaces with three BSCs that are used to cover the three areas.
Each BSCs has several RBSs based on population density and nature of area (urban, rural, industrial etc)
The GMSC provides connection: the gateway connection to the PSTN for MSC-1 and MSC-2.



- Software view of the cellular network:

Local area Identity

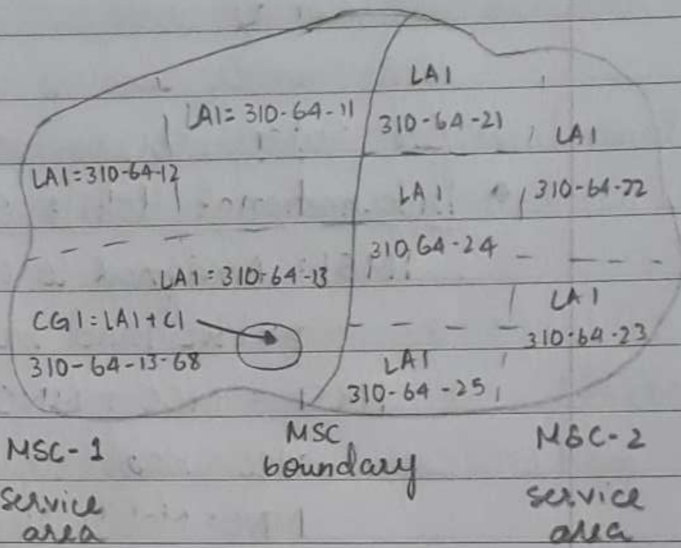
LAI = MCC + MNC + LAC

MCC : Mobile country code

MNC: Mobile Network code

LAC: Local area code

LAI: International unique identifier used for defining an area and updating location of mobile subscribers.



CGI: cell Global Identity : used to locate a particular cell

* 3G cellular systems components:

- Each proposed 3G system uses the designation RNC (Radio Network Controller) instead of BSC.
- It is similar to BSC. It is a governing element whose function is to provide interface between the wireless subscriber and the core networks.
- core networks: Network for all circuit switched voice and data calls and for all packet data calls.

* cellular component Identification:

- Subscriber Device Identification:

Each SD has several different identification numbers associated with it based on the type of cellular technology employed (TDMA, GSM and CDMA).

- Mobile station Integrated services Digital Network Number
MSISDN : dialable number to reach a telephone.
North America and other parts of the world have slight variation between them in the MSISDN number.

North America

MSISDN = CC + NPA + SN

CC: Country code

NPA: Number Planning Area

SN: Subscriber Number

Rest of the world

MSISDN = CC + NDC + SN

CC: Country Code

NDC: National Destination Code

SN: Subscriber Number

- International Mobile Subscriber Identity:

  IMSI: Assigned to each subscriber for International public land mobile networks.

  IMSI = MCC + MNC + MSIN

  MCC: Mobile Country code

  MNC: Mobile Network code

  MSIC: Mobile subscriber Identification Number

  TMSI: Temporary Mobile subscriber Identity Number

  temporary number instead of IMSI to provide security over air Interface.

- International Mobile Equipment Identity:

  IMEI: Used to identify a mobile station as a piece of equipment to be used within the network.

  IMEI = TAC + FAC + SNR + SVN

  TAC: Type Allocation code

  FAC: Final Assembly code

  SNR: Serial Number

  SVN: software Version Number.

– Cellular system Component Addressing:

- Local Area Identity:

  LAI: MCC + MNC + LAC

  MCC: Mobile Country code

  MNC: Mobile Network Code

  LAC: local Area code

- Cell Global Identity:

  CGI: used to identify a cell within a location area.

  16 bits added to end of a LAI

  MCC + MNC + LAC + CI

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- Radio Base Station Identity code:
  RBSIC: To identify RBSs within the wireless network
- Location Numbering:
  Assigned by service provider to various regional and national areas to provide subscriber features such as regional or national calling plans.
- Global Title (GT) and Global Title Translation (GTT):
  GT: Address of a fixed network element. An address for routing signalling messages on tellcommunication networks.
  GTT: To provide correct signalling address information for the routing of the message to the correct network node.

★ Call Establishment:

1. Mobile Teminated Call:
   1. Any incoming call from PSTN is routed to GMSC.
   2. When the mobile station determines an incoming call, the mobile system determines where the mobile is located at that particular time. GMSC will make use of the MSISDN to find out to which HLR the mobile station is registered in.
   3. HLR looks up which MSC is presently serving MS and HLR will send request to appropriate MSC and request for MSRN.
   4. Mobile station Roaming Number (MSRN) is sent to HLR.
   5. MSRN is sent back to GMSC by HLR.
   6. GMSC routes the call to MSC/VLR
   7. MSRN is used to retrieve the MSISDN. At this point the temporary MSRN is released.
   8. Using MSISDN the MSC/VLR determines the location area where mobile is located.
   9. MS is paged in all the cells that make up location area
   10. When MS responds to the paging message, authentication is

performed and encryption is enabled.

11. Call is connected from MSC to the BSC to the RBS.

2. Mobile Originated Call:

1a. The originating MS sends a request for signaling channel using control channel.

1b. If possible, the system assigns a signaling channel to the mobile.

2. Using assigned signalling channel, the MS sends request for system service from the system. The VLR sets the status of the mobile to "busy".

3. Authentication and encryption are performed.

4. MS specifies the type of service it wants and the called party number. The MSC acknowledges the request with a response.

5. Link is set up between MSC and BSC to assign a traffic channel.

6. An alerting message is sent to MS to indicate that the called party is being sent a ringing tone.

3. Call Release:

1. MS sends disconnect message to RBS → BSC → MSC

2. MSC sends release message to MS

3. MS sends release complete message back to MSC as an acknowledgment.

4. Clear command message from MSC to BSC

5. BSC sends clear message to MS on control channel.

6. When the mobile gets the channel release message, MS disconnect the traffic channel, LAPD (Link Access Procedure on Dchannel) protocol sends the disconnect frame

7. A release indication message is sent from the RBS to the BSC.

8. BSC sends an RF release channel message to RBS and RF channel release acknowledgement is sent from RBS to MSC.

SIE: UNIT-3: Common Cellular System Components

Cloud / Centralized RAN

→ As the amount of data traffic on mobile networks continues to grow, network operators are meeting the demands by adopting cloud / centralized Radio Access Network architectures (C-RAN)

Advantages:

- Reduced CAPEX/OPEX for operators
- Improved user experience through less interference.

solution:

Areas with high concentration network users → high stress on BTS that serve them → Adding more base stations → increases cost and signal interference if not coordinated carefully.

Separate base station into: Baseband Unit (BBU) and Remote Radio Head (RRH), allows network operators to maintain or increase the number of network access points (RRHs) while centralizing the baseband processing functions into a "master base station".

UNIT - 4

GSM and TDMA Technology

★ **GSM System Overview:**

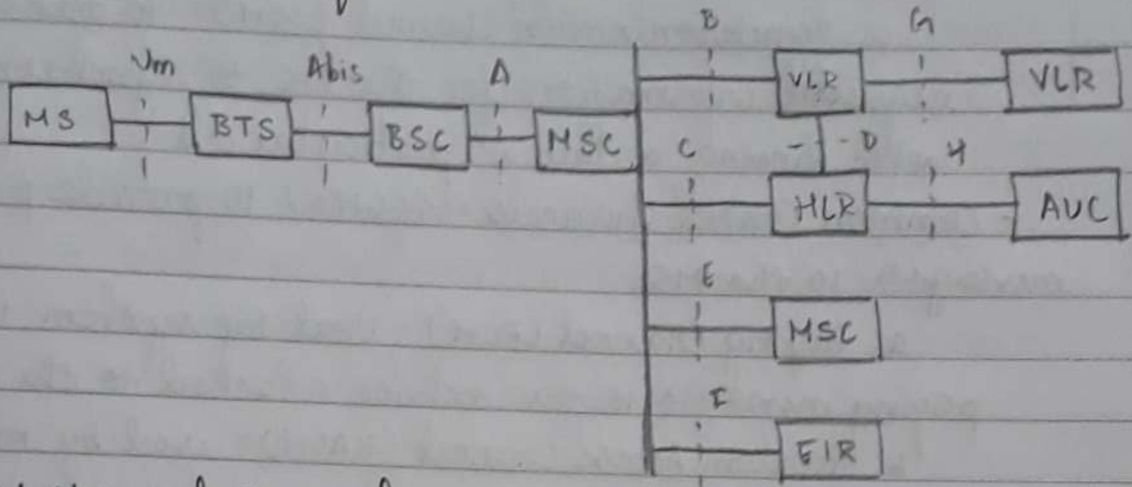
- Global System for Mobile Communications (GSM) services
- Standard collection of applications and features available to mobile phone subscribers all over the world.
- Common standard makes it possible to use the same phones with different companies services or even roam into different countries.
- Most dominant mobile standard in the world.
- Design of service is complex because it must be able to locate a moving phone anywhere in the world, accommodate the relatively small battery capacity, limited input/output capabilities and weak radio transmitters on mobile devices.
- Inorder to access GSM services, a user needs three things:
  - A billing relationship with a mobile phone operator (prepaid or postpaid).
  - A mobile phone that is GSM compliant and operates at the same frequency as the operator.
  - A Subscriber Identity Module (SIM) card which is activated by the operator once the billing relationship is established. After which MSISDN number is programmed.
- Then services they are allowed to access are stored in a sim record in the "Home Location Register (HLR)".
- Once the SIM card is loaded into the phone, it will search for the nearest mobile phone BTS with strongest signal. It is said to be in coverage area once it is successfully contacted with BTS. The phone then identifies itself to the network through the control channel. Then the phone is said to be attached to the network.

- Every SIM contains a secret key called ki to provide authentication and encryption services. It is useful to prevent theft of service.
- Every GSM phone contains a unique identifier called the International Mobile Equipment Identity. It is used to locate stolen phones and facilitate monitoring.
- TDMA:
  - data and voice communication.
  - offers personal communication-like services including fax, voiceband data and short message services (SMS) as well as multimedia and video conferencing.

★ <u>GSM Network and System Architecture</u>: (Block diagram Pg: 3-1)

- Mobile Station: - Subscriber identity Module
- Base Station System:
  - Network switching system
    - SMS gateway
    - Flexible numbering register
  - Operational and support system and other nodes
    - Administrative and control system.
- GSM network interfaces and protocols
  - GSM interfaces
    - Um interface: Radio interface for exchange between mobile and a base station (BTS)
    - Abis interface: linking the BSC and a BTS.
    - A interface: communication between BSS and MSC
    - After interface:
      - B interface: between MSC and VLR
      - C interface: between HLR and GMSC
      - D interface: between VLR and HLR
      - E interface: between two MSCs
      - F interface: between an MSC and EIR

- G interface: interconnects two VLRs of different MSCs
- H interface: between MSC and SMS-G
- I interface: between MSC and ME.



* GSM channel concept:
  - A single GSM RF carrier can support up to eight MS subscribers simultaneously. Each channel occupies the carrier for one eighth of the time. This technique is called the Time Division Multiple Access and each discrete periods of time is called a time slot.
  - Timeslots are arranged in a sequence of 0 to 7 and each repetition of this sequence is called a frame. Each MS call occupies one timeslot within the frame until the call is terminated or handed over.
  - The information carried in one time slot is called a burst.
  - Logic channels:
    They carry either subscriber traffic or signaling and control information to facilitate subscriber mobility
    - Broadcast channels: To provide information to the mobile station about various system parameters and also about LAI.
      a. Broadcast control channels (BCCH): information needed to be able to start making or receiving calls or to start roaming.

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b. Frequency correction channel (FCCH): transmit burst of zeros to synchronize itself to the correct frequency and the MS can verify that this is the BCCH carrier.

c. Synchronization Channel (SCH): to transmit the required information for the MS to synchronize itself with timing within a particular cell.

- Common Control Channels: (CCCHs) to provide paging messages to the MS.

a. Paging Channel (PCH): Used by system to send paging messages to the mobiles attached to the cell.

b. Random Access Channel (RACH): used by mobile to respond to the paging message.

c. Access Grant Channel (AGCH): Used by network to assign a signaling channel to the MS.

- Dedicated Control Channels (DCCHs): For specific call setup, handover, measurement, short message delivery functions.

a. Stand-alone Dedicated Control Channel (SDCCH): The call setup procedure is performed on it.

b. Slow associated control channel (SACCH): To transmit information about measurements made by the MS or instructions from BTS about the mobile parameters of operation.

c. Fast associated Control Channel (FACCH): To facilitate handover operation in GSM system.

d. Cell Broadcast Channel (CBCH): to deliver short message service in the downlink direction.

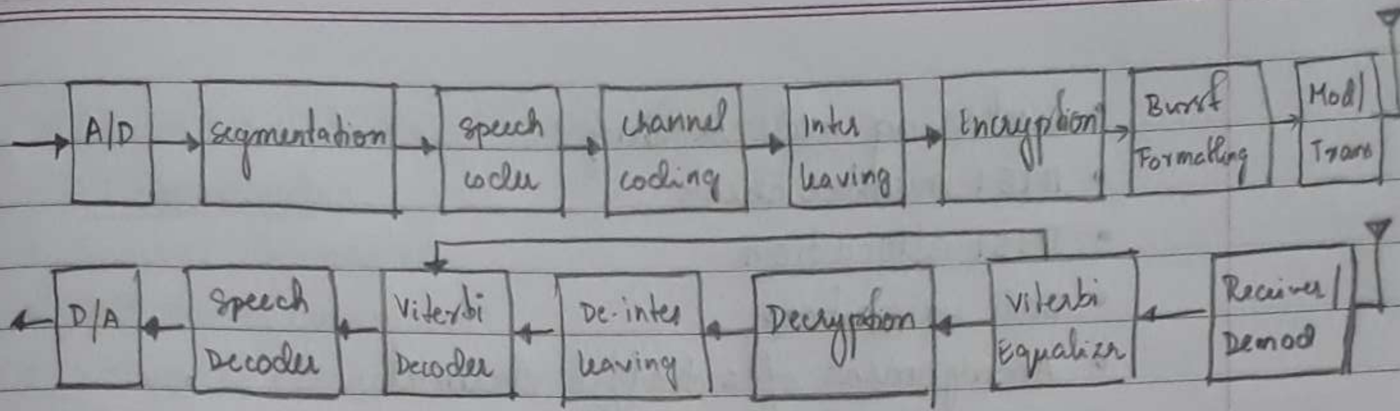
- Speech Processing:

Time slots and TDMA frames:

TDMA Frames: 8 time slots constitute a TDMA frame.

- Hyperframes: A multiframe sequence of 2048 superframes and is the largest time interval in the GSM system.

- Superframe: 51 traffic frames or 26 control multiframes.



- Traffic multiframe : 26 bursts.
- Control multiframe : 51 bursts
- Functions of hyperframe
    - frequency hopping
    - encryption

* **GSM Identities:**

- Mobile Station Associated numbers :
    - Mobile Station ISDN number (MSISDN)
    - International Mobile subcriber Identity (IMSI)
    - Temporary Mobile Subscriber Identity (TMSI)
    - International Mobile Equipment Identity (IMEI)
- Network Numbering Plans :
    - Local Area Identify (LAI)
    - Cell Global Identify (CGI)
    - Base Station Identification Code (BSIC)
        - ↳ Network color code (NCC)
        - ↳ Base Transceiver Color code (BCC)
- Mobile station Roaming number (MSRN)

* **GSM system Operations** : (Traffic cases)

Call set up :

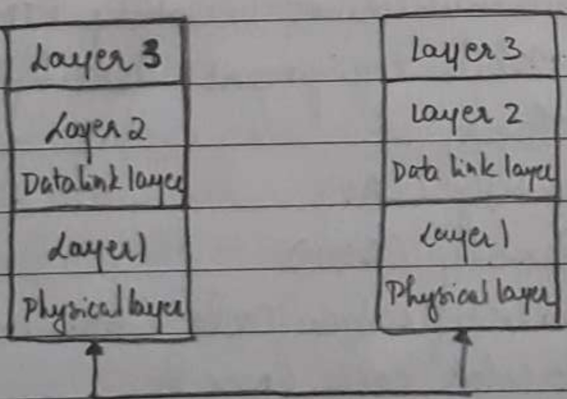
- Interrogation
- Radio resource connection establishment
- Service request
- Authentication

- ciphering mode setting
- IMEI number check
- TMSI allocation
- call initiation
- Assignment of a traffic channel
- user alerting signaling
- call accepted signaling

Location updating:
- Normal location updating (idle mode)
- IMSI detach/attach location updating
- Periodic location updating.

call Handoff
- Intra BSC-handover
- Inter BSC-handover

* GSM Infrastructure communications:



Linking of three layers of interface in GSM

- Layer 3 : Network layer operations
  - connection management
  - Mobility management
  - Radio resource management.
- Layer 2 : Data link Layer Operations
  - LAPD operations
  - service access points
  - Data link procedure
  - Physical services required by the Data Link layer
  - Data link timers.

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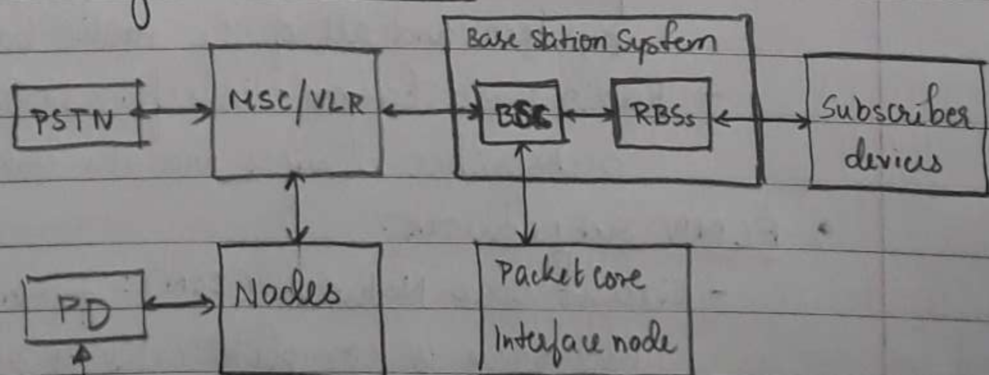
UNIT-5

CDMA Technology

* CDMA Overview:
  - It is a digital modulation and radio access system that employs signature codes (rather than time slots or frequency bands) to arrange simultaneous and continuous access ~~to~~ a radio network by multiple users.
  - Advantages:
    - The spread spectrum system's performance is relatively immune to radio interference.
    - cell sectorization and voice activity used in CDMA radio scheme provides additional capacity compared to FDMA and TDMA.
  - Disadvantages:
    - capacity is limited by the access interference.
    - Near-far effect requires an accurate and fast power control scheme.
  - The first cdma cellular radio system was constructed with IS-95 specifications and now commercially known as cdmaOne.

- CDMA Network and System Architecture:

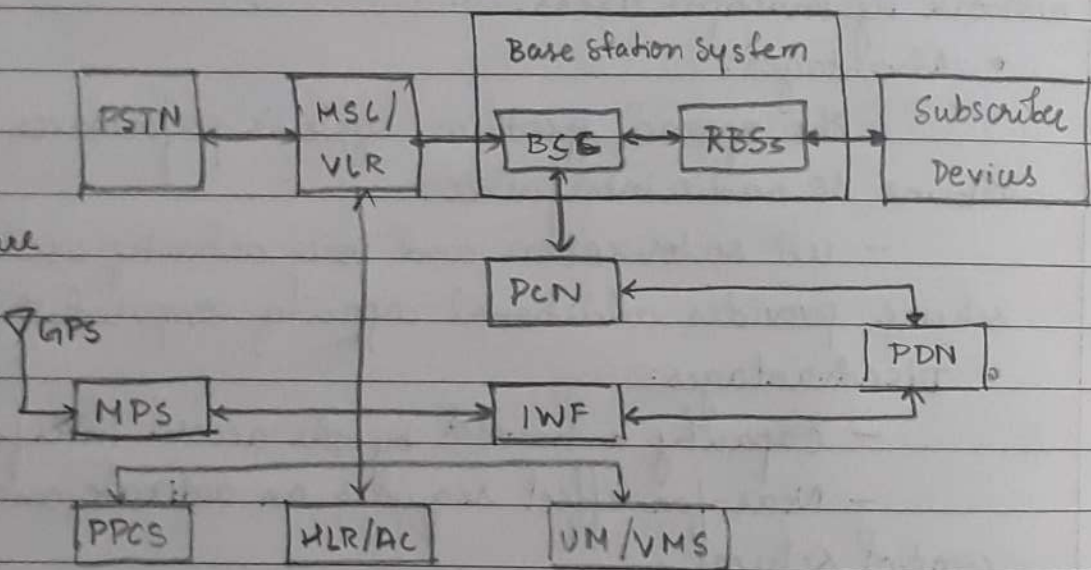
Network Architecture of CDMA



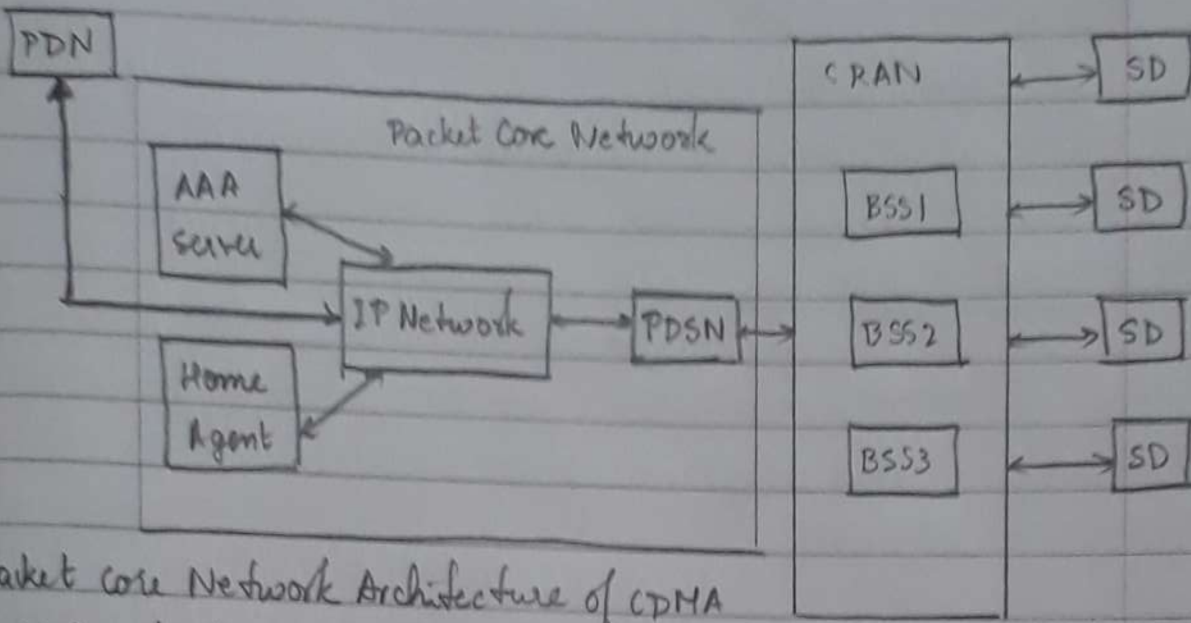
- Mobile-services switching center and Visitor location register
MSC - serves as an interface between the PSTN and BSS.
VLR - provide data base containing information about registed subscribers

- Interworking function:
- Mobile positioning system: based on GPS and is to be used for emergency services. The ability to locate the caller is known as Enhanced 911
- Unified Messaging / Voice Mail service: It is a part of Ericsson corporation's new cdma2000 systems as a node that integrates email and voice mail access.
- HLR/AC:

Packet Network Architecture of CDMA



- <u>Base station subsystem</u>:
  - Base station controller: interface between MSC, the packet core network (PCN), other BSSs in the same system and all of the radio base station it controls.
  - Radio Base station: interface between the BSC and the subscriber devices via the common air interface.
- <u>PLMN subnetwork</u>:
  - circuit core Network (CCN): provides switching functions necessary to complete calls to and from the mobile subscriber to the PSTN.
  - CDMA Radio Access Network (CRAN): interface between wireless cellular subscriber and CCN.
  - Packet core Network (PCN): interface between CRAN and public data network (PDN) for wireless packet-switched data service

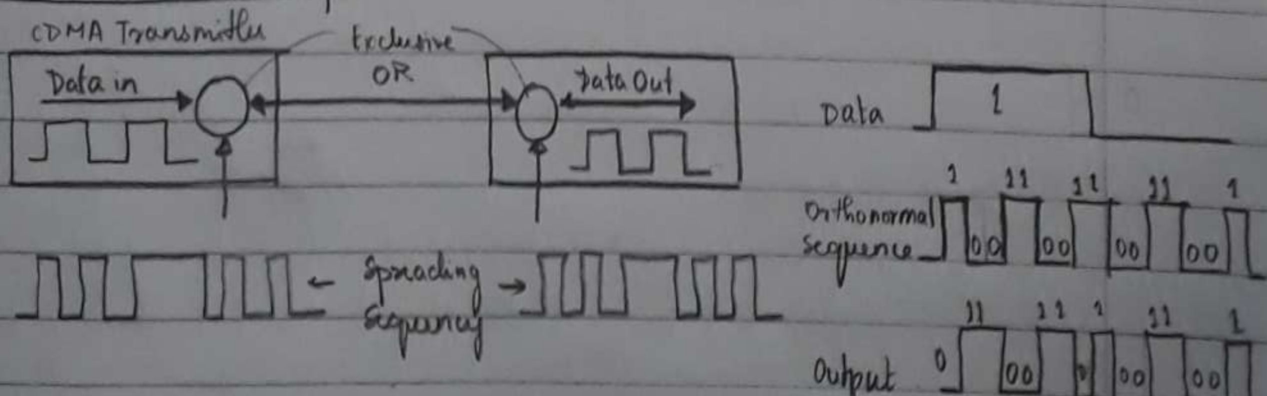


Packet core Network Architecture of CDMA

- Network Management System
  - Network Management: a platform that allows one to monitor the overall Network
  - Subnetwork Management and Element Management.
    Subnetwork management platform provides management of the circuit, packet and radio networks that compose the typical CDMA system.
    Element management refers to the ability to interface directly with a network element through a craft data port.
- System Communication links:

* CDMA Basics:

- CDMA Channel Concept:



The basic spectrum spreading operation

- CDMA Frame Format
  - Forward channel frame formats
  - Reverse channel frame formats

- CDMA System Operations: (Layer 3)
  - Initialization / Registration
    - It is dependent upon the status of the mobile station.
    - The mobile maybe in either attached or detached condition
    - When attached it is one of the three ~~modes~~ states:
      - mobile station idle state
      - system access state
      - mobile station control on the traffic channel state
  - Call Establishment
    - Initialization state: when the mobile is first powered on. Mobile searches for pilot channel.
    - Idle state: After acheiving initialization. It is waiting for a call or message or is ready to originate a call or some form of data transfer.
    - Access state: when it receives a mobile directed message requiring an acknowledgement, orginates a call or is required to perform registration.
    - Traffic state: when it begins to transfer user information between the mobile and the base station.
      - ↳ Mobile originated call
      - ↳ Mobile terminated call
      - ↳ call termination.
  - Call Handoff
    - Idle / Access Handoff:
    - Soft Handoff: make before break
    - Hard Handoff: break before make
  - Power Control
    - Forward link Power control:
    - Reverse Open Loop:
    - Fast close loop:

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* 3G CDMA:

- IS 95B:
  - features the use of combinative channels i.e., primary channel may be combined with upto seven supplementary data channels.
  - It employs supplementary code channels (SCCHs) in both forward and reverse direction.
  - Provide extra bandwidth capacity needed to increase the packet data transfer rate for a subscriber.
- CDMA 2000:
  - One of the primary air interface technologies for implementation of 3G cellular.
  - Two phases of development:
    - enhancement of IS-95B to CDMA 2000 (a single carrier system) with enhanced packet data capacities.
    - use enhanced higher level modulation schemes that allow for more data bits per CDMA frame.
  - CDMA forward and reverse channel structures:
    - Forward logic channels
      ↳ overhead, control and traffic channels.
    - Reverse link channels
      ↳ various operational modes of the mobile
      ↳ types of reverse channel that can be transmitted by the mobile station within each operational group.